FEDERAL UNIVERSITY OF RIO GRANDE DO SUL

CENTER FOR STUDIES AND RESEARCH IN AGRIBUSINESS

GRADUATE PROGRAM IN AGRIBUSINESS

HEITOR VIEIRA RIOS

PRECISION LIVESTOCK FARMING TOWARDS BROILER WELFARE

Porto Alegre

2021

HEITOR VIEIRA RIOS

PRECISION LIVESTOCK FARMING TOWARDS BROILER WELFARE

Doctoral thesis presented to the Postgraduate Program in Agribusiness of the Center for Studies and Research in Agribusiness of the Federal University of Rio Grande do Sul, as a partial requirement for obtaining the title of Doctor in Agribusiness.

Advisor: Prof. Dr. Paulo Dabdab Waquil–UFRGS

Porto Alegre

2021

CIP - Catalogação na Publicação

Rios, Heitor Vieira
Precision Livestock Farming Towards Broiler Welfare / Heitor Vieira Rios. -- 2021.
127 f.
Orientador: Paulo Dabdab Waquil.

Tese (Doutorado) -- Universidade Federal do Rio Grande do Sul, Centro de Estudos e Pesquisas em Agronegócios, Programa de Pós-Graduação em Agronegócios, Porto Alegre, BR-RS, 2021.

1. Poultry welfare. 2. Information technology. 3. Smart sensor. 4. Welfare Quality. 5. Smart farming. I. Waquil, Paulo Dabdab, orient. II. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

HEITOR VIEIRA RIOS

PRECISION LIVESTOCK FARMING TOWARDS BROILER WELFARE

Doctoral thesis presented to the Postgraduate Program in Agribusiness of the Center for Studies and Research in Agribusiness of the Federal University of Rio Grande do Sul, as a partial requirement for obtaining the title of Doctor in Agribusiness.

Aproved on__/__/______

EXAMINING BOARD

____

Prof. Dr. Liris Kindlein – UFRGS

____

Prof. Dr. Catarina Stefanello – UFSM

____

Prof. Dr. Iran José Oliveira da Silva – USP

____

Prof. Dr. Tomas Norton – KU Leuven

I dedicate this work to all Brazilian broiler farmers. I hope this study contributes to improving animals´ and farmers´ welfare

ACKNOWLEDGMENTS

It is always hard to thank people without incurring the risk of forgetting someone. However, as the situation requires, I will take the risk (please, if you are reading this and feel that I did not properly addressed your contribution, I ask for apologies). First and foremost, I would like to thank my family, especially my mother and father, Luiza and Jayme, who provided me with much more than I could have asked for and supported me in such a lovely way I can barely express. I thank my brothers Gustavo and João, for all our fun and sometimes stressful moments, all of them were important for my formation. I extend this gratitude to my other family members, especially to my grandparents, Helena and Antônio, who had never measured efforts help me with all they could, and to my uncles, aunts and cousins for all joy, fun and advices. To my family: thank you very much.

To Brows and Conclave, my childhood friends, for all the moments we spent together. “True friends multiply joys and divide griefs”. You are the best friends one could have. I expect to get “a real job” now, guys!

During my PhD I had the opportunity to join M3-Biores group in KU Leuven for six months for which I am really thankful. Having the opportunity to join such an incredible group and having contact with such wonderful researchers was definitely a key part for this thesis accomplishment and to my personal formation. I would like to thank Professor Tomas Norton for his attention and willingness to share his outstanding knowledge and for making me feel more than welcomed in his research group. I am thankful to all M3-Biores group members who kindly received me and with whom a made real friends. I hope to meet you (in person) again, guys!

I am especially thankful to Professor Paulo Waquil, my PhD advisor who helped me to build the present thesis. Always humble and surgical in his notes and directions he was an incredible advisor. Thanks to the members of our Agrarian Economy research group, who contributed with advices and suggestions that certainly improved the quality of this work. To CEPAN professors for the disciplines which I attended, especially to Homero Dewes whose ideas influenced me about the subject of the present thesis. Also, I want to express my gratitude to Professor Marcelino Souza for his remarkable ability to make complex and bureaucratic issues easier, helping me to seize the opportunity to do the Sandwich Doctorate in KU Leuven.

The thesis would not be the same if I did not have the help of Thiago Luís Noetzold, Vinicius Teixeira, Rafael Abs Fontana da Cruz, Cesar Pontin and Diego Puntel who gave me special help in the empirical phase of the present thesis. Also, thanks to the companies’ professionals and to the broiler farmers who dedicated part of their valuable time to answer and disseminate questionnaires, this was of main importance for the thesis.

I thank Patrícia Soster for her friendship and love, you were really special during this journey. I could not forget to mention you. To all friends I made in the *Aviário de Ensino e Pesquisa* during my undergraduation and master´s degree, you are friends for life. To Professor Sergio Vieira, who introduced me to the poultry world and provided me countless opportunities in academia and private sector, thank you.

Last but not least, thanks to all Brazilians for providing me the opportunity to dedicate so many years of my life to my professional formation. I will try to retribute it in the best way I can.

Using animals for food is an ethical thing to do, but we've got to do it right.

Temple Grandin

ABSTRACT

Due to intensification of the livestock system the ratio between number of broilers and number of farmers have been increasing, making impossible the individualized attention to animals without the use of appropriate tools. Increasingly societal concern on broiler welfare requires farmers to find means to improve animal welfare level. Precision livestock farming (PLF) emerges as a possible solution as it enables the monitoring of animals and its environment 24/7. The present study aims to provide information on how PLF technologies can address broiler welfare and to evaluate reasons for their adoption (or non-adoption) by farmers. The results discussions and analysis are based in the three main pillars that guide the present research: animal welfare, PLF technologies and innovation adoption. Methodologically, the study consists of two different steps. Initially, a systematic review of the literature was carried out to identify which are the PLF technologies related to broiler welfare and to assess how they address birds´ welfare. Results indicate that most PLF technologies are related to image analysis and mainly focused on broiler health improvements. In the second stage, an empirical research was carried out with broiler farmers in the Southern Brazil. From this survey, information on broiler farmers´ opinions towards broiler welfare and PLF potentialities were assessed as well as on the determinants and limiting factors for technologies adoption. In general, Brazilian broiler farmers attribute great importance to broiler welfare and perceive the current level of welfare as high; however higher scores for importance than for perception indicate that there is room for welfare improvements. In broiler farmers´ opinions, providing animals food/water and good housing and health conditions are more important than provide means for the animals to express their natural behaviors. Broiler farmers believe that technologies can help them on welfare improvements and are willing to adopt them even when no extra income come from this. Broiler farmers with less experience, producing chicken grillers, having other farm activity besides broiler production and presenting high beliefs on PLF potentialities regarding animal welfare improvements are more likely to adopt PLF technologies. Major limiting factors for PLF technologies adoption are regarding technology high prices, maintenance requirements and to possible financial consequences with technical problems. It is expected the present thesis to be useful to clarify about PLF technologies opportunities in the broiler farmers point of view and that the results obtained to be valuable to increase PLF adoption, which can potentially improve animal and farmers welfare alike.

Keywords: Information technology, livestock welfare, smart farming, , smart sensor.

RESUMO

A intensificação do sistema produtivo aumentou a relação entre o número de frangos de corte e o número de trabalhadores rurais, impossibilitando a atenção individualizada aos animais sem o uso de ferramentas adequadas. Em paralelo, a sociedade pressiona os produtores a encontrarem meios para aumentar o nível bem-estar animal (BEA). Tecnologias da zootecnia de precisão (ZP) surgem como possível solução, pois possibilitam o monitoramento dos animais e de seu ambiente de forma contínua. O presente estudo objetiva fornecer informações sobre como as tecnologias da ZP abordam o bem-estar de frangos de corte e avaliar os fatores que influenciam a sua adoção pelos produtores. A discussão e a análise dos resultados baseiam-se em três pilares, a saber: BEA, tecnologias da ZP e adoção de inovações. Metodologicamente, o estudo é composto por duas etapas distintas. Inicialmente, uma revisão sistemática da literatura foi realizada para identificar quais são as tecnologias da ZP relacionadas ao bem-estar de frangos de corte e para avaliar como elas abordam o bem-estar das aves. Os resultados indicam que a maioria das tecnologias está relacionada à análise de imagens e principalmente focada na melhoria da saúde dos frangos. Na segunda etapa, foi realizada uma pesquisa empírica com produtores de frangos de corte no Sul do Brasil. A partir desta pesquisa, foram avaliadas informações sobre as opiniões dos criadores de frangos de corte em relação ao BEA e às potencialidades das tecnologias, bem como sobre os fatores determinantes e limitantes para adoção de tecnologias. Em geral, os avicultores brasileiros atribuem grande importância ao bem-estar dos frangos e consideram alto o nível atual de BEA; no entanto, maiores escores para importância do que para percepção indicam que há espaço para melhorias. Na opinião dos produtores, fornecer aos animais comida/água e boas condições de alojamento e saúde é mais importante do que fornecer meios para que os animais expressem seus comportamentos naturais. Os produtores acreditam que as tecnologias podem ajudá-los a aumentar o BEA e estão dispostos a adotá-las mesmo que isso não resulte em maior renda. Produtores com menos experiência, que produzem *grillers*, que possuem mais de uma atividade agropecuária e que acreditam nas potencialidades das tecnologias em melhorar o BEA são mais propensos a adotar tecnologias. Os principais fatores limitantes para a adoção de tecnologias são os preços elevados, as exigências de manutenção e as possíveis consequências financeiras com problemas técnicos. Espera-se que a presente tese seja útil para esclarecer sobre as oportunidades da ZP do ponto de vista dos produtores e que os resultados obtidos sejam valiosos para aumentar a adoção de tecnologias, as quais podem melhorar o BEA e o bem-estar dos produtores.

Palavras-chave: Pecuária inteligente, tecnologias da informação, sensor inteligente.

LIST OF FIGURES

CHAPTER 2

Figure 1. General scheme of measuring, modelling, and managing traits of interest. 28

CHAPTER 3

Figure 1. Processes adopted in the present systematic review 44

Figure 2. Temporal distribution of publications...46

LIST OF TABLES

CHAPTER 2

Table 1. Principles, criteria and measurements of Welfare Quality® Assessment Protocol for broiler chickens........26

CHAPTER 3

Table 1. Terms and booleans utilized in the search fields of Web of Science and Scopus databases........43

Table 2. Approaches and possible answers related to the information technology (IT)-based studies selected in the systematic review (SR).........45

Table 3. Description of technologies........47

Table 4. Categorization of IT-based studies and of ITs in the different approaches........52

Table 5. Description of each IT group in the approaches utilized........54

CHAPTER 4

Table 1. Sociodemographic, productive and economic data of broiler farmers in Southern Brazil (n=184)........78

Table 2. Principles and criteria used to evaluate broiler welfare level present in the Welfare Quality® Assessment Protocol for broiler chickens........79

Table 3. Mean scores of importance, perception and importance-perception divergence for welfare principles and criteria........83

Table 4. Broiler farmers’ opinion on technology potentialities to improve broiler welfare principles.........84

Table 5. Spearman correlations between the importance broiler farmers allocate to broiler welfare, their perception on animal welfare and importance-perception divergence and their opinions on technology potentialities.........85

Table 6. Broiler farmer´s willingness to adopt PLF technologies aiming at improving broiler welfare.........86

CHAPTER 5

Table 1. Description of explanatory variables on broiler farmers´ adoption of PLF-AW technologies.........102

Table 2. Descriptive analysis of the sample (n=173)........103

Table 3. Broiler farmers´ frequencies of adoption and interest of adopting PLF technologies........104

Table 4. Barriers for broiler farmers adoption of PLF-AW technologies (n=172)........105

Table 5. Coefficient estimates of the logistic model on the determinants for PLF-AW adoption........106

CONTENTS

CHAPTER 1: INTRODUCTION 15

1.1 RESEARCH PROBLEM 15
1.2 OBJECTIVES 16
1.2.1 General objective 16
1.2.2 Specific objectives 17
1.3 JUSTIFICATION 17
1.4 THESIS STRUCTURE 18

REFERENCES 19

CHAPTER 2: THEORETICAL FRAMEWORK 21
2.1 BROILER WELFARE: STATE OF ART 21
2.1.1 What is animal welfare? 21
2.1.2 Farmer and farm animal welfare 23
2.1.3 The Welfare Quality® assessment protocol for broiler chickens 25
2.2 WHAT IS PRECISION LIVESTOCK FARMING? 27
2.2.1 The complexity of PLF technologies 29
2.2.2 The added value of PLF technologies 30
2.2.3 The boundaries of PLF technologies 32
2.3 METHODOLOGICAL PROCEDURES 35

REFERENCES 36

CHAPTER 3: HOW ARE INFORMATION TECHNOLOGIES ADDRESSING BROILER WELFARE?: A systematic review based on the welfare quality® assessment 40
ABSTRACT 40

1. INTRODUCTION 40
1.1 GENERAL OVERVIEW AND OBJECTIVES 40
1.2 INFORMATION TECHNOLOGY AS A POTENTIAL MEANS TO ADDRESS THE LIMITATIONS OF WELFARE QUALITY 41

2. MATERIAL AND METHODS 42
2.1 SYSTEMATIC REVIEW 42
2.2 PAPERS ANALYZED AND APPROACHES UTILIZED 44

3. RESULTS 46
3.1 HOW DO THE UTILIZED ITs WORK? 46
3.1.1 Image technologies 49
3.1.2 Force-measurement platform and kinematic technologies 49
3.1.3 Sound technology 49
3.1.4 Automatic weighing scales 50
3.1.5 Radio frequency identification 50
3.1.6 Environmental sensors 50
3.1.7 Animal sensors 50
3.1.8 Algorithms 51
3.2 HOW IS WELFARE ADDRESSED BY THE ITs or IT-BASED STUDIES? 51
3.2.1 What principle(s) of WQ for broiler's are the ITs and IT-based studies related to? 51
3.2.2 What phase of the animal's life do the ITs and the IT-based studies correspond to? 51

3.2.3 On what production system are the ITs and IT-based studies focussed? 51
3.2.4 Are the ITs and the IT-based studies related to environmental or animal-based variables?...51
3.2.5 What aspect of the production chain are the its and it-based studies addressing? .53
3.2.6 Are the ITS and IT-based studies related to practical or experimental situations?53
3.3 HOW ARE EACH IT GROUP CLASSIFIED WITHIN THE DIFFERENT APPROACHES? 53
3.3.1 What principle(s) of broiler's welfare is each IT group related to? 53
3.3.2 What phase of the animal's life each IT group correspond to? 56
3.3.3 In which production system can each IT group be utilized? 56
3.3.4 Does the IT group evaluate environmental or animal-based variables? 56
3.3.5 What aspect of the production chain did the IT group attend to? 57
3.3.6 Did the IT group intend to be practical or experimental? 57

4. DISCUSSION 57

5. CONCLUSIONS 59

APPENDIX A – TABLE A1 - authors, year of publication, country, its utilized, facilities and main achievement of each paper evaluated 61

REFERENCES 68

CHAPTER 4: TECHNOLOGY POTENTIALITIES BASED ON BRAZILIAN BROILER FARMERS´ OPINIONS ON ANIMAL WELFARE 74
ABSTRACT 74

1. INTRODUCTION 74

2. MATERIAL AND METHODS 77
2.1 DATA COLLECTION AND SAMPLE DESCRIPTIVE ANALYSIS 77
2.2 STATISTICAL ANALYSIS 80

3. RESULTS 81

4. DISCUSSION 86

5. FINAL CONSIDERATIONS 91

REFERENCES 92

CHAPTER 5: FACTORS INFLUENCING BRAZILIAN BROILER FARMERS´ ADOPTION OF PRECISION LIVESTOCK FARMING TECHNOLOGIES 96
ABSTRACT 96

1. INTRODUCTION 96

2. MATERIAL AND METHODS 99
2.1 DATA COLLECTION AND SAMPLE ANALYSIS 99
2.2 STATISTICAL ANALYSIS 101

3. RESULTS 103
3.1 SAMPLE DESCRIPTIVE ANALYSIS 103
3.2 RESULTS ON THE BARRIERS FOR BROILER FARMERS ADOPTION OF PLF-AW TECHNOLOGIES 105
3.3 RESULTS ON THE LOGISTIC REGRESSION MODEL 105

4. DISCUSSION 107

5. FINAL CONSIDERATIONS 113

APPENDIX 1 – QUESTIONNAIRE 115
APPENDIX 2 – CORRELATION MATRIX OF EXPLANATORY VARIABLES 118
APPENDIX 3 – MULTICOLLINEARITY COEFFICIENTS 119

REFERENCES 120

CHAPTER 6: ADDITIONAL CONSIDERATIONS 124

APPENDIX A – FIRST PAGE OF PUBLISHED PAPER 127

CHAPTER 1

INTRODUCTION

1.1 RESEARCH PROBLEM

The increased world population pressures food production sectors to increase productivity sustainably. Poultry meat is the main animal protein source (excluding fish) demanded worldwide (USDA, 2021), with Brazil playing an important role, as the second largest world`s producer and the first world exporter (ABPA, 2020). Poultry meat supply chain in Brazil has both social and economic relevance since it generates approximately 4.1 million employments (along with pig farming) (ABPA, 2020) and contributes to approximately 6% of gross value of agricultural production of the country (CNA, 2021). Thus, the increasing world demand for poultry meat represents a challenge and a timeliness for Brazilian poultry meat supply chain.

In parallel, there is an increasing societal concern on the living conditions of farm animals, demanding improvement on animal welfare. In Brazilian backstage, urbanization has led to a decrease in farm labor force and farmers are forced to get higher outputs with lesser inputs. As broiler production is a low margin product activity, broiler stocking densities must be increased, so that farmers can make fair profits and a way of living from their land. As a result, less attention is given to individuals, which can potentially impair broiler welfare.

Technological innovations are alternatives to overcome this challenge. The advent of technologies such as smart sensors, learning machines, deep learning and big data have revolutionized data management. These innovation on animal farm is called Precision Livestock farming (PLF) and it can be defined as a set of technologies that aim to collect and to analyze data continuously, automatically monitoring livestock, their products and the farming environment (ROWE; DAWKINS; GEBHARDT-HENRICH, 2019). The PLF technologies enable the real-time monitoring of animals 24/7 and are capable to automate daily tasks precisely, simplifying farm management in an accurate way and providing means to better control livestock productivity and welfare (BERCKMANS, 2017).

Despite PLF potentially improves both farmer´s productivity and animal welfare, studies on the utilization of these technologies by farmers have received little attention until the present moment. Farmers are in close contact with broilers and the ones responsible for taking care of them during the longest period of their lives. Besides, the decision to adopt or not a given PLF technology involved with animal welfare is made by the farmers and it can be closely related to their opinions and perceptions on animal welfare.

The development of PLF technologies related to broiler welfare is relatively new and up-and-coming. As they are promising technologies, there are also several questions on this remaining to be addressed (WATHES et al., 2008). Some of the questions requiring special attention are: which are the technologies related to broiler welfare and how do they address it? What are farmers´ perceptions and opinions on broiler welfare and PLF? In what level of welfare farmers believe animals are living and what is the importance of animal welfare for them? Do they believe that PLF technologies can improve broiler welfare? What are the most important factors influencing PLF adoption by farmers? Unfortunately, not all of these questions present clear responses. Because PLF technologies are innovations and their development is dynamic there are huge possibilities for their utilization and improvements

Animal welfare is gaining repercussion in society and technologies have been developed to assist farmers to improve animals´ condition of living. However, the possible outcome that farmers and animals can get by PLF technologies as well as the diffusion of such technologies on broiler production is still unclear. Therefore, the aims of the present thesis are two-fold: (i) to provide information for a better understanding of PLF technologies´ potentialities and limitations in assisting farmers in taking care of their animals and (ii) to elucidate the reasons for the (non)adoption of these technologies by broiler farmers.

1.2 OBJECTIVES

1.2.1 General objective

To provide information on how PLF technologies can address broiler welfare and to evaluate factors that influence their adoption (or non-adoption) by farmers, using as object of study broiler farmers in the Southern Brazil.

1.2.2 Specific objectives

- To broaden and deepen knowledge on PLF technologies related to broiler welfare, identifying which are these technologies and how they can address broiler welfare.

- To investigate broiler farmers´ opinions and perceptions on broiler welfare and their beliefs on how PLF technologies can help improving animal welfare.

- To investigate the diffusion of PLF in broiler houses in Southern Brazil, analyzing factors that influence the adoption (or non-adoption) of PLF technologies by broiler farmers.

1.3 JUSTIFICATION

A growing concern on animal welfare is observed nowadays. There are evidences that animals´ mistreatment can negatively affect human wellbeing, being animal welfare considered a common good (MCINERNEY, 2004). In 2015, the United Nations launched the 2030 Agenda with 17 Sustainable Developments Goals that should be pursued by all world nations, being goal number 2 “zero hunger” by producing food sustainably (UN, 2015). Due to the social sustainability, it is not possible to produce animal protein sustainably if animal welfare level is below the level society requires (BROOM, 2010).

Moreover, neglecting farm animals´ welfare can be a reason for commercial non-tariff barriers (BROOM, 2017). Since Brazil is the greatest exporter of poultry meat worldwide and broiler chicken production is of great socio-economic importance for several regions in the country (ABPA, 2020), there is no sense to doubt that broiler welfare is of fundamental importance for Brazilian income and for social wellbeing. Despite the economic success of broiler production in Brazil, urbanization has decreased the availability of workforce in rural areas and increased the ratio between number of animals/number of farmers. Consequently, attention for individuals is not possible without appropriate technologies since a broiler house can roost thousands of broilers and the welfare of animals may be jeopardized.

The PLF technologies emerge as a possible solution to address such concerns. One of their advantages is the possibility to monitor and control animals and their environment in an automate and non-invasively way 24/7, providing farmers means to take better care of animals (BERCKMANS, 2014). Such technologies have created a whole new universe of opportunities for animal production as they allow the measuring and processing of a great volume of data in a level never seen before. However, information on how these technologies are addressing broiler welfare is still lacking. Thus, one of the objectives of the present study was to gather relevant information on which PLF technologies are related to broiler welfare and to analyze how they can address animal welfare.

There is a gap between PLF technologies development and the utilization of these tools by farmers. Whereas technologies are being studied and developed in great velocity, their adoption by farmers seems to happen in a much slower ratio. There is a lack of scientific studies on the farmers´ utilization of PLF technologies. Concerning to that, Berckmans (2017) criticize the manner that scientific disciplines and technical fields interacts, as research groups are putting more efforts to hunt for research money than they are focused in making progress in their study field or to provide real solutions for farmer issues. As a result, farmers are probably not seeing any advantages by PLF technologies adoption. Therefore, the present research also aims to investigate reasons for the adoption (non-adoption) of PLF technologies by broiler farmers, focusing on technologies related to welfare and on farmers´ opinions and attitudes towards broiler welfare.

The present thesis provides novel insights on which farmer profiles are more likely to adopt PLF related to broiler welfare by analyzing technology attributes, farmers´ perceptions on broiler welfare as well as socioeconomic factors. Additionally, it provides valuable information on how farmers interpret broiler animal welfare and on how aware and optimistic they are on PLF technologies. This information can be used to trace future scenarios for broiler welfare improvements and to elaborate plans of action to increase the level of technology adoption by farmers, which can potentially increase both animal and farmer welfare.

1.4 THESIS STRUCTURE

The present thesis consists of six chapters. The first chapter focus on the contextualization of the study object. The research problem is presented as well as the objectives and the expected results of the current research. In the chapter two, the theoretical basis of the thesis discussion is presented. Information on broiler welfare and on PLF technologies are presented, being discussed the current state of art of both topics and emphasized the intersections between both. In the Chapter 3, PLF technologies related to animal welfare are identified and their potentialities and limitations are discussed. In this chapter, a systematic literature review is utilized to attend these objectives. Chapter 3 was written an article format and it is already published in the journal Sustainability (2020) (Appendix A), being formatted according to this journal norms.

After identified the PLF technologies that have been developed and the ones ready to be used, an assessment of farmers´ opinions and attitudes towards broiler welfare and PLF technologies are addressed in the Chapter 4. Complementary, in Chapter 5 an investigation of the PLF technologies being currently used by farmers as well as the determinants and limiting factors influencing their adoption by farmers is assessed through statistical modelling. Important to be mentioned that Chapter 4 and 5 were also written in an article format; however, they have not been published yet. Finally, Chapter 6, brings the final considerations of this thesis.

REFERENCES

ABPA - ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL. **Relatório anual 2020**. São Paulo: ABPA, 2020.

BERCKMANS, D. Precision livestock farming technologies for welfare management in intensive livestock systems. **Revue Scientifique et Technique de l'O.I.E**, Paris, v. 33, n. 1, p. 189–196, 2014.

BERCKMANS, D. General introduction to precision livestock farming. **Animal Frontiers**, London, v. 7, n. 1, p. 6–11, 2017.

BROOM, D. M. **Animal welfare in the European Union**. Brussels: European Parliament Policy Department, Citizen's Rights and Constitutional Affairs, Study for the PETI Committee, 2017.

BROOM, D. M. Animal welfare: an aspect of care, sustainability, and food quality required by the public. **Journal of Veterinary Medical Education**, Toronto, v. 37, n. 1, p. 83–88, 2010.

CNA - CONFEDERAÇÃO DA AGRICULTURA E PECUÁRIA DO BRASIL. Valor bruto da produção agropecuária deve atingir R$ 1,142 trilhão em 2021. **Valor Bruto da Produção – VBP**, Brasília, DF, 12 fev. 2021. Available at: https://www.cnabrasil.org.br/assets/arquivos/boletins/sut.VBP.12fev2021-v2.pdf. Accessed:

14 Feb. 2021.

MCINERNEY, J. **Animal welfare, economics and policy**. London: Defra, 2004.

ROWE, E.; DAWKINS, M. S.; GEBHARDT-HENRICH, S. G. A Systematic Review of Precision Livestock Farming in the Poultry Sector : Is Technology Focussed on Improving Bird Welfare ? **Animals**, v. 9, n. 614, p. 1–18, 2019.

UN - UNITED NATIONS. General Assembly.**Transforming our world:**the 2030 agenda for sustainable development. New York: United Nations, 2015. 35 p.

USDA – UNITED STATES DEPARTMENT OF AGRICULTURE. Foreign Agricultural Service. **Livestock and poultry:** world markets and trade. Washington, DC: USDA, 2021

WATHES, C. M. *et al*. Is precision livestock farming an engineer's daydream or nightmare, ananimal's friend or foe, and a farmer's panacea or pitfall? **Computers and Electronics in Agriculture**, Amsterdam, v. 64, n. 1, p. 2–10, 2008.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1 BROILER WELFARE: STATE OF ART

2.1.1 What is animal welfare?

After the Second Great War, a great concern on food availability arose worldwide. The population was growing in high rates and ensuring food security was an enormous challenge. To illustrate this point, world population was about 2.6 billion in 1950, whereas nowadays the number has increased 3 times, reaching 7.8 billion (UN, 2019). Producing animals in higher stocking densities was a successful manner of increasing productivity and food availability, being animal confinement practices adopted in large-scale (FRASER, 2008). Nonetheless, it is possible that increments on food production have occurred at expense of animal welfare (AW).

In 1964, Ruth Harrison published the book "Animal Machines", in which she criticized the living conditions of confined animals. The publication had a great societal repercussion and one year later, the British Parliament instituted the Brambell Committee to enquiry into the welfare of animals kept under intensive livestock husbandry systems. The Committee concluded that, in order to increase AW level, it would be necessary a better understanding of biology and animal needs (FAWC, 2009). After that, it was stipulated the minimum conditions that should be provided to farm animals, which included providing animals the possibility of turning around, lying down, standing up, stretching their limbs, and grooming themselves. This was a milestone for the scientific approach of AW. Years later, these standards were refined by the Farm Animal Welfare Committee (FAWC) and the "Five Freedoms" concept were created. This concept defines that animals must be: free from hunger and thirst; free from discomfort; free from pain, injury, or illness; free to express their normal behavior; and free from fear and distress (FAWC, 2013).

The Five Freedoms concept is well known and widely utilized in farming, policy making, and academic circles, being the framework of many welfare legislations (MCCULLOCH, 2013). However, these prerogatives define only ideal states and not standards for acceptable welfare since they were defined to serve as a guide to analyze any production system through the AW optic. Thus, some issues emerge related to the Five Freedoms, such as the impossibility to provide all freedoms at the same time and the existence of possible trade-offs between them (MCINERNEY, 2004).

In intensive poultry production, animals are kept in houses with no access to the exterior, high stocking density, and sometimes low light intensity. One could argue that the intensive production system disagrees with the freedom to express natural behavior (GOLDBERG, 2016). However, an intensively production system supporter could defend that confinement protects animals of possible predators (free from fear and distress), that animals have free access to feed and water (free from hunger and thirst), and it is probably better for general animal health (free from diseases) when compared to other system (ANDERSON; KOELKEBECK, 2007). Therefore, the Five Freedoms concept has some limitations, being a great framework to indicate what would be ideal for animal lives, but failing in defining the weight that each freedom would have for a general animal welfare assessment (see MCCULLOCH (2013) for details about the Five Freedoms).

Regarding that, Mcinerney (2004) observed that animal welfare is not about the animal's point of view, but rather about human perceptions; because humans use animals, and because we take the decisions about how to treat them, in final instance, animal welfare will be a human decision. In this context, Fraser (2003) identified three different human views on how farm animals should be treated and judged:

(i) The view that "animals should be raised in conditions that promote good biological functioning in the sense of health, growth and reproduction". This is the case of McGlone (1993), who stated that a poor state of welfare is observed only when physiological systems are affected, compromising survival or reproduction. Also, the case of Anderson and Koelkebeck (2007) who criticized that animal welfare has been interpreted by an anthropomorphic view, and that we do not know if animals have consciousness of feelings. Individuals who agree with this view argue that subjective experience of animals cannot be scientifically enquired and, if we intend to analyze the question through the optic of science, it is necessary to conceptualize it in terms of biological functioning (DUNCAN, 1993).

(ii) The view that “animals should be raised in ways that minimize suffering and promote contentment”. This ideology is supported by humanitarians, and is represented mainly by Duncan (1993), who believed that the affective and cognitive states of animals are the only basis to assess their welfare.

(iii) The view that “animals should be allowed to live relatively natural lives”. It is probably supported by general public (PRICKETT; NORWOOD; LUSK, 2010; CLARK et al., 2016; YUNES; VON KEYSERLINGK; HOTZEL, 2017). In this sense, some authors indicated that an animal that is not allowed to perform all the behaviors of its repertoire will be frustrated and will suffer (KILEY-WORTHINGTON, 1989; MENDL., 2001; BROOM; MOLENTO, 2004).

A supporter of view “i” can conclude that the welfare of an animal is good in high-health confinement systems because animals are healthy and growing properly. A supporter of view “ii” can disagree with “i” because animals are too crowded and not feeling well under intensively production systems. Finally, a supporter of view “iii” disagrees with the others because animals should live “natural lives” and should be able to express their natural behavior freely. Perhaps all of them agree that animals should be raised in larger spaces and with the best sanitary condition as possible; their disagreement is about what they believe it is more important for animal welfare.

2.1.2 Farmer and farm animal welfare

In broiler production, there is close contact between stockpersons and farm animals, being the stockperson responsible for animal care, health, and maintenance. Human-animal interactions have been demonstrated to influence not only animals´ behavior but also their welfare and performance (HEMSWORTH, 1997). The corticosterone liberated by animals on stressful conditions, impairs their immune system by decreasing the heterophiles/lymphocytes ratio (SCANES, 2016), predisposing animals to diseases. In addition, stressful conditions can be related to losses on growth performance due to decreases of energy utilization (LIU et al., 2015).

The nature and the frequency of positive actions, as patience and sensitivity, determine the reaction of animals to the farmer (LEWIS; HURNIK, 1998), being animal welfare inextricable to stockperson wellbeing. Stockpersons´ personality is related to their attitudes towards farm animals, as demonstrated by Waiblinger, Menke and Coleman (2002), who observed that pessimist stockpersons were related to negative attitudes towards dairy cows; whereas people high on “agreeableness” used more positive interactions with the animals. It seems to exist a feedback process between the attitudes of humans towards the attitudes of animals; the more positive is the attitude of humans on animals, the more positive it will be the attitude of animals towards human beings, which generates a virtuous cycle. On the contrary, an unsatisfied stockperson can be associated to losses on animal productivity and impairments on animal welfare (HEMSWORTH; VERGE; COLEMAN, 1996).

It must be kept in mind that the relationship between the farmer and the broiler chicken are not the same as a general person has with *pets*. Farmers make their living from animals, spending a significant amount of their time in close contact with them, in a relationship that can include pleasure, fear, animosity and so on. However, it does not necessarily imply that farmers are not concern to animal welfare. As they work with living beings, they may feel responsible for animals´ lives, especially when they consider animals as sentient beings (DOCKÈS; KLING-EVEILLARD, 2006).

The human-animal interaction can be influenced by farmers´ internal feelings of moral obligation. This can happen when farmers become aware of the animal pain as a consequence of certain situation or management (HANSSON; LAGERKVIST, 2012). Similarly, social pressure can play an important role on positive human-animal interaction because negative attitudes towards farm animals can lead to a negative reputation among consumers and other farmers. By the sake of an example, in a study evaluating farmers´ perceptions on animal welfare, Te Velde, Aarts and Woekrum (2002), observed that a so called “license to produce” was of great value to farmers. Such “license” comprehends the extension farmers perceive legitimacy of their activities in society. In both cases, farmers will feel a loss of utility when animals present lower than expected level of welfare.

As individuals may shape their behavior based in a reference group (BORGES; FOLETTO; XAVIER, 2015), it is possible that farmers do not want to be misjudged as someone who is not concern to animal welfare in a context where society demands better treatment for farm animals. In such scenario, it is likely that farmers pursue animal welfare improvements because they experience a negative feeling of not being a good farmer if animals are not in an acceptable level of welfare or because they have altruistic concern for other people behavior or for the animals themselves (HANSSON; LAGERKVIST, 2012). However, the views regarding AW can widely differ among people as it is intrinsic related to moral aspects. Therefore, objective means to evaluate animal welfare is the first step for identifying eventual problems and propose feasible solutions.

2.1.3 The Welfare Quality® assessment protocol for broiler chickens

The Welfare Quality® project was launched in Europe in 2004, motivated by studies that pointed out that European citizens were not purchasing animal friendly products because they had no information on the level of welfare animals were experiencing through their lives (BLOKHUIS, 2008). The project objective is to develop protocols for assessing overall farm animal welfare, to identify AW problems and to create strategies for AW improvements. The welfare standards present in the protocols were developed after an extensive research, which took place in several European countries and involved: animal and social scientists, consumers, citizens, farmers, and other stakeholders (MIELE et al., 2011). These protocols are specie-specific, contemplating until the present date: cattle, poultry and pig (for details about Welfare Quality® achievements see Blokhuis et al. (2010)).

The Protocol is based on 4 welfare principles, namely: “Good feeding”, “Good housing”, “Good health”, and “Appropriate behavior”. These four principles generate 12 welfare criteria, being each one of them measured by one or more variables at the farm and/or slaughterhouses, with exception of “expression of social behaviors”, to which a validated measure was not yet developed (WELFARE QUALITY®, 2009). A score is calculated for each principle after measuring the variables. By evaluating the score of all principles, an overall assessment of broiler welfare is produced, which can be classified into four categories: Excellent, Enhanced, Acceptable, or Not classified (the welfare is considered too low and then unacceptable). Welfare principles and criteria can be visualized in Table 1.

Table 1. Principles, criteria and measurements of Welfare Quality® Assessment Protocol for broiler chickens¹.

Welfare Principles	Welfare Criteria		Measured at farm	Measured at slaughterhouse
Good feeding	1	Absence of prolonged hunger	Criterion measured at slaughter house	Emaciation
	2	Absence of prolonged thirst	Drinker space	Criterion measured at farm
Good housing	3	Comfort around resting	Plumage cleanliness, litter quality, dust sheet test	Criterion measured at farm
	4	Thermal comfort	Panting, huddling	Criterion measured at farm
	5	Ease of movement	Stocking density	Criterion measured at farm
Good health	6	Absence of injuries	Lameness, hock burn, foot pad dermatitis	Breast blister, hock burn, foot pad dermatitis
	7	Absence of disease	On farm mortality, culls on farm	Ascites, dehydration, septicaemia, hepatitis, pericarditis, abscess
	8	Absence of pain induced by management procedures	Not applied in this situation	
Appropriate behaviour	9	Expression of social behaviours	No measure developed until the present moment	
	10	Expression of other behaviours	Cover on the range, free range	Criterion measured at farm
	11	Good human-animal relationship	Avoidance distance test	Criterion measured at farm
	12	Positive emotional state	Qualitative behavioural assessment	Criterion measured at farm

Source: Adapted from Welfare Quality® assessment protocol for poultry (Welfare Quality, 2009).

Although, the Welfare Quality® Protocol provides an objective and scientific approach for AW assessment, it presents several practical limitations. Among them, it can be cited:

(i) The assessment is time consuming and laboring intensive, being necessary up to 4 hours to evaluate the welfare of broilers of a flock.

(ii) The traits of interest are measured by a person; therefore, it is possible to have variability in results due to the interpretation of different observers (RUSHEN; CHAPINAL; DE PASSILLÉ, 2012).

(iii) The animals are evaluated only within five days of slaughter, so the evaluation is just a portrait of a particular time of the animals´ live, not considering their whole life-time period (WEBSTER, 2009).

(iv) For the evaluation of some variables at farm, it is necessary the presence of the observer in the broiler house, which can affect broiler chickens´ behavior when it is not demanded, possibly causing data misinterpretation.

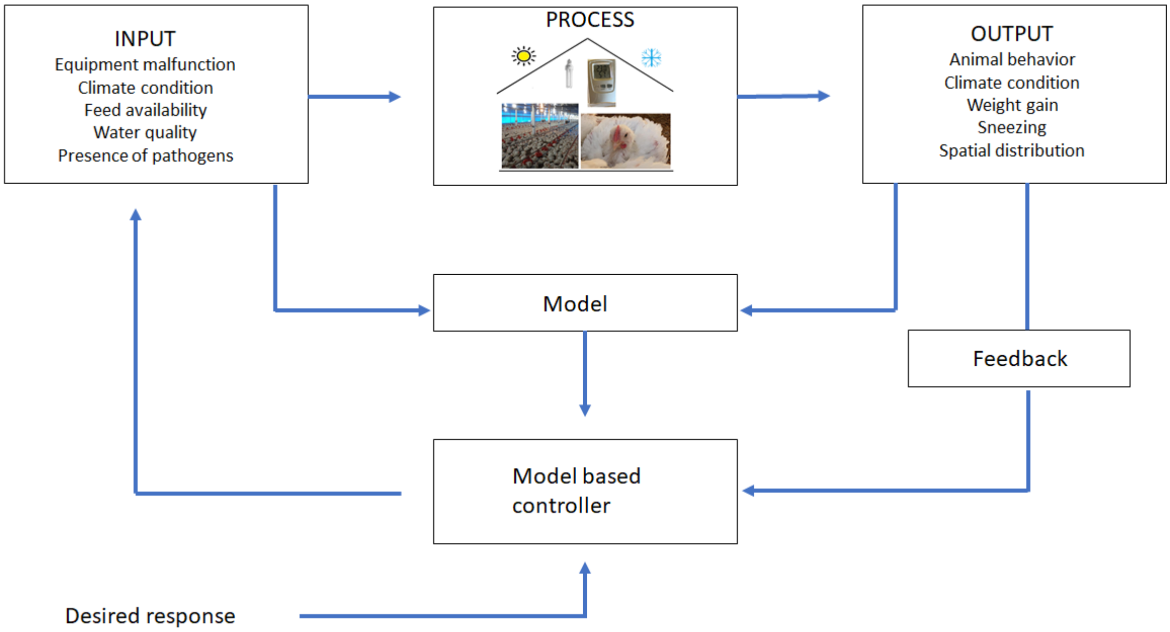
Measuring animal welfare properly is still a challenge for scientists, being especially difficult to develop measurements that can be used in a real environment. There are several factors that can potentially impair broilers´ welfare, such as: stocking density, environmental deterioration, thermal stress, unsuitable social environments and difficulties to access essential resources (SASSI; AVERÓS; ESTEVEZ, 2016). Animals and environment are dynamic and information on AW cannot be humanely collected without appropriate tools. The use of Precision Livestock Technologies (PLF) emerges as a feasible alternative for this since they permit the continuously monitoring of animals and environment in an automate way.

2.2 WHAT IS PRECISION LIVESTOCK FARMING?

The recent development of smart sensors, big data, neural networks, and artificial intelligence created a new universe of opportunities for data measuring and processing. Humans are now able to collect and analyze data in a velocity and precision never seen before, which is being considered the newest Industrial Revolution (JUKAN; MASIP-BRUIN; AMLA, 2017). In the livestock context, PLF can automate daily tasks and continuously monitor animals 24/7, reducing laboring time and precisely detecting and analyzing traits of interest (BERCKMANS, 2017). Such technologies can potentially improve farming activities efficiently since the use of information and communication technology can be utilized for taking practical actions in an accurately way (BANHAZI et al., 2012).

For the development of a PLF technology, initially it is required an accurate model of what is aimed to be measured and controlled. For this, it is necessary to collect the inputs and outputs of a given system. It is desirable to collect the output data at a frequency and scale sufficient to feed the mathematical model in real-time. The output feedbacks to a model-based controller, which gets information from the modelling results and compares with the information with an optimal target (desirable response). The information is passed to an actuator which can control the inputs of the system, making the necessary adjustments when needed or informing farmers of what is occurring through an alarm, for example (BERCKMANS, 2017). An illustration of the process can be visualized on Figure 1.

Figure 1 – General scheme of measuring, modelling, and managing traits of interest.



Source: Adapted from Berckmans (2017).

For the measuring of inputs and outputs, sensors are needed, which can be classified in wearable and non-wearable. Wearable sensors, like GPS or accelerometers, are devices placed on animals that can collect their information individually. Wearable sensors are widely used for measuring welfare and productive variables of dairy cows (CARPIO et al., 2017); nonetheless, it may not be the most suitable for broiler chickens. Because a broiler house can hold thousands of animals, wearable sensors are too costly to be implemented in practical situations, being non-wearable sensors especially important for indoor farming (JUKAN; MASIP-BRUIN; AMLA, 2017). Through cameras, acoustic and environmental sensors, it is achievable to monitor flock´s welfare precisely, evaluating animals´ behavior and environmental conditions in real-time. Such data can inform farmers on animal health, physiological and cognitive states (SASSI; AVERÓS; ESTEVEZ, 2016).

2.2.1 The complexity of PLF technologies

Living organisms are complex, individually different, time-varying and dynamic, which is technically named “CITD system” (QUANTEN; VALCK; CLUYDTS, 2006). To put a light on the complexity matter, a single cell can be used as an example, as it presents numberless mechanisms of actions and metabolic routes, making the attempt to interpret the result of the interactions of billions of cells not a simple task. The *individually different* character refers to the distinct ways animals perform behaviors, which can be explained by the fact that they have their own organic system and psychological states. They are *time-varying* because their responses due to a given stimulus of today can widely differs from tomorrow´s. By way of an example, the thermal comfort zone of a 1-day-old broiler chicks is way different from the thermal zone of 42-day-old broiler. The dynamic character becomes obvious because animals are not static (BERCKMANS, 2017).

The fact that animals are CITD systems makes the development of PLF technologies a complex task. Outputs and inputs of a given system must be measurable and feasible to be mathematically modelled. Due to the complexity of animals, comprehending the reason a given input is provoking a given output can be puzzling. Additionally, the PLF algorithm must be elaborated enough to interpret and to respond adequately to responses that changes through time, which is a crucial characteristic of fast growth broiler chickens. Thus, algorithms must adapt to the time-varying characteristics of the animals, desirably in a continuous way (BERCKMANS, 2017).

The PLF technologies are complex to be produced, especially when they intend to measure and control data in a continuous fashion. A given technology that can measure and model traits of interest successfully but does not provide valuable information to farmers is unlikely to be adopted. The form that data or information are presented to farmers is fundamental for PLF technology usefulness. In one hand, the model-based controller´s mode of action will imply in the level of technology sophistication, getting more complex to be produced as it includes alarms, data interpretation and automation. In the other hand, a PLF technology that effectively communicates with farmers and serves their interests, presents a real added value to them, which potentially increases the probability of its adoption.

There are countless opportunities for developing PLF technologies, as they have enabled the measuring, modelling, and management of a great number of variables continuously. Nevertheless, PLF technology must attend to farmers´ interests if they intend to be useful. It is not feasible to consider that farmers will expend money in innovations that do not provide them any benefits. Regarding this, farmers must be aware of PLF potentialities and limitations, thus they can make their decision for adopting (or not) PLF technologies wisely.

2.2.2 The added value of PLF technologies

Broiler production presents several risks and uncertainties that can easily impair productive performance and animal welfare. Unexpected issues such as animal disease, equipment malfunctioning and oscillation in broiler house environment can imply in economic losses and welfare problems. PLF technologies are particularly relevant for group-housed large-scale production systems, where individual attention to animals cannot be properly paid by the human sensing system solely. Examples of possible benefits provided by PLF technologies will be stressed out in the next paragraphs.

Indicators present on the Welfare Quality® protocol for poultry welfare assessment to evaluate hunger and thirst include bird:feeder and bird:drinker ratios, which are indirect variables for assessing broiler welfare status. Although they are practical to be measured, such variables do not guarantee that animals themselves are well hydrated and nourished and that the equipment are working properly (SOUZA et al., 2015). In concern to that, Kashiha et al. (2013) used cameras to monitor animals´ spatial distribution in a broiler house and infer on possible equipment malfunctions. The technology involved the monitoring of the animals and if any outcome deviated from the expected response of the model-based controller, farmers could be warned by an alarm. Such PLF technology could detect problems in feeder and drinker lines with 95% accuracy, enabling the early detection of equipment malfunctioning, and thus, reducing productive losses and welfare problems.

The PLF technologies potentially minimizes animal and human stress by measuring traits of interest without the need of directly interact with animals. Broiler chickens can present a completely different behavior when they fell threatened as when humans are observing or manipulating them (WAIBLINGER et al., 2006). Such characteristic behavior does not allow farmers to assess animals´ condition properly. An interesting way for avoiding this bias was studied by Dawkins, Cain and Roberts (2012). The researchers studied a system that could detect walking abnormalities in poultry flocks due to hockburn and lameness by recording images from a boiler house and analyzing the mean, variance, skew, and kurtosis of movement along with the spatial distribution of the animals in the broiler house. The authors stated that the system could identify mortality and poor gait scores in an efficiently way.

Monitoring the sounds of a broiler house can also provide relevant information on broilers´ welfare. By analyzing broiler chickens´ vocalization, de Moura et al. (2008) observed a correlation between its amplitude and frequency with animals´ thermal comfort, being verified that broilers in thermal comfort vocalize less than those stressed by temperature. In another experiment, also evaluating broiler chickens´ vocalization, Fontana et al. (2016) could distinguish between distress and calling vocalizations in young chicks, as well as propose a method to predict broiler weight as a function of the sounds emitted by the animals.

A great number of variables can be extracted from animals and their environment using different types of sensors. The gathering of data from different sensors in a single remote technology constitutes a real opportunity for adding value to PLF. The aim of these technologies is to transform the caretaker-farmer in a farm manager, who is getting several information from their broiler houses in real-time being also able to take actions remotely if needed. Van Hertem et al. (2017) used a set of sensors, including cameras and microphones, to get information from broilers and their environment, and produced an innovative visual display that allowed farmers to be aware about the living conditions of broiler chickens in real time. The authors emphasized the importance of training farmers to effectively use the PLF technology and pointed out that it is crucial that the technology delivers information in a simple and useful way to farmers.

Animal welfare may present less value for farmers than other aspects such as growth performance and data management. AW improvements is something farmers probably do not see as clearly as they see performance improvements or feel laboring tasks easier and less time-consuming. However, the societal concern on AW is a major driver requiring these modifications in the productive sector. A given technology can serve for more than one purpose at the same time. By adopting a PLF technology aiming at reducing their time dedicated to animals, farmers can increase their income and improve animals´ condition of living. For instance, a climate controller panel can monitor and control environmental conditions in a more effectively way than a farmer, providing animals better housing conditions, which can lead to a better growth performance and to a higher income.

Technologies aiming at improving animal welfare can also present other benefits to farmers such as economical, by improving animals´ performance, managerial, by better controlling environment and animal data, and those related to farmers´ welfare, since technologies can potentially reduce their labor time, for example. Although there is great scientific effort on the development of such technologies, information on how they are addressing broiler welfare regarding the animals´ necessities are still lacking in the literature. Along with that, little attention has been given to broiler farmers´ decision for PLF technologies adoption. Opinions and attitudes of farmers towards PLF potentialities seems to be lacking and information on the current level of PLF diffusion among farmers are not easily found. Such lack of data is curious, considering that farmers are the ones in closest contact to the animals and those who are responsible for taking care of them during the most period of animals´ lives. Farmers comprehend a crucial link between the development of a new technology and its utilization in a real environment.

2.2.3 The boundaries of PLF technologies

Despite all potentialities PLF technologies present, their currently level of adoption by farmers have been much slower than their scientifical development. According to Wathes et al.

(2008), there are mainly three reasons that can explain this. Firstly, a significant amount of animals´ monitoring systems are not being developed along with manufacturing companies or towards their interests, being, in many cases, not feasible to be produced. Secondly, several studies on the development of PLF technologies do not offer practical solutions for farmers. Most of technologies were studied in experimental situations only, being few of them tested in commercial conditions. A commercial broiler house with thousands of broilers widely differs from small groups or individuals used in experimental conditions and a real environment is complex and dynamic, presenting several variables such as dust, noise, equipment malfunctioning, temperature/humidity variations and health challenges that are often controlled in experimental conditions. Thirdly, there is a lack of information regarding the market demand for PLF technology.

Farmers´ awareness and interests in PLF technologies, as well as their willingness for PLF adoption, has been timidly studied until now. In one of the rare studies regarding this, Hartung et al. (2017) assessed the opinions of European farmers on PLF technologies and could take interesting insights from that. The conducted research involved the trial of image, sound and environmental sensors by broiler, pig and dairy farmers in Europe and the impressions of farmers were assessed through interviews. The authors reported that broiler farmers focused their interest on technologies that enable animal monitoring and that can integrate data and management, expecting to improve animals´ health and productivity. Regarding AW improvements due to the utilization of PLF, broiler farmers judged the topic an important factor of production; however, they stressed out that improving AW with no economic return is unrealistic. Besides, farmers believed that the main advantages of PLF adoption came from less routine work and better monitoring of animals´ growth and behavior; nonetheless, the possible high price of such technology was a pivotal concern.

In concern to that study, farmers had a positive impression on PLF. Notwithstanding, they emphasized that the expected positives about PLF utilization, such as improving animal welfare and working environment as well as reducing laboring time, must be high enough to pay for their investment. In Hartung´s research, not all technologies worked properly during all the time, and it is something to stress out, as it is a reason to concern on PLF. As any innovation, it is common to face unforeseen problems in their initial steps; however, it is unlikely that farmers will trust in a monitoring system that can stop working suddenly and compromise their results. Technologies must be robust enough, with low cost of maintenance and with a supportive technical assistance behind them if it intends to be largely adopted. Additionally, it must present information in a simple way, that allows farmers to interpret data properly (VAN HERTEM et al., 2017). Some aspects related to possible limitations of PLF adoption by farmers in need of more in-depth attention are cited next:

(i) The complexity of a technology present can be a hindrance for its adoption (BORGES; FOLETTO; XAVIER, 2015). Regarding this, PLF technologies can be difficult to be managed and used. In general, farmers do not have high education levels and it can be an obstacle for learning complicated technologies. PLF technologies can be a black box and expending money on something that is not completely understandable is often avoided.

(ii) Farmers can be slow in accepting new ideas, avoiding the intrinsic risks of innovations. There is a transactional cost involved with changing routine activities and the benefits of adoption must be higher than this cost (VIEIRA FILHO; SILVEIRA, 2012). Farmers may have aversion of changing their routine and they may wait for an encouraging environment that gives them some guarantee on the return over their investment, such as a positive experience of other broiler farmers using PLF.

(iii) Technologies can substitute some farmers´ routine activities, controlling animal and environmental conditions automatically; however, what could be the consequences if something compromises PLF functioning? Technical issues intrinsic to technologies as routine maintenances as well as extrinsic ones, such as poor internet connection and unstable electric power in rural areas, can lead to negative impacts on animal welfare and performance.

(iv) Farmers may not perceive any economic benefits of adhering to technologies. The possibility of losing money if something goes wrong with the technology demotivate their use. It is unrealistic that farmers will adopt a given technology if it does not imply in a fair return over their investment (WATHES et al., 2008).

(v) The awareness of technologies is a fundamental step for increasing their adoption by farmer (PIVOTO et al., 2019). The lack of information on the existence and potentialities of PLF technologies can be a crucial factor for the poor using of PLF.

(vi) If the technology does not attend farmers´ needs, there is a low level of compatibility between them (TEY; BRINDAL, 2012). Farmers can be not interested in technology because they do not foresee any benefits from its utilization, in other words, it is possible that they do not perceive any relatively advantage with PLF use. If farmers are not concern to animal welfare or to any other improvement that PLF technologies may offer, it is unlikely that they will adopt such technologies.

Therefore, there is gap to be fulfilled between the development of PLF technologies and the utilization of these technologies by farmers. The development of PLF technologies is complex, requiring expertise of engineers, veterinarians, ethologists, information and technology professionals, and etc. It is not the objective of the present thesis to aim on technical aspects of PLF development, but to analyze how these novel technologies are being developed to address broiler welfare and to bring elements for a more in-depth discussion on their utilization by farmers.

2.3 METHODOLOGICAL PROCEDURES

Methodologically, the thesis is divided in two steps. Firstly, an exploratory approach was made through a systematic review of the literature in order to obtain more in-depth knowledge on the object of the research. The PLF technologies consist of a set of technologies that can aim at different purposes. Thus, the literature review brings information on the types of PLF being developed to assess broiler welfare, on the manner that such technologies are addressing the different principles of broiler welfare as well as on the specific characteristics of each PLF being developed. A total of 57 peer-reviewed papers extracted from the Web of Science and Scopus databases were suitable for the research purpose and analyzed using the Welfare Quality® protocol for broilers as a framework (WELFARE QUALITY®, 2009). Details on the methodological procedures carried out in this part of the thesis is in Chapter 3.

Information from the systematic literature review was used as a guide to formulate the questions that compose the second methodological step. In this step, a survey was conducted with 204 broiler farmers in Southern Brazil. Broiler farmers were asked to voluntarily answer a questionnaire about their socioeconomic and productive data, as well as about their opinions on broiler welfare, PLF technologies potentialities and about their adoption of such technologies. The diffusion of the questionnaires was made with the help of two poultry industries. The analysis of these data originated Chapter 4 and 5.

In Chapter 4, a sample of 184 broiler farmers were analyzed (20 questionnaires had to be disregarded due to incomplete answers). In this Chapter, the importance broiler welfare has to farmers, broiler farmers´ perceptions on the current level of broiler welfare and their opinions on technologies potentialities regarding welfare improvements were assessed. The Welfare Quality® protocol for broilers was used as a framework for the definition of welfare criteria and principles. Statistical analysis were used to perform comparisons and correlations. Details on the methodology utilized to evaluate these data are presented in Chapter 4.

Finally, in Chapter 5, a sample of 173 broiler farmers (31 questionnaires had to be disregard due to incomplete answers) was analyzed. Information on the utilization of PLF technologies related to broiler welfare and on determinants and limiting factors influencing the adoption of such technologies were assessed. Logistic regression was performed to analyze and quantify the influence of socioeconomic and productive data as well as of PLF technologies potentialities on broiler farmers´ likelihood of PLF adoption. More details about this methodological procedure are find in Chapter 5.

REFERENCES

ANDERSON, K. E.; KOELKEBECK, K. W. Realistic views concerning poultry welfare. **Poultry Science**, Champaign, v. 86, p. 1251–1252, 2007.

BANHAZI, T. M. *et al*. Precision livestock farming: an international review of scientific and commercial aspects. **International Journal of Agricultural and Biological Engineering**, Beijing , v. 5, n. 3, p. 1–9, 2012.

BERCKMANS, D. General introduction to precision livestock farming. **Animal Frontiers**, London, v. 7, n. 1, p. 6–11, 2017.

BLOKHUIS, H. J. International cooperation in animal welfare: the welfare project. **Acta Veterinaria Scandinavica**, London, v. 50, p. 1–5, 2008. Supl. 1.

BLOKHUIS, H. J. *et al*. The Welfare Quality ® project and beyond: safeguarding farm animal well-being. **Acta Agriculturae Scandinavica**, Stockholm, v. 60, n. 3, p. 129–140, 2010.

BORGES, J. A. R.; FOLETTO, L.; XAVIER, V. T. An interdisciplinary framework to study farmers' decisions on adoption of innovation: insights from expected utility theory and theory of planned behavior. **African Journal of Agricultural Research**, Nairobi, v. 10, n. 29, p. 2814–2825, 2015.

BROOM, D. M.; MOLENTO, C. F. M. Bem estar animal: conceito e questões relacionadas - revisão. **Archives of Veterinary Science**, Curitiba, v. 9, n. 2, p. 1–11, 2004.

CARPIO, F. *et al.* **Beyond production indicators:** a novel smart farming application and system for animal welfare. *In*: INTERNATIONAL CONFERENCE ON ANIMAL-COMPUTER INTERACTION, 4., 2017, Milton Keynes. **Proceedings** [...]. Milton Keynes: Association for Computing Machinery, 2017. p. 1-11.

CLARK, B. *et al.* A systematic review of public attitudes, perceptions and behaviours towards production diseases associated with farm animal welfare. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 29, n. 3, p. 455–478, 2016.

DOCKÈS, A. C.; KLING-EVEILLARD, F. Farmers' and advisers' representations of animals and animal welfare. **Livestock Science**, Amsterdam, v. 103, n. 3, p. 243–249, 2006.

FAWC – FARM ANIMAL WELFARE COUNCIL. **Farm animal welfare in Great Britain:** past, present and future. London: FAWC, 2009.

FONTANA, I. *et al*. Vocalisation sound pattern identification in young broiler chickens. **Animal**, Cambridge, v. 10, n. 9, p. 1567–1574, 2016.

FRASER, D. Understanding animal welfare. **Acta Veterinaria Scandinavica**, London, v. 50, p. 1–7, 2008. Supl. 1.

GOLDBERG, A. M. Farm animal welfare and human health. **Current Environmental Health Reports**, [Switzerland], v. 3, n. 3, p. 313–321, 2016.

HANSSON, H.; LAGERKVIST, C. J. Measuring farmers' attitudes to animal welfare and health. **British Food Journal**, Bradford, v. 114, n. 6, p. 840–852, 2012.

HARTUNG, J. *et al*. European farmers' experiences with precision livestock farming systems. **Animal Frontiers**, London, v. 7, n. 1, p. 38–44, 2017.

HEMSWORTH, P. H. Human-animal interactions in agriculture and their impact on animal welfare and performance. **BSAP Occasional Publication**, Cambridge, v. 20, p. 27–34, 1997.

HEMSWORTH, P. H.; VERGE, J.; COLEMAN, G. J. Conditioned approach- avoidance responses to humans: the ability of pigs to associate feeding and aversive social experiences in the presence of humans with humans. **Applied Animal Behaviour Science**, Amsterdam, v.

50, p. 71–82, 1996.

JUKAN, A.; MASIP-BRUIN, X.; AMLA, N. Smart computing and sensing technologies for animal welfare: a systematic review. **ACM Computing Surveys**, New York, v. 50, n. 1, p. 1–27, 2017.

KASHIHA, M. *et al*. Development of an early warning system for a broiler house using computer vision. **Biosystems Engineering**, London, v. 116, p. 36–45, 2013.

KILEY-WORTHINGTON, M. Ecological, ethological, and ethically sound environments for animals: toward symbiosis. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 2, p. 323–347, 1989.

LEWIS, N. J.; HURNIK, J. F. The effect of some common management practices on the ease of handling of dairy cows. **Applied Animal Behaviour Science**, Amsterdam, v. 58, p. 213–220, 1998.

LIU, L. *et al.* Effect of immune stress on growth performance and energy metabolism in broiler chickens. **Food and Agricultural Immunology**, v. 26, n. 2, p. 194–203, 2015.

MCCULLOCH, S. P. A critique of FAWC's five freedoms as a framework for the analysis of animal welfare. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 26, n. 5, p. 959–975, 2013.

MCINERNEY, J. **Animal welfare, economics and policy**. London: Defra, 2004.

MENDL, M. Assessing the welfare state. **Nature**, London, v. 410, n. 6824, p. 31–32, 2001.

MIELE, M. *et al*. Animal welfare: establishing a dialogue between science and society. **Animal Welfare**, Hertsmere, v. 20, p. 103–117, 2011.

PIVOTO, D. *et al*. Factors influencing the adoption of smart farming by Brazilian grain farmers. **International food and agribusiness Management Review**, Stamford, v. 22, n. 4, p. 571–588, 2019.

PRICKETT, R. W.; NORWOOD, F. B.; LUSK, J. Consumer preferences for farm animal welfare: results from a telephone survey of US Households. **Animal Welfare**, Hertsmere, v. 19, p. 335–347, 2010.

QUANTEN, S.; VALCK, E. D. E.; CLUYDTS, R. Individualized and time-variant model for the functional link between thermoregulation and sleep onset. **Journal of Sleep Research**, Regensburg, v. 15, p. 183–198, 2006.

RUSHEN, J.; CHAPINAL, N.; DE PASSILLÉ, A. M. Automated monitoring of behavioural-based animal welfare indicators. **Animal Welfare**, Hertsmere, v. 21, n. 3, p. 339–350, 2012.

SASSI, N. B.; AVERÓS, X.; ESTEVEZ, I. Technology and poultry welfare. **Animals**, Basel, v. 6, n. 62, p. 1–21, 2016.

SCANES, C. G. Biology of stress in poultry with emphasis on glucocorticoids and the heterophil to lymphocyte ratio. **Poultry Science**, Oxford, v. 95, p. 2208–2215, 2016.

SOUZA, A. P. O. *et al*. Broiler chicken welfare assessment in GLOBALGAP ® certified and non-certified farms in Brazil. **Animal Welfare**, Hertsmere, v. 24, p. 45–54, 2015.

TE VELDE, H.; AARTS, N.; WOERKUM, C. V. A. N. Dealing with ambivalence: farmers' and consumers' perceptions of animal welfare in livestock breeding. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 15, p. 203–219, 2002.

TEY, Y. S.; BRINDAL, M. Factors influencing the adoption of precision agricultural technologies: a review for policy implications. **Precision Agriculture**, Monticello, v. 13, p. 713–730, 2012.

UN - UNITED NATIONS. **World population prospects 2019**: highlights. New York: United Nations, 2019.

VAN HERTEM, T. *et al*. Appropriate data visualisation is key to precision livestock farming acceptance. **Computers and Electronics in Agriculture**, Amsterdam, v. 138, p. 1–10, 2017.

VIEIRA FILHO, J. E. R.; SILVEIRA, J. M. F. J. Mudança tecnológica na agricultura: uma revisão crítica da literatura e o papel das economias de aprendizado. **Revista de Economia Sociologia Rural**, Brasília, DF, v. 50, n. 4, p. 721–742, 2012.

WAIBLINGER, S. *et al*. Assessing the human–animal relationship in farmed species: a critical review. **Applied Animal Behaviour Science**, Amsterdam, v. 101, p. 185–242, 2006.

WAIBLINGER, S.; MENKE, C.; COLEMAN, G. The relationship between attitudes, personal characteristics and behaviour of stockpeople and subsequent behaviour and production of dairy cows. **Applied Animal Behaviour Science**, Amsterdam, v. 79, p. 195–219, 2002.

WATHES, C. M. *et al*. Is precision livestock farming an engineer's daydream or nightmare, ananimal's friend or foe, and a farmer's panacea or pitfall? **Computers and Electronics in Agriculture**, Amsterdam, v. 64, n. 1, p. 2–10, 2008.

WEBSTER, A. J. F. The virtuous bicycle: a delivery vehicle for improved farm animal welfare. **Animal Welfare**, Hertsmere, v. 18, n. 2, p. 141–147, 2009.

WELFARE QUALITY ®. **Welfare Quality® assessment protocol for poultry (broilers, laying hens)**. Lelystad: Welfare Quality® Consortium, 2009.

YUNES, M. C.; VON KEYSERLINGK, M. A. G.; HÖTZEL, M. J. Brazilian citizens' opinions and attitudes about farm animal production systems. **Animals**, Basel, v. 7, n. 10, p. 1–15, 2017.

CHAPTER 3

How are Information Technologies Addressing Broiler Welfare? A Systematic Review Based on the Welfare Quality® Assessment

Heitor Vieira Rios [1,2,*], Paulo Dabdab Waquil [3], Patrícia Soster de Carvalho [2,4] and Tomas Norton [2,*]

[1] Center for Studies and Research in Agribusiness, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS, 91540-000, Brazil
[2] Department of Biosystems, Division Animal and Human Health Engineering, Group M3-BIORES: Measure, Model & Manage of Bioresponses, KU Leuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium
[3] Department of Economics and Foreign Affairs and Center for Studies and Research in Agribusiness, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS, 91540-000, Brazil
[4] Departament of Zootechny, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS, 91540-000, Brazil
* Correspondence: heitorvieira_rios@hotmail.com (H.V.R.); tomas.norton@kuleuven.be (T.N.)

Received: 23 December 2019; Accepted: 12 February 2020; Published: date

Abstract: This systematic review aims to explore how information technologies (ITs) are currently used to monitor the welfare of broiler chickens. The question posed for the review was "which ITs are related to welfare and how do they monitor this for broilers?". The Welfare Quality® (WQ) protocol for broiler assessment was utilized as a framework to analyse suitable articles. A total of 57 studies were reviewed wherein all principles of broiler welfare were addressed. The "good health" principle was the main criteria found to be addressed by ITs and IT-based studies (45.6% and 46.1%, respectively), whereas the least observed principle was "good feeding" (8.8%). This review also classified ITs and IT-based studies by their utilization (location, production system, variable measured, aspect of production, and experimental/practical use). The results show that the current focus of ITs is on problems with conventional production systems and that less attention has been given to free-range systems, slaughterhouses, and supply chain issues. Given the valuable results evidenced by the exploitation of ITs, their use in broiler production should continue to be encouraged with more attention given to farmer adoption strategies.

Keywords: information technology; precision livestock farming; welfare quality

1. Introduction

1.1. General Overview and Objectives

The world population growth is putting pressure on all food production sectors and, in particular, demanding agricultural chains to be more productive, efficient, and sustainable. Poultry meat is currently the main source of animal protein produced worldwide and is expected to comprise approximately 38% of global demand for animal protein (excluding fish) by 2028 [1]. At the same time, ethical and moral concerns about the way we produce our food have gained prominence in contemporary society. Societal concern regarding the welfare of farm animals and the sustainability of animal production systems has provoked important discussions and has emerged as an important point in the agenda of many scientific debates [2].

Animal welfare is considered tightly associated with livestock farm sustainability [3]. In fact, Broom [4] argues that it is a duty of humans to ensure adequate living conditions for farm animals as animal welfare is one of the foundations of sustainable livestock farming. However, ensuring high welfare levels for farm animals is not a simple task as they are generally produced in large-scale intensive production systems which offer marginal income to farmers [5]. In the past, poultry production was predominantly a subsistence activity where there was a lower number of animals per farm and they could be almost individually managed. Nowadays, however, the number of individual animals per farm worker has increased considerably [6], making the individualized attention to the animals impossible without appropriate management tools and technology. Thus, the assessment and management of animal welfare is a great challenge to be addressed in order to achieve the global demand for animal protein while attending to these societal concerns [7]

As an attempt to define objective methods to assess farm animal welfare (FAW), the European Commission launched the Welfare Quality® (WQ®) project in 2004 [8]. The project developed species-specific protocols, which provided a score for four main principles of FAW (good feeding, good housing, good health, and appropriate behaviour) based upon 12 criteria that can be measured on the farm and/or in the slaughterhouse [9]. The welfare standards presented in the protocols were developed after extensive research, which took place in several European countries and involved animal and social scientists, consumers, citizens, farmers, and other stakeholders [10]. Since its publication, the WQ® protocol for broiler chickens has been used as a framework by several researchers for a wide range of purposes. For instance, Wilhelmsson et al. [11] utilized the protocol to compare the level of welfare of fast growing and slow growing broiler strains. Tuyttens et al. [12] used it to assess broiler welfare in Brazil and in Belgium. Vanhonacker et al. [14] utilized the protocol to develop a questionnaire to evaluate citizens' and producers' opinions on the welfare of broilers, and Gocsik et al. [14] used it to compare the cost efficiency of increasing the level of broiler welfare when reared in different systems of production. Therefore, WQ® is largely accepted by the scientific community as the state-of-art approach in welfare assessment and should therefore play a role in welfare management in the future.

Welfare assessment on farms is also rapidly evolving due to the development and utilization of new information technologies (ITs). Sensors, cameras, machine learning, wireless systems, mobile software applications, cloud/fog computing, and internet of things (IoT) are all elements of the information revolution impacting society [15]. Many of these innovations are now being applied to animal production systems to help in the management of farms and to better control an animal´s condition and its environment, a field also known as Precision Livestock Farming (PLF) [16,17]. PLF technologies comprise a set of ITs to capture, measure, and process a great volume of data in real time [18]. The PLF approach can automate the assessment of variables involved in the monitoring and in the management of FAW. PLF can increase the control of the variables involved in the FAW and can enable the sharing of these information among sectors of the production chain. Therefore, it is interesting to identify and evaluate how ITs can address issues and can promote the welfare of broiler chickens.

In the current study, WQ® has been used as a framework in order to carry out a systematic review (SR) aimed to achieve three objectives related to welfare assessment by ITs:

1. Identify and analyse ITs that could help capturing, measuring, processing and controlling variables involved with the welfare of broiler chickens;
2. Evaluate how ITs are addressing the main concerns of broiler chickens welfare;
3. Provide insights on possible gaps between the literature on IT and welfare issues in order to alert for possible problems and encourage future studies.

1.2. Information Technology as a Potential Means to Address the Limitations of Welfare Quality

Despite being a validated protocol to assess welfare, the WQ® protocol for broilers does present some limitations. Among them, the following are included:

1. The time necessary to evaluate all the variables needed [19], as it can take up to 4 hours to assess the welfare of broilers of a single farm.
2. As the measures are made by an individual observer, differences in scoring can be due to inter-observer variability and not due to the actual animal welfare level [20].

3. The animals are generally evaluated only within five days of slaughter, so the evaluation is just a snapshot at a particular time of the animals′ life, not taking in consideration their living conditions during its life-time period [21].
4. For the evaluation of some variables at farm level it is necessary for the observer to be present in the building, which could affect animal behaviour and possibly cause misinterpretation of the data collected.

On the other hand, there has been a significant effort to develop ITs to assess the welfare status of animals over recent years. Information technologies make possible the generation of a large volume of data and information to derive knowledge on the measured processes. With respect to bird welfare, cameras have been shown to be able to measure indicators on the frequency, duration, and sequence of behaviours expressed by poultry [22]. For example, Dawkins et al. [23] were able to detect walking abnormalities in poultry flocks due to hock burn and lameness by recording images from a broiler house and by analysing the spatial distribution of broiler chickens and their movement characteristics. In a similar way, research conducted by Montis et al. [24] evaluated the poultry eating and drinking patterns by using cameras installed in broiler houses to monitor animal behaviour in a continuous fashion.

Monitoring not only the response of birds but also the housing conditions can provide farmers with interesting information to help manage broiler welfare. For example, a bird's vocalization response can be evaluated to estimate heat stress [25,26]. The correlation between these vocalizations and thermal comfort of broiler chickens can be obtained by analysing the amplitude and frequency of the signals [27]. Following this, the data can be interpreted and information can be presented to the farmers in an acceptable and actionable way [28]. In this way, PLF-oriented ITs have a potentially powerful role to play on research and practical assessments of poultry behaviour and on appropriate environment conditions. Although a significant number of ITs are being developed and oriented towards farm animal management, not all of them are related to their welfare. Moreover, ITs can be focused in different principles of welfare in distinct manners. Therefore, this SR will assess only the ITs associated with broiler chicken welfare.

2. Materials and Methods

2.1. Systematic Review

The main question that guided this SR was "which ITs are related to broiler welfare and how can they monitor it?". Peer-reviewed papers extracted from the Web of Science and Scopus databases were utilized. These databases were chosen because both index agricultural research. Web of Science and Scopus databases were accessed by the Portal of the Library of the Federal University of Rio Grande do Sul, UFRGS, Brazil provided by *Coordenadoria de Aperfeiçoamento de Pessoal do Ensino Superior, Brazil (CAPES)* and KU Leuven, Leuven, Belgium.

The SR was performed using StArt (State-of-the-Art Through Systematic Review). This tool helps the researcher to organize and to elaborate a SR following three main steps, namely planning, execution, and summarization. In the planning phase, the study protocol was created, inclusion and exclusion criteria were created, extraction form fields were elaborated, and the initial papers were searched using terms and booleans. A description of the study protocol can be visualized in the Supplementary Materials (Table S1, Supplementary Results).

The "execution" part was comprised of two steps: selection and extraction. In the selection phase, title and abstract of each paper were read and passed through a selection process considering the inclusion and the exclusion criteria. Duplicated papers were also identified in this part of the study. In the extraction phase, the papers selected were fully read and subjected to inclusion and to exclusion criteria again. After that, they were classified and analysed according to the extraction form fields. Finally, in the summarization phase, visualizations were created and the conclusions were written.

As the objective of the study was to evaluate all papers related to the subject, no limitations for publication year were defined. One researcher was responsible for the literature search. The search period comprised every year until April 17, 2019. After initial research and recurrent tests, the keywords were defined. A combination of keywords were carefully chosen to achieve the highest number of results. Initially, only the terms "Broiler" AND "technolog*" AND "welfare" were used. Nevertheless, by reading the selected papers, other studies related to the object of the present SR were identified and new terms were added to the search. The process was repeated with each new study found. By the end of this process, the terms found fell into different classes: animal, information technology, and animal welfare (Table 1).

The search was done by combining the animal term with each information technology term and each animal welfare term with the boolean "AND". The boolean OR was used to add different information technology and/or welfare terms to the search. For example, "broiler AND technolog* AND welfare" OR "broiler AND technolog* AND wellbeing" OR "broiler AND Precision livestock farm* AND welfare", etc. The asterisk was utilized in all information technology terms to automatically include related words. The term "wellbeing" was also used as a synonym for "welfare". These keywords were inserted into the field "topic" of Web of Science and in the fields "article title, abstract, and keywords" of Scopus.

Table 1. Terms and booleans utilized in the search fields of Web of Science and Scopus databases.

Animal	Information Technology	Animal Welfare
Broiler	Technolog*	Welfare
	"Precision Livestock farm*"	Wellbeing
	Computer*	
	Digital*	
	Informatic*	
	Remote*	
	Automat*	
	Camera*	
	Sensor*	
	Radio*	
	Image*	
	Sound*	

Asterix (*) was used to indicate the acceptance of any number of characters at the end of a keyword; phrases enclosed in quotation marks ("") were searched as a whole word e.g. ("precision livestock farming")

A total of 406 publications were finally obtained. From Web of Science, 221 documents were obtained, while from Scopus, a total of 185 documents was found. Duplicated papers (n = 125) were identified and excluded utilizing the StArt tool in the selection phase. Title and abstracts were then screened by two researchers in the area, and documents that were not relevant to the present research topic were excluded utilizing inclusion/exclusion criteria. Whenever the two researchers disagreed on the papers to be excluded/included, they discussed until they reach an agreement.

Inclusion/exclusion criteria were used to screen each search result. Only peer-reviewed articles were included in the analysis, with conference papers (n = 34), editorial notes (n = 2), and reviews (n = 70) being excluded. Papers that do not address the object of the study were also excluded, for instance, papers that were not about broiler welfare (n = 49), that did not involve any kind of IT (n = 66), and that did not have an available summary (n = 1). Amongst the 59 full texts selected, two papers were not written in Portuguese or English and were then excluded. Therefore, by the end of this process, a total of 57 peer-reviewed articles was included in the SR. The process is visualized in Figure 1.

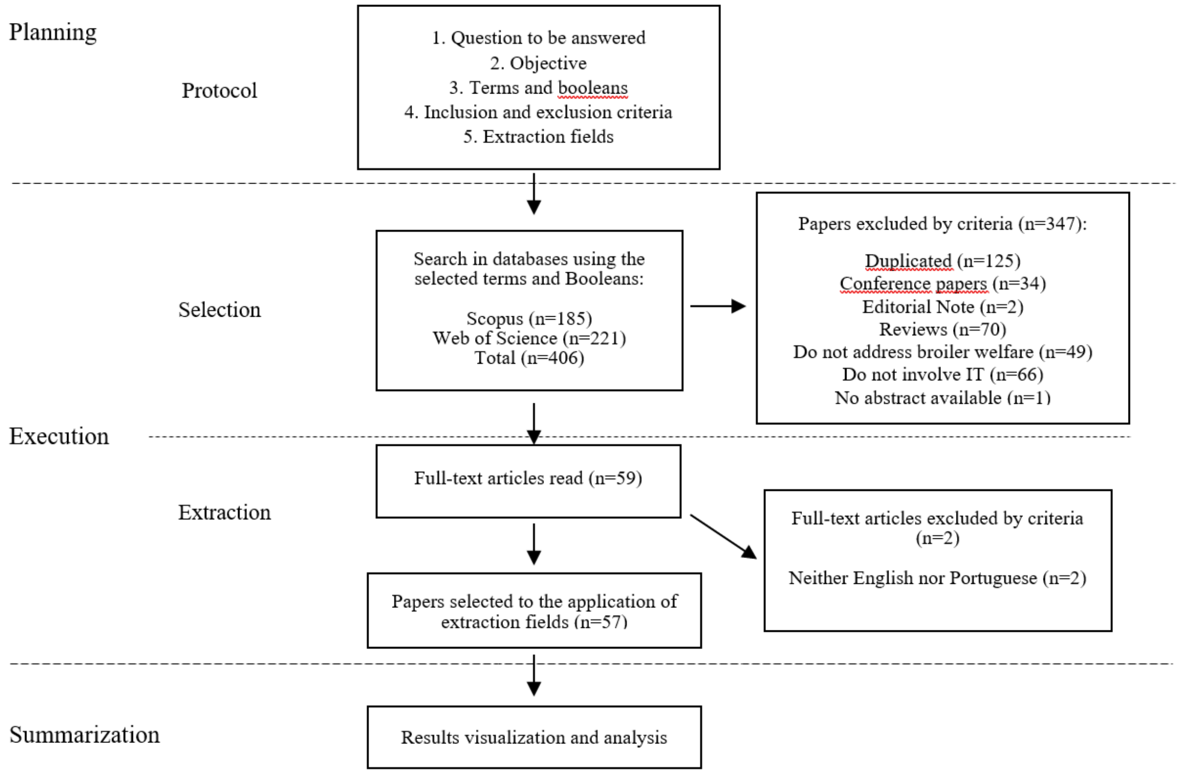


Figure 1. Processes adopted in the present systematic review.

2.2. Papers Analysed and Approaches Utilized

A thorough evaluation was then done on the accepted studies. Afterwards, key data were extracted from each evaluated paper and analysed using the spreadsheet software Excel®. To ensure the objectivity and consistency of the procedure, these data were then checked and qualified by two PhD-level researchers with relevant expertise. Different types of ITs were evaluated and grouped according to their main characteristics within 9 categories, namely image, sound, algorithm, radio frequency identification (RFID), automatic weighing scale, environmental sensor, animal sensor, kinematic, and force measurement platform. A full description of data collection is given in the Supplementary Materials (Table S2, Supplementary Results).

The ITs themselves and IT-based studies were considered separately. A distinction between them was made because a single IT study can contain more than one IT and can address different FAW issues. The ITs and IT-based studies were analysed and categorised with the aim of answering three questions:

1. What are the ITs and how they were utilized?
2. How are the welfare assessment approaches addressed by ITs and IT-based studies?
3. How can each IT group be classified?

In order to answer questions 2 and 3, six approaches were used. Questions, approaches, and possible answers are visualized in Table 2.

Table 2. Approaches and possible answers related to the information technology (IT)-based studies selected in the systematic review (SR).

Questions	Possible Answers
1. What are the ITs and how they are utilized?	Description of each IT identified in the evaluated IT-based studies
2. How is welfare addressed by the ITs and IT-based studies?	Description of IT-based studies, ITs and ITs groups
3. How is each IT group classified in the different approaches?	
Approaches	
1. What principle(s) of WQ for broiler´s are the ITs and IT-based studies related to?	Good feeding Good housing Good health Appropriate behaviour Humane slaughter
2. What phase of the animal´s life do the ITs and the IT-based studies correspond to?	Farm Slaughterhouse
3. Are the ITs and IT-based studies related to which production system?	Conventional Free-range Both
4. Are the ITs and the IT-based studies related to environmental or animal-based variables?	Environmental-based Animal or flock-based Both
5. What aspect of the production chain are the ITs and IT-based studies addressing?	Technical aspects of production Aspects about actors of the supply chain Both
6. Are the ITs and IT-based studies related to practical or experimental situations?	Practical Experimental Both

The approaches were defined based on the following: WQ® principles (approach 1 and 2), aspects of the production systems (approach 3), and characteristics of the IT (approaches 4–6). Some publications and ITs selected were about humane slaughter, which is a process wherein high animal welfare should be maintained. However, this item was not present in the WQ® principles. Thus, for the present SR, the "humane slaughter" principle was created. The questions were aimed at extracting relevant welfare-oriented information about the ITs and the IT-based studies wherein they were applied. Each of these were carefully assessed for each question, paying attention to the following items:

1. A single study can implement or test more than one IT;

2. A study often has wider objectives than an IT, since the IT is generally used for a given purpose during the evaluation of other aspects of an animal´s life;
3. A given variable can be measured by an IT in one phase of animal´s life but the variable was produced in other phase (e.g. foot pad dermatitis - which is a problem of the farm phase but is measured in the slaughterhouse).

3. Results

The object of this study was limited to the evaluation of peer-reviewed journal articles related to the welfare of broiler chickens where IT(s) was utilized. A total of 57 articles satisfied the criteria applied. More details about each publication, consisting of details about the authors, year, country, circumstances in which the ITs were utilized, facilities wherein the studies were conducted, and main achievements, can be found in Appendix A. Apart from one publication in 1990 and another in 2000, the analysed peer-reviewed journal papers were published in the last 15 years, with the most frequent occurrence in the 2016–2018 period (Figure 2). The results for each question previously described are presented in the next subsections.

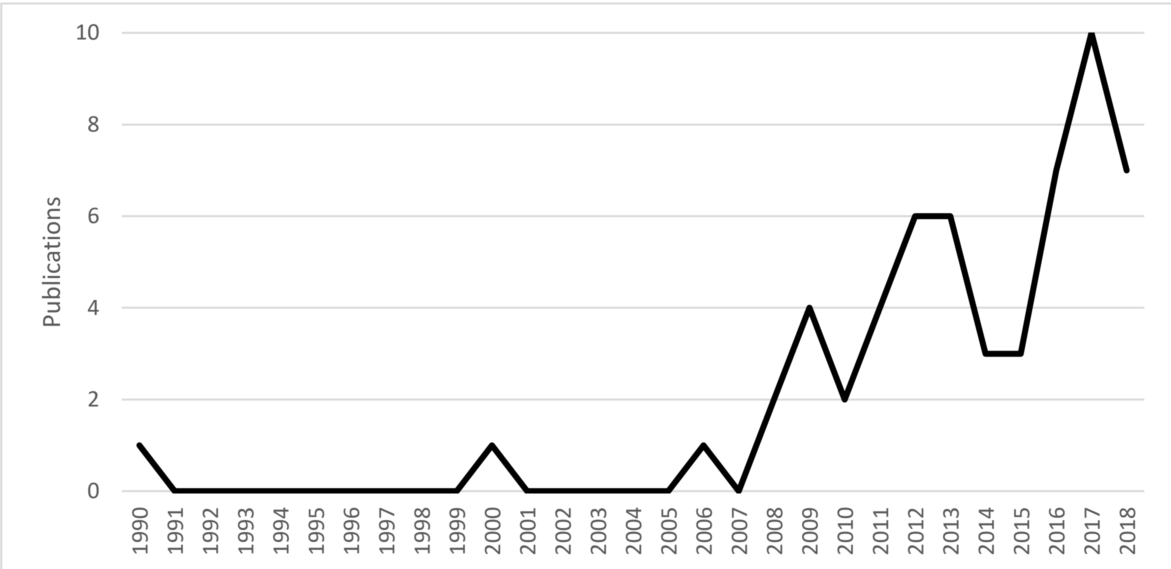


Figure 2. Temporal distribution of publications.

3.1. How do the Utilized ITs Work?

An answer to this question was necessary to produce guidelines that permit the study of ITs using a systematic approach. By analysing how the IT works, it was possible to understand their function, to identify patterns, and to classify them in groups. A description of each technology group, the number of times they were observed, and the percentage of their appearances in total publications are shown in Table 3.

Image technologies presented the highest number of appearances (n = 46) among the IT observed in the SR. However, because different kinds of image technologies were identified, this category was divided in five subcategories according to their similarities, namely digital video recording, flock distribution analysis, thermal image analysis, other image analyses, and image display tool. Although all image technologies generally involve some kind of video recording, the subgroup *digital video recording* was created to classify image technologies that could not be allocated to other image technology subgroups.

Table 3. Description of technologies.

Technology	Description	Authors	Times Appeared (n = 102)	% In Articles[1]
Image technologies	Digital video recordings were used to monitor the behaviour of broilers. Sometimes they were utilised in the development of algorithms. They can also be used to validate other technologies by capturing information about the animals′ behaviour.	[27,29–45]	18	31.6
	Broiler flock distribution analysis: cameras positioned in different areas of houses capture flock activity, movement and distribution. These data were submitted to statistical analysis to calculate mean, variance, skewness, kurtosis, etc. This analysis approach was widely used to predict leg problems, such as footpad dermatitis and hock burns, to infer about the percentage of dead birds and to evaluate gait scores. Additionally, it was used to analyse feeding, drinking and resting behaviour of animals and to detect equipment malfunctioning in broilers house.	[23,24,28,46–55]	13	22.8
	Thermal image analysis: infra-red cameras to analyse the heat emitted by an animal or a flock of birds. The images can provide important information about heat stress and diseases. Additionally, it has been used to provide images of dark places.	[56–64]	9	15.8
	Other images analyses: Evaluation of digital images, generally for space and posture. Sometimes such analyses are used to develop an algorithm to automate analysis.	[65–69]	5	8.8
	Image display tool: A visualization tool through which the farmer can be made aware of animal and environmental conditions in a broiler house.	[28]	1	1.8
Force-measurement platform	This measures kinetic forces involved in walking. The platform surface has a thin mat constituted by piezoelectric sensors that are sensitive to the walking pressure applied by the birds. The force-measurement platform consists of hardware, which is the force mat itself and a software which record, process and analyse the data provided by the force mat.	[40–42]	3	5.3
Kinematic	This is the analysis of broiler body motion. Kinematics uses geometry to identify position, velocity and acceleration of any part of a given system. The distance and the duration of strides and stance are examples of evaluations done by kinematics.	[42,56]	2	3.5
Sound	Microphones can detect and analyse sound of animals in different ages and conditions.	[27,28,43,44,70]	5	8.8
Radio frequency identification (RFID)	Tags are fixed in the animals and the signals are transmitted to receivers placed at fixed positions, indicating the position of a given animal. The positioning is calculated based on the time of arrival of the signal.	[45,71–73]	4	7.0

Table 3. *Cont.*

Technology	Description	Authors	Times Appeared (n = 102)	% In Articles[1]
Automatic weighing scale	A platform that automatically measures the weight of broilers or their feed intake.	[44,53]	2	3.5
Environmental sensor	These can measure environmental conditions in a broiler house. Temperature, humidity, CO_2 and NH_3 concentrations are common examples of the environmental variables measured. In addition to that, environmental sensors can measure concentration of gases and used in the control of atmospheric pressure in the slaughtering process of animals.	[28,30,34,35,64, 74–76]	8	14.0
Animal sensor	ECG and EEG represent sensors equipped to the animal to measure heart rate via electrocardiogram (ECG) and brain activity via electroencephalogram (EEG).	[34,77,78]	3	5.3
	Animal microchip: sensors implanted in the animal to measure a given physiological-based variable.	[79]	1	1.8
	Animal probe: range of equipment that can measure some variable by contacting it on the animal`s surface.	[79,80]	2	3.5
	Telemetry-logging system: this is positioned on the animal and can interface with many sensors and store their data. The logged data can be downloaded and stored in a computer.	[34,77,79]	3	5.3
Algorithm	In general algorithms contain a sequence of logical instructions or operations aimed at achieving an objective. Algorithms can analyse data from others IT used as input data and transform them into information.	[23,24,28,30,36 –39,44,46–55,68,69,75,81]	23	40.4

[1] Percentage of IT appearances in the total of publications.

3.1.1. Image Technologies

Digital video recording was observed in 18 publications. This IT subcategory was observed in 31.6% of total publications, being the most prevalent subgroup of image technologies. Such technologies can be used for a wide range of objectives related to animal welfare because the analysis of behaviour can provide valuable insights on their housing conditions. Image technologies have been used to evaluate broiler behaviour under different light intensities [29], under different thermal conditions [27,30], under distinct stocking densities [31,32], under different gait scores [33], and during their slaughter [34,35]. Additionally, digital video recording was used to help the development of methods and algorithms to detect lameness in broiler chickens [36–42] and to analyse behaviour of isolated chicks [43]. It was also used to assess short-term feeding behaviours [44] and to analyse possible changes in behaviour of animals using a tag to monitor their movement [45].

The subcategory "flock distribution" was observed in 13 publications, 22.8% of total publications. The analysis of movement, distribution, and activity of a flock can provide important information on the welfare status of the animals. Technology to capture broiler distribution was used to predict thermal comfort of young chicks [46]; to evaluate the relationship between individual behaviour and optical flow [47]; and to assess mortality, gait abnormalities, hock burn, and foot pad dermatitis on flock basis [23,48–53]. Moreover, it was utilized to analyse poultry eating and drinking behaviour [24], to detect equipment malfunctioning [54], and to monitor animals in broiler houses [55] and as part of a set of technologies used to provide an easy tool for farmers to assess production, environmental, and behaviour data in a broiler house [28].

Thermal image analysis was observed in nine papers, corresponding to 15.8% of total publications. In these papers, this technology was utilized either as part of a kinematic system [56] to provide information on broiler´s metabolic heat loss [57], to estimate broiler´s thermal comfort [58], or to develop a thermal comfort index [59]. Furthermore, thermal images were used to study the relationship of skin surface temperature with body core temperature [60], to analyse temperature variation when broilers are under stress [61], and to monitor animal movement and behaviour under dark or low light intensities [62–64].

The subcategory "other image analyses" was identified in five publications, corresponding to 8.8% of total. This IT was used to study posture deviations [65], to evaluate appropriate stocking densities in broiler houses [66], and to detect locomotion problems in broiler chickens [67]. In addition to that, image analyses were verified to be part of an automated system to evaluate foot pad dermatitis in slaughterhouses [68] and to help the development of an algorithm to detect sick animals based on their posture [69].

The image display tool was verified in one publication (1.8% of total publications). This IT was used by Van Hertem et al. [28] as a practical technology for farmers to assess broilers' conditions. The study involved other ITs to capture and to analyse variables in the broiler house. The variables measured by several sensors were presented by this innovative display in an informative and actionable way to farmers. Part of the study also evaluated how farmers dealt with this technology and how it could be further improved.

3.1.2. Force-Measurement Platform and Kinematic Technologies

A force-measurement platform was used for kinetic studies. This IT was identified in three papers (5.3% of total publications). The force-measurement platform was part of the IT that aimed to study the walking ability of broiler chickens [40–42]. In a similar way, kinematic technologies, which were present in two publications (3.5% of total publications), were also utilized to study gait abnormalities by producing and analysing 3D images [56] and by utilizing a system that involved the use of a force-measurement platform [42].

3.1.3. Sound Technology

Sound technology was studied in five publications, corresponding to 8.8% of the total. In these studies, the sound of birds was recorded using microphones. Broiler feeding behaviour [44] and the vocalization patterns of young broiler chickens [43] were studied. Additionally, sound technology was used to evaluate chick thermal comfort [27] and to predict the broiler growth [70] and was integrated with other ITs to provide information about broiler house and animal conditions to farmers [28].

3.1.4. Automatic Weighing Scales

Automatic weighing scales were observed in 3.5% of the IT-based studies, being used in combination with other ITs. The technology was utilized to measure the feed intake of birds in a study about broiler feeding behaviour [44] and to automatically measure the body mass of broilers in a system developed to predict gait scores [53].

3.1.5. Radio Frequency Identification

Technologies that used radio frequency data transmission were classified as RFID and were present in four papers (7.0%). These ITs were used to evaluate broilers' behaviour in free-range systems: monitoring their location [71], evaluating their ranging behaviour [72,73], and assessing if a RFID tag placed on their back could interfere with their behaviour [45].

3.1.6. Environmental Sensors

This group includes sensors for measuring concentration and pressure of gases, temperature, humidity, and airflow, being observed in 8 publications (14.0% of total publications). These "environmental sensors" were used in broiler houses to measure CO_2 [74] and NH_3 [76] concentrations as part of ventilation control systems [75] to provide information about environmental conditions to farmers [28] and as a component in the gas concentration control when using foam to humanely slaughter broilers in extreme situations [34]. Moreover, environmental sensors were also used in the control of ventilated chamber [30], as part of slaughter chambers used for small-flock depopulation [35], and in a study about the effects of low atmospheric stunning on broilers [64].

3.1.7. Animal Sensors

As done for "image technologies", subcategories were also created for "animal sensors". The animal sensor group represented ITs that were placed in the animal´s body and were able to provide information about the animal. Although this category had less appearances in publications than the image technologies (9 times vs. 46 times), four different kinds of sensors were identified, namely "ECG and EEG" (see Table 3), "animal microchip", "telemetry-logging system", and "animal probe".

The "ECG and EEG" category involved studies that used electroencephalograms and electrocardiograms. It was present in three publications (5.3% of total publications). These ITs were used to measure heart rate and brain activity of broilers during their slaughtering to verify the effectiveness of humane slaughtering methods [34,77,78]. The subcategory "animal microchip" was identified in one paper (1.8% of total), being used to measure the intramuscular temperature of broiler chickens [79]. The telemetry-logging system was observed in three publications (5.3% of total publications). This IT was used together with ECG and EEG by logging and storing body core temperature of broilers during studies by Coenen et al. [77], McKeegan et al. [34], and Iyasere et al. [79]. "Animal probe" was verified in two documents (3.5% of total publications). Hoffmann et al. [80] used a probe that measured the moisture content of tissue in order to measure footpad lesions in broiler chickens, while Iyasere et al. [79] used an infrared thermometer to study the possible relationship between the broiler temperature measured by this probe and the core body temperature.

3.1.8. Algorithms

Algorithms were identified in 23 papers, representing 40.4% of total publications. They were primarily used to process image data involved with the detection and assessment of broiler lameness and/or leg disorders [23,36–39,47–53,55], to characterize chick behaviour under different temperatures [46] and other environmental conditions [30], to detect equipment malfunctioning [54], and for early detection of sick broilers [69]. In addition, they were used to process sound data and to provide information about feeding and/or drinking behaviours [24,44], to automate the detection of footpad dermatitis along the slaughter line [68], to define the best positions to install CO_2 sensors in a broiler house [75], to control broiler chickens growth curve [81], and to develop an innovative image display tool that allowed farmers to assess broilers´ living conditions [28].

3.2. How is Welfare Addressed by the Its Or IT-Based Studies?

The classification of IT group and IT-based studies into different approaches was necessary to evaluate and to analyse the main FAW issues being addressed. The frequency of appearances of IT-based studies and ITs for the different approaches are listed in Table 4.

3.2.1. What Principle(s) of WQ for Broiler´s are the ITs and IT-Based Studies Related to?

Information technologies and IT-based studies had to address a welfare issue to be evaluated in the present SR. An IT-based study may contain more than one IT and may measure more than one WQ® principle. In a similar way, ITs can also be classified into more than one welfare principle, since it can measure/control one or more variables.

Among the principles of welfare, the most prominent was good health, representing 45.6% of total publications and 46.1% of total ITs. On the other hand, good feeding and humane slaughter were the least principles observed for publications, being present in 8.8% of total publications. Good housing and appropriate behaviour were the subject of 36.8% and of 19.3% of total documents and 26.5% and 16.7% of total ITs, respectively.

3.2.2. What Phase of the Animal´s Life Do the ITs and the IT-Based Studies Correspond to?

The WQ® protocol for broiler chickens has established measurements to assess the welfare of animals in the farm and in the slaughterhouse. IT-based studies and ITs had similar results when analysed under this question. Both were observed to be more focused on the farm phase (93.0% of IT-based study and 93.1% of ITs) compared to slaughterhouse (7.0% and 6.9%, respectively).

3.2.3. On What Production System are the ITs and IT-Based Studies Focussed?

This approach intends to figure out if the IT or IT-based studies are about conventional, free-range, or both systems. This information is useful to analyse what production system has been given more attention in the literature and to identify where the ITs described have potential. Higher frequencies of IT-based studies and ITs were found to be applied to conventional production systems when compared to free-range or to both systems. In this context, 82.5% of total studies and 83.3% of total ITs concerned the conventional system; 8.8% and 6.9% of IT-based studies and ITs were about the free-range system, respectively; and 8.8% and 9.8% of total documents and ITs were about both systems, in this order.

3.2.4. Are the ITs and the IT-Based Studies Related to Environmental or Animal-Based Variables?

It is possible for an IT and for an IT-based study to evaluate an environmental-based variable, an animal-based variable, or both together. The WQ® project suggested that animal-based variables are more reliable to identify FAW states. Evaluating the frequencies of IT-based studies and of ITs based on the kind of variable they measured, both were higher for animal/flock-based variables (87.7% and 86.3%, respectively) when compared to "environmental-based" (5.3% and 8.8%) or "both" (7.0% and 4.9%).

Table 4. Categorization of IT-based studies and of ITs in the different approaches.

Item	IT-Based Studies (n = 57)		Technology (n = 102)	
	Number of Appearances	% of Appearances in Total Publications	Number of Appearances	% of Appearances in Total Technologies
Principle of welfare				
Good feeding	5	8.8	9	8.8
Good housing	21	36.8	27	26.5
Good health	26	45.6	47	46.1
Appropriate behaviour	11	19.3	17	16.7
Humane slaughter	5	8.8	11	10.8
Phase of life				
Farm	53	93.0	95	93.1
Slaughterhouse	4	7.0	7	6.9
Production system				
Conventional	47	82.5	85	83.3
Free Range	5	8.8	7	6.9
Both	5	8.8	10	9.8
Measurement variable based				
Animal/flock based	50	87.7	88	86.3
Environmental based	3	5.3	9	8.8
Both	4	7.0	5	4.9
Main focus of the study/IT				
Technical aspects of production	56	98.2	100	98.0
Aspects about actors of the supply chain	0	0.0	0	0.0
Both	1	1.8	2	2.0
Practical or experimental application				
Practical	40	70.2	61	59.8
Experimental	17	29.8	41	40.2

3.2.5. What Aspect of the Production Chain are the ITs and IT-Based Studies Addressing?

The focus of a given IT or IT-based study can be on technical aspects of production, aspects related to actors in the supply chain, or both of these issues. IT-based studies and ITs were classified into "technical aspects of production" when they permit the control and the analysis of variables involved on broiler behaviour and environmental conditions. On the other hand, when the IT or IT-based study aims to analyse how a technology is accepted or used by consumers, producers, and other stakeholders, it was classified as "aspects about actors of the supply chain". No IT-based study or IT was about actors of the supply chain only.

3.2.6. Are the ITs and IT-Based Studies Related to Practical or Experimental Situations?

Some ITs are developed or used to solve practical issues related to FAW and can be used in broiler production management routines. These kinds of ITs were classified as "practical". On the other hand, some ITs can be used experimentally only. These ITs are used to develop new knowledge about some welfare issue or certain practices or managements and were classified as "experimental". Additionally, an IT was classified as "experimental" if it was used to validate another IT. Higher frequencies were observed for IT-based studies and ITs that were practical (70.2% and 59.8%) when compared to those that were experimental (29.8% and 40.2%, respectively).

3.3. How are Each IT Group Classified within the Different Approaches?

In this part of the SR, it was aimed to classify how each IT group linked with the different approaches. This made it possible to evaluate the characteristics and opportunities for each IT group. The frequency of each IT group by animal welfare principle, phase of life, production system, measured variable, aspect of the production chain, and practical or experimental utilization are visualized in Table 5.

3.3.1. What Principle(s) Of Broiler´s Welfare Is Each IT Group Related to?

Image technologies covered a higher number of principles of welfare when compared to other groups, addressing all five principles analysed. Among image technologies, digital video recording addressed all principles of welfare evaluated, and broiler´s distribution and image display tool were verified to be on every principle except for humane slaughter. Thermal image analysis addressed all principles except for good feeding, while image analyses was used for good housing and good health.

When analysing the frequencies of appearance of each subcategory based on the principles they addressed, higher frequencies of digital video recording, broiler´s distribution, and image analysis technologies on good health were observed (44.4%, 61.5%, and 80.0%, respectively). Hence, the digital video recording subgroup presented 27.8% of its ITs related to good housing, 22.2% related to appropriate behaviour, and 11.1% related to good feeding and to humane slaughter. The broiler´s distribution subgroup presented 7.7% of ITs related to good feeding and 15.4% related to good housing and appropriate behaviour. For the image analysis subgroup, 20% of the ITs involved good housing. Regarding thermal image analysis, good housing was the most frequent principle addressed by the ITs classified in this subgroup (44.4%), followed by appropriate behaviour (22.2%) and humane slaughter (11.1%). The image display tool group comprises a single IT that addressed good feeding, good housing, good health, and appropriate behaviour.

Table 5. Description of each IT group in the approaches utilized.

Item		Principle of Welfare		Phase of Life		Production System		Measurement Variable		Aspects of Production Chain		Practical or Experimental	
		Principle	%[1]	Phase	%[1]	System	%[1]	Kind of Variable	%[1]	Aspect	%[1]	Focus of IT	%[1]
Image technologies (n = 46)	Digital video recording (n = 18)	Good feeding Good housing Good health A. behaviour[2] H. slaughter[3]	11.1 27.8 44.4 22.2 11.1	Farm	100	Conventional Free-range	88.9 11.1	Animal/flock Both	88.9 11.1	Technical aspect	100	Practical Experimental	27.8 72.2
	Broiler´s distribution (n = 13)	Good feeding Good housing Good health A. behaviour	7.7 15.4 61.5 15.4	Farm	100	Conventional	100	Animal/flock	100	Technical aspect	100	Practical	100
	Thermal image (n = 9)	Good housing Good health A. behaviour H. slaughter	44.4 22.2 22.2 11.1	Farm S. house[4]	88.9 11.1	Conventional Both	77.8 22.2	Animal/flock Both	88.9 11.1	Technical aspect	100	Practical Experimental	44.4 55.6
	Image analyses (n = 5)	Good housing Good health	20.0 80.0	Farm S. house	80.0 20.0	Conventional Both	80.0 20.0	Animal/flock	100	Technical aspect	100	Practical Experimental	60.0 40.0
	Image display tool (n = 1)	Good feeding Good housing Good health A. behaviour	100 100 100 100	Farm	100	Conventional	100	Both	100	Both	100	Practical	100
Force-measurement platform (n = 3)		Good health	100	Farm	100	Conventional	100	Animal/flock	100	Technical aspect	100	Experimental	100
Kinematic (n = 2)		Good health	100	Farm	100	Conventional	100	Animal/flock	100	Technical aspect	100	Experimental	100
Sound (n = 5)		Good feeding Good housing Good health A. behaviour	20.0 20.0 20.0 40.0	Farm	100	Conventional	100	Animal/flock	100	Technical aspect	100	Practical	100

Table 5. *Cont.*

Item		Principle of Welfare		Phase of Life		Production System		Measurement Variable		Aspects of Production Chain		Practical or Experimental	
		Principle	%[1]	Phase	%[1]	System	%[1]	Kind of Variable	%[1]	Aspect	%[1]	Focus of IT	%[1]
Radio frequency identification (RFID) (n = 4)		A. behaviour	100	Farm	100	Free-range	100	Animal/flock	100	Technical aspect	100	Experimental	100
Automatic weighing scale (n = 2)		Good feeding Good health	50.0 50.0	Farm	100	Conventional	100	Animal/flock	100	Technical aspect	100	Experimental	100
Environmental sensor (n = 8)		Good housing H. slaughter	62.5 37.5	Farm S. house	87.5 12.5	Conventional Free-range Both	75.0 12.5 12.5	Environmental	100	Technical aspect	100	Practical Experimental	87.5 12.5
Animal sensor (n = 9)	ECG and EEG (n = 3)	H. slaughter	100	Farm S. house	33.3 66.7	Conventional Both	66.7 33.3	Animal/flock	100	Technical aspect	100	Experimental	100
	Animal microchip (n = 1)	Good housing	100	Farm	100	Both	100	Animal/flock	100	Technical aspect	100	Experimental	100
	Animal probe (n = 2)	Good health Good housing	50.0 50.0	Farm	100	Conventional Both	50.0 50.0	Animal/flock	100	Technical aspect	100	Experimental	100
	Telemetry-logging system (n = 3)	Good housing H. slaughter	33.3 66.7	Farm S. house	66.7 33.3	Conventional Both	33.3 66.7	Animal/flock	100	Technical aspect	100	Experimental	100
Algorithm (n = 23)		Good feeding Good housing Good health A. behaviour	13.0 21.7 69.6 8.7	Farm S. house	95.7 4.3	Conventional Both	95.7 4.3	Animal/flock Environmental Both	91.4 4.3 4.3	Technical aspect Both	95.7 4.3	Practical	100

[1] Percentage of each category on total publication of the IT group.; [2] appropriate behaviour.; [3] humane slaughter.; [4] slaughterhouse.

All force-measurement platform and kinematic technologies addressed good health. In a similar way, all ITs classified in the subgroup ECG and EEG of animal sensor were used in humane slaughter. The animal sensor microchip was completely used on good housing, and RFID was completely used for appropriate behaviour. On the other hand, sound and algorithm technologies were verified to cover all principles of welfare except for humane slaughter. The sound and the algorithm IT frequencies were classified as follows: 20.0% and 13.0% good feeding, 20.0% and 21.7% good housing, 20.0% and 69.6% good health, and 40.0% and 8.7% appropriate behaviour, respectively.

The environmental sensor and the animal sensor telemetry-logging system focused on good housing (62.5% and 33.3%, respectively) and humane slaughter (37.5% and 66.7%, respectively). Automatic weighing scale was assigned to good feeding (50.0%) and good health (50%). The animal sensor subgroup animal probe had IT assigned to good health (50%) and to good housing (50%).

3.3.2. What Phase of the Animal´s Life Each IT Group Correspond to?

Regarding the phase of an animals´ life, all groups had ITs involved in the farm phase. All ITs present in digital video recording, broiler´s distribution, image display tool, force-measurement-platform, kinematic, sound, RFID, automatic weighing-scale, animal microchip, and animal probe were used 100% on farm. Meanwhile, ITs about thermal image analysis, image analyses, environmental sensor, ECG and EEG, telemetry-logging system, and algorithm were 88.9%; 80.0%, 87.5%, 33.3%, 66.7%, and 95.7% classified on the farm and 11.1%, 20.0%, 12.5%, 66.7%, 33.3%, and 4.3% in the slaughterhouse, respectively.

3.3.3. In Which Production System Can Each IT Group Be Utilized?

When the production system where the technologies were utilized were analysed, it was verified that all groups addressed conventional systems except for RFID, of which the ITs were about free-range systems. In contrast, the groups/subgroups that presented their ITs on conventional systems are broiler´s distribution and image display tool, force measurement-platform group, kinematic group, sound group, and automatic weighing-scale group. Lastly, ITs classified in the subgroup animal microchip were used 100% in both systems. The subgroup digital video recording presented 88.9% of technologies utilized in conventional and 11.1% in free-range systems, while the subgroups thermal image analysis and image analyses were classified to have ITs being used in conventional (77.8% and 80.0%, respectively) and both systems (22.2% and 20.0%, respectively). The animal probe subgroup presented 50% of ITs involved with conventional and 50% with both systems. The animal sensor subgroups ECG and EEG and telemetry-logging system were utilised 66.7% and 33.3% in conventional systems and 33.3% and 66.7% in both systems, respectively. Moreover, for 95.7% of appearances, the algorithm group was in conventional systems and, for 4.3%, it was in both systems. The environmental sensor was the only group that presented technologies in 3 possible classifications: conventional (75.0%), free-range (12.5%), and both of them (12.5%).

3.3.4. Does the IT Group Evaluate Environmental or Animal-Based Variables?

Concerning the kind of variable the measurement was based on, all groups had ITs involved with animal/flock-based variables. Among the image technologies, all broiler´s distribution and image analyses ITs were focused on animal/flock variables only, while image display tool was only observed in "both". Digital video recording and thermal image presented technologies classified as animal/flock (88.9%) and both (11.1%).

Analysing the other groups, all technologies were 100% animal/flock-based except for environmental sensor, for which measurements were totally environmental-based, and for algorithm, which had technologies classified in the three possible answers (91.4% animal/flock, 4.3% environmental, and 4.3% both).

3.3.5. What Aspect of the Production Chain Did the IT Group Attend to?

All groups presented 100% of technologies on technical aspects of production systems except for the subgroup of image technology “image display tool”, which was 100% “both” (technical and actors of supply chain), and for the algorithm group, which presented 95.7% of technologies classified as technical aspects of production and 4.3% classified as both.

3.3.6 Did the IT Group Intend to Be Practical or Experimental?

The ITs were classified as practical or experimental. Among image technologies, 72.2% of digital video recordings was used for validation of methods or techniques and 27.8% was for practical purposes. Also, 55.6% of thermal image analysis was used for experimental purposes and 44.4% was for practical situations. Along with that, image analysis technologies were 60% practical and 40% experimental, while broiler´s distribution and image display tool were 100% practical.

Environmental sensors technologies were classified as 87.5% practical and 12.5% experimental. The groups force-measurement platform, kinematic, RFID, automatic weighing-scale, and animal sensors all have their technologies used for experimental purposes. In contrast, the groups sound and algorithm were 100% used in practical situations.

4. Discussion

In this SR, information was organized and grouped respecting the characteristics of each technology and the focus of each reviewed publication. Nevertheless, it should be noted that the present IT categories and characteristics are derived from this specific set of studies and that the results observed would be probably different by using other databases or other search guidelines.

The categorization of ITs into 9 groups was necessary to systematically interpret the data. It was not the objective of the study to specifically describe each one of the ITs identified but to provide insights on how they addressed welfare issues. The classification of the ITs in their respective groups was made to analyse their potential and limitations in addressing the different approaches.

Image technologies were the most prevalent group identified in the current SR. It can be explained by the fact that the ITs classified in the current group are relatively straight-forward, cheap, and efficient to be used in a broiler house [20]. Moreover, the ITs classified in this group could be used alone or in combination with others technologies [28,37,44,82]. By using cameras, it is possible to monitor and evaluate hundreds of individuals at the same time, which can be extremely useful to farmers. However, the use of such technologies in broiler houses can also be challenging as a lot of variables can interfere in the quality of images. For instance, broiler houses are usually dusty and not uniformly lighted.

Monitoring animals by image analysis is described in the oldest publication evaluated (1990; see Appendix A) as a simple and noninvasive method to evaluate stocking densities and to infer broiler welfare [32]. New studies are observed only one decade after that, when Weeks et al. [33] utilized cameras to evaluate the behaviour of lame broilers. Since then, camera devices have improved, increasing their possible utilizations to assess broiler´s welfare. By way of an example, infrared cameras were utilized in 2011 to infer on thermal comfort of animals [31] and 3D cameras were used by Aydin et al. [37], in 2017, to detect the number of lying events and the latency to lie down that is associated with lameness. Indeed the development of image technologies has been intensely pursued as it represents a real opportunity for improving broiler´s welfare.

The ITs from the group “algorithm” were the second most frequently seen. Algorithms can automate processes, reducing time and labour costs by automating processes. Such technologies present wide opportunities of utilization. It is possible that the group was underestimated, since some authors may have implemented algorithms in their studies but did not make explicit reference to their use.

On the other hand, the IT groups that were observed least were automatic weight scaling and kinematics, probably because they presented technologies with narrow possibilities of use. For instance, kinematics was used only in experimental applications and it is not valuable to achieve practical goals, while automatic weight scaling is available to farmers nowadays. However, its appearances in the present SR is scarce probably because its utilization is not always related to animal welfare.

Sound technologies were found to cover a large range of principles of animal welfare. Nevertheless, their appearances in publications were scarce in comparison to image technologies. As observed with cameras, microphones have desirable characteristics enabling their feasibility in commercial broiler house applications: they are relatively cheap, noninvasive, and nonintrusive [83]. Moreover, a single sound device can monitor several broilers at the same time [70].

Environmental sensors were mostly used in practical situations and are widely used by farmers, while animal sensors do not represent a real opportunity for farmer's utilization but can be explored for scientific purposes. In a similar way, the groups force-measurement platform and RFID also presented very specific utilizations. These technologies were focussed on a single animal welfare principle and measured only animal/flock-based variables for experimental purposes.

The IT-based studies and the ITs addressed all principles of broiler welfare. It must be noticed that the framework used to categorize the technologies were based on the WQ® principles, which were developed to provide an overall assessment of broiler chickens in the farm. Thus, it is likely that the publications analysed were mostly about the farm period of the animals and that the results observed in the present SR have this bias.

The highest number of publications and ITs addressed the good health principle. This can be explained by a possible interest of scientists in addressing leg abnormalities. Locomotor problems in broilers are often correlated with litter quality [84–90], since the ammonia excreted by the animals can provoke lesions in their feet. Additionally, they can be consequence of the high growth rate of animals [91–94] and of the increasing genetic selection for heavier *major pectoralis* muscle [56,65,95]. Clark et al. [96] proposed that leg problems are an animal welfare issue as a result of animals being pushed beyond their physiological limits.

A higher number of IT-based studies and ITs aimed at measuring and managing the welfare of broilers on the farm compared to the slaughterhouse was observed. This is in accordance with the WQ® protocol, where most of the measurements are made in the farm since animals spend the most of the time of their lives in this stage of the production system [97]. However, transportation and slaughtering of animals can cause acute stress on broilers, also impairing their welfare [98–102]. Thus, more IT studies should focus on these phases of broiler's lives. As way of an example, technologies aimed at automating interpretation of carcass condemnation in abattoirs could provide interesting insights on the welfare of broilers.

The highest number of publications and ITs addressed conventional production, as frequently, these systems are associated with higher risk of low level of welfare [97,103–105]. This result also meets the general opinion of citizens who are not usually concerned about the welfare of broilers reared in outdoor systems [10]. In a study interviewing citizens about their opinion and attitudes regarding farm animal production systems, Yunes et al. [106] observed that the majority of participants expressed a preference for "more natural systems", also expressing concern about the movement limitations of animals created in indoor systems. However, it is important to be noticed that free-range animals can also have poor conditions of living and a good welfare level should be ensured.

The highest number of IT-based studies and ITs involved with animal/flock-based variables are in accordance to what is recommended by the WQ® protocols. The assessment of animal-based variables enables the comparison of welfare among flocks reared in different farms and systems of production [9]. To illustrate this point, by applying the WQ® protocol to broilers, Tuyttens et al. [12] could evaluate the welfare of broilers reared in Belgium and in Brazil, even though the characteristics of production varies significantly between countries. For Miele et al. [10], the measurement of animal/flock-based variables instead of environmental ones allows the interpretation of data about how animals are interacting with each other and with their environment. This permits animal welfare assessment to be based on what animals are expressing instead of their conditions.

Similarly, most IT-based studies were focused on the technical aspects of production, which evidences a lack of ITs addressing transparency in the supply chain. Some of the conflicts existing about FAW are likely due to the increasing separation of the public from the production processes. In an SR regarding FAW in intensive systems, Clark et al. [96] observed that people who are not familiar with animal production processes are more likely to be concerned with modern production when compared to those who have previously worked or visited a farm or to those who are living (or have lived) in rural areas. It can be presumed, by this data, that many misconceptions exist about farm animal production, and maybe narrowing the distance between stakeholders can facilitate FAW improvements. Vizzier Thaxton et al. [107] also state that there is a lack of knowledge among citizens about production practices and that this creates asymmetries among stakeholders. Providing practical ways to inform citizens on production reality can potentially help the productive chain to be more efficient and sustainable. In this aspect, the implementation of transparent and integrated information systems can allow organizations to improve their public image and to be more competitive [108].

Although more IT-based studies were found to have a practical focus, a relatively high number of ITs and IT-based publications had an experimental focus. Thus, ITs not only help farmers with their routine activities but also help to advance science by providing more information on the welfare of broilers. Not all ITs with a practical focus are being used by farmers or are available to them. Technologies are generally initially developed under controlled conditions, which can be different from the real broiler houses. Most of the ITs assessed were first implemented experimentally as a first step to develop a practical tool for farmers (Appendix A). For example, the development of an algorithm to control the growth of broilers was developed by Demmers et al. [81]; however, no studies in the present SR evaluate such an IT in a real broiler house environment.

Similarly, relatively cheap devices such as microphones can be of great value to monitor hundreds of animals simultaneously and to infer their welfare. Aydin and Berckmans [44] developed an algorithm to measure broiler feed intake by analysing pecking sounds in experimental situations only. Several technologies have been assessed in experimental settings, but their potential in real situations are not challenged.

Another fact to take into consideration is the willingness of farmers to adopt PLF ITs. Even if the IT works well in a real broiler house, it must still be clear for the farmers on how much value it can provide to them. Technologies can serve a variety of purposes, as could be seen in the present SR, but how they are aligned with objectives and interests of farmers is still unclear. In this regard, it is common sense that the development of new technologies is far beyond the reality of farmers' everyday experiences, and studies evaluating how this gap can be narrowed are necessary.

In this SR, it was seen that the ITs can address all broiler welfare principles. New technologies could potentially disrupt the current management practices of farms and management of broiler welfare. Additionally, the poultry meat production chain offers ideal conditions for the application of new technologies, since its management is very similar around the world: the governance structure is vertical, and its cycle of production is relatively short [109].

5. Conclusions

The present SR utilized the WQ® assessment of broiler chickens as a framework to identify and to analyse ITs involved in studies on the welfare of broiler chickens. By characterizing the ITs involved in broiler welfare, it was possible to compare their potential and limitations and to appraise their potential. The technologies evaluated can assess the welfare of animals distinctively, and 9 different groups of ITs with different possibilities of utilization were found in this SR. Most of the ITs addressed the good health principle, mainly focusing on locomotor problems, and indicate the significant research effort on this aspect of a broiler's wellbeing. Overall, among all possible classifications evaluated in the present paper, IT-based studies and ITs were mainly focussing on farm phase of animal´s life, conventional production system, technical aspects of broiler production, animal/flock-based variables, and practical situations.

The development of ITs aiming at broiler welfare is relatively new, and there is a lot of space for improvements. Special focus should be given technologies that can be tested and used in real conditions. A lack of studies and ITs were observed in addressing new production systems, such as free-range systems and addressing aspects of the supply chain. Sound technologies have been less utilized than image technologies. For future IT-based studies, valuable focus could be put on quantifying the welfare of broilers in free-range systems, exploring how the ITs can be used by farmers, developing sound technologies for practical utilization, and assessing how ITs could reduce information asymmetries among the stakeholders of the productive chain.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: Protocol description, Table S2: Classification of IT-based studies and ITs.

Author Contributions Conceptualization, H.V.R., P.D.W., P.S.C., and T.N.; methodology, H.V.R., P.D.W., and P.S.C..; validation, H.V.R., P.D.W., P.S.C., and T.N; formal analysis, H.V.R.; investigation, H.V.R., P.D.W., and P.S.C.; writing—original draft preparation, H.V.R.; writing—review and editing, H.V.R., P.D.W., P.S.C, and T.N.; visualization, H.V.R., P.D.W., P.S.C., and T.N.; supervision, P.D.W and T.N; project administration H.V.R. All authors read and approved the final manuscript. All authors have read and agree to the published version of the manuscript.

Funding: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001. The authors acknowledge the partial funding from Conselho Nacional de Pesquisa (CNPq—Brasilia, DF, Brazil).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Authors, year of publication, country, ITs utilized, facilities, and main achievement of each paper evaluated.

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Lewis and Hurnik	[32]	1990	Canada	Broiler chickens monitored under different stocking densities, focal bird movements tracked by using cameras.	Experimental	The distance travelled by birds could be monitored. Increasing density reduced their movements.
Weeks et al.	[33]	2000	UK	Cameras used to evaluate the time budgets of sound and increasingly lame broilers performing 16 behaviours.	Experimental	Lameness altered broiler behaviour.
Febrer et al.	[31]	2006	UK	Video recordings of broilers under five stocking densities were assessed.	Broiler farm	Broilers may feel socially attracted and not aversive to contact with others.
Moura et al.	[27]	2008	Brazil	Microphones used to assess thermal comfort of chicks, image recording used to validate data.	Experimental and broiler farm	Thermal comfort of chicks can be estimated by frequency and amplitude of vocalizations.
Naas et al.	[40]	2008	Brazil	Force-measurement platform and video recording used to evaluate morphological asymmetries of broiler chickens and to assess their walking ability.	Experimental	No correlation observed between morphological asymmetries and walking ability using this method.
Alvino et al.	[29]	2009	USA	Digital video records used to assess behavioural synchrony and rest in different light programs.	Experimental	Behaviour synchrony and rest is influenced by light intensity: 8 h per day of uninterrupted darkness is the best for welfare.
Coenen et al.	[77]	2009	UK	Animal sensors (ECG and EEG) and telemetry-logging system used to evaluate implications of euthanizing broilers in a controlled atmosphere stunning.	Experimental	Less negative impacts on welfare with more gradual induction to unconsciousness were observed.
Dawkins et al.	[48]	2009	UK	Optical flow statistics of flock movements were assessed.	Broiler farm	Mean, variance, skewness, and kurtosis of broiler movements were significantly correlated with gait scores.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Naas et al.	[41]	2009	Brazil	Force-measurement platform and video recording used to evaluate toe asymmetry and walking ability of broiler chickens.	Experimental	Toe morphological asymmetry was not clear in predicting walking ability.
Hindle et al.	[78]	2010	Netherlands	ECG and EEG used to evaluate stunner settings.	Experimental	Broiler could be effectively stunned with 50 Hz between 45 and 240 mA: Constant current supply should be used.
Naas et al.	[42]	2010	Brazil	Force-measurement platform used to assess step vertical peak force of the feet while walking and cameras were used to assess gait scoring.	Experimental	Gait patterns were influenced by the asymmetric vertical peak force of feet.
Cordeiro et al.	[46]	2011	Brazil	Flock distribution and algorithm used to assess thermal comfort of broiler chickens.	Broiler farm	Grouping and dispersion can be used as an indication of thermal comfort/discomfort of broiler chicks in the first and second weeks of life.
Nascimento et al.	[59]	2011	Brazil	Thermal images of feathers and skin of broiler chickens were evaluated to create an index of thermal comfort.	Experimental and broiler farm	The index estimated conditions of comfort, alertness, and danger of heat-stressed broilers.
Ferreira et al.	[57]	2011	Brazil	Infrared thermography analysis used to assess sensible heat loss of young chicks.	Experimental	Infrared cameras successfully recorded the temperature variation of young broilers.
Kristensen and Cornou	[55]	2011	Denmark	Flock distribution and algorithm used to detect deviation in the activity of undisturbed broiler chickens.	Experimental	The method proposed efficiently monitored deviation in broiler activities.
Caplen et al.	[56]	2012	UK	Kinematic analysis and infrared cameras used to record temporospatial gait data from current broiler chicken strain and its ancestral line, jungle fowl.	Experimental	Gait patterns could be efficiently assessed by the method proposed. Several differences related to body movement exists between modern broiler strain and jungle fowl.
Dawkins et al.	[23]	2012	UK	Flock distribution used to analyse welfare indicators of commercial broiler chicken flocks.	Broiler farm	Characteristics of flock movement were significantly correlated with % mortality, hock burn, and poor gaits of individuals.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Giloh, Shinder and Yahav	[60]	2012	Israel	Thermal image analysis used to analyse body surface temperature and to correlate with body core temperature.	Experimental	Strong correlation between body core and surface temperatures was identified.
Roberts, Cain and Dawkins	[51]	2012	UK	Optical flow descriptor was combined with a multivariate forecasting to predict welfare problems.	Broiler farm	Total flock mortality, hock burn, and gait scores could be predicted by the model.
Schwean-Lardner, Fancher and Classen	[63]	2012	Canada, USA	Infrared cameras used to monitor broiler chickens behaviour under different lighting programs.	Experimental	Best welfare level based on expression behaviour obtained with 16 or 17 light hours per day.
Webster and Collett	[35]	2012	USA	Digital video recording and environmental sensors used to validate a modified-atmosphere killing system.	Experimental	The system was efficient in killing backyard flocks. Its maximum capacity was up to 600 broiler chickens weighing 1.4 kg.
Dawkins et al.	[47]	2013	UK	Flock behaviour used to clarify the relationship between optical flow measurements and individual behaviours.	Broiler farm	Optical flow measures correlate welfare outcomes better than single behavioural measures, no correlations observed between flock and individual movements.
Montis et al.	[24]	2013	Belgium	Flock distribution and activity used for automatic monitoring of feeding and drinking behaviour.	Broiler farm	Feeding and drinking behaviour could be automatically assessed. Good definitions of drinking and eating behaviour are necessary to improve system reliability.
Hoffmann et al.	[80]	2013	UK	Animal probe used to make dielectric measurements on broiler chicken feet and detect footpad lesions.	Experimental	Higher conductivity and pH observed with higher footpad lesion scores.
Kashiha et al.	[54]	2013	Belgium	Flock distribution and algorithm used to detect abnormal events in broiler houses and to alert farmers.	Broiler farm	Method reported malfunctioning of feeders, drinkers, heating, and ventilation to farmers with 95.24% of accuracy.
McKeegan et al.	[34]	2013	UK, Netherlands	Video recordings, environmental sensors, ECG and EEG, and telemetry-logging system used in a high-expansion gas-filled foam as a potentially humane killing method to emergency depopulations.	Experimental	Animals died from anoxia. The method provided a humane and effective method of euthanasia.
Vanderhasselt et al.	[68]	2013	Belgium	Photographs of broiler feet taken in a slaughter line to develop a system to automatically assess footpad dermatitis.	Experimental	The system was not reliable in identifying footpad lesions on broiler chickens.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Calvet et al.	[74]	2014	Spain	Tested multipoint simultaneous CO_2 sensors operating.	Experimental	Sensor precision ranged between 80 and 110 ppm CO_2. Sensor time response was approximately 5 minutes.
Nascimento et al.	[58]	2014	Brazil	Thermal image used to associate the broiler´s surface temperature with facilities temperatures and to estimate sensible heat transfer, tested in broiler houses with positive and negative pressures.	Broiler farm	Surface temperatures of birds are associated with the surface temperature of rearing facilities. Broiler house with negative pressure provided better thermal control.
Schwean-Lardner et al.	[62]	2014	Canada, USA	Infrared cameras used for assessment of behavioural expression of resting, walking, standing, feeding, and drinking in different light programs.	Experimental	Adequate hours of darkness observed in between 4 and 7 hours per day. More than 20 h of light per day led to sleep deprivation.
Aydin, Bahr and Berckmans	[39]	2015	Turkey, Belgium	Video recording and algorithm used to automatically estimate lying behaviour of broiler chickens with different gait scores.	Experimental	Significant correlation observed between number of lying events and gait score and between latency to lie and gait-score level, accuracy of 83% in detecting lying events was achieved.
Fontana et al.	[43]	2015	Italy, UK	Sound analysis used to evaluate broiler vocalisations identifying the relationship between animal sounds and their weight.	Broiler farm	Peak frequency of sounds observed as inversely proportional to weight and age of birds.
Youssef, Exadaktylos and Berckmans	[30]	2015	Belgium	Video recordings used to investigate activity level of broiler chickens as a function of environmental changes.	Experimental	Chickens looked for zones with low air velocities under cold stress and high air velocities under heat stress. Chickens started to move when conditions deviate from their comfort zone.
Aydin and Berckmans	[44]	2016	Turkey, Belgium	Microphones to detect pecking sounds, weighing scale to assess feed intake, and video recording to monitor the animals were used to develop a novel monitoring system to detect short-term feeding behaviours of broiler chickens.	Experimental	The method had precision to detect 90% of meal size, 95% of meal duration, 94% of the number of meals per day, and 89% of feeding rate.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Alves et al.	[65]	2016	Brazil	Photometry was used to analyse broiler posture and gait abnormalities in two modern broiler strains and indigenous chicken.	Experimental	Gait score, posture angle, and equilibrium condition could be associated.
Fontana et al.	[43]	2016	UK	Microphones were used to assess vocalization patterns in young broilers. Digital recording was used to assess their behaviour.	Broiler farm and experimental	Frequency of sounds was inversely correlated to weight and age. Calling sounds were made by isolated 1-d-old chicks and distress calls were made by isolated 5-d-old chicks.
Giersberg et al.	[66]	2016	Germany	Photographs from standing and squatting chickens were taken and analysed to estimate adequate stocking density.	Broiler farm	Broilers occupied between 48.5%–77.7% of 1 m^2, depending in their position, weight target, and stocking density. EU directive established adequate stocking densities for broiler chickens.
Lin et al.	[76]	2016	USA	A metal oxide semiconductor (MOS) sensor to monitor NH_3 in poultry houses was tested.	Experimental	The monitor was accurate in determine NH_3 concentrations. The time of response was approximately 1.5 minutes.
Mackie and McKeegan	[64]	2016	UK	Infrared cameras used to assess the welfare of broiler chickens in a low atmospheric pressure stunning.	Experimental	The method provokes mandibulation, head shaking, and open bill breathing, indicating a non-painful physiological response to hypoxia.
Mendes et al.	[67]	2016	Brazil, USA	Photogrammetry used to identify locomotion disorders in broilers.	Experimental	Photogrammetry could be applied to evaluate gait score level in 35-d- and 42-d-old broilers.
Aydin, A.	[36]	2017	Turkey	Video recording and algorithm used to early detect lameness of broilers by analyzing the effects of gait score on speed, step length, step frequency, and lateral body oscillations.	Experimental	The real-time monitoring tool could efficiently detect lameness in broilers from gait score 3.
Aydin, A.	[37]	2017	Turkey	3D cameras and algorithm were used to early detect lameness of broilers by detecting number of lying events and latency to lie down.	Experimental	Gait score level presented positive correlation with number of lying events and negative correlation with latency to lie down, accuracy of 93% for estimating number of lying events.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Curi et al.	[75]	2017	Brazil	Different positions of sensors to control ventilation system during the critical period in summer were assessed.	Broiler farm	Strategic positioning of ventilation system could improve the control of the microclimate in hot period.
Dawkins et al.	[49]	2017	UK	Camera used to monitor optical flow to identify footpad dermatitis and hock burn in chickens.	Broiler farm	Optical flow predicted footpad dermatitis and hock burn better than estimated water consumption, bodyweight, or cumulative mortality.
Iyasere et al.	[79]	2017	UK	Temperatures from intramuscularly implanted microchip, broiler surface, and core body temperature during heat stress were compared.	Experimental	Intramuscularly implanted microchip and infrared thermometers combined were efficient to estimate core body temperature in birds exposed to heat stress
Moe et al.	[61]	2017	Norway	Infrared thermography used to evaluate feet and head temperature under manual restraint.	Experimental	Under manual restrain, the footpad temperature and temperature in head regions raised.
Silvera et al.	[52]	2017	Sweden, Belgium, Netherlands	Flock distribution analysis and algorithm used to identify broiler gait scores.	Broiler farm	Age of broilers and their activity level induced by an observer presence were correlated with gait score.
Taylor et al.	[73]	2017	Australia, Switzerland	RFID used to track individual ranging behaviour in free-range systems.	Broiler farm	Ranging behaviour varied between individuals. Males spent more time ranging than females. The animal's weight was also involved with ranging behaviour.
Taylor et al.	[72]	2017	Australia, Switzerland	RFID used to track individuals and to assess flock ranging behaviour	Broiler farm	Ranging behaviour varied according to the period of day, the season, and the environmental conditions
Van Hertem et al.	[28]	2017	Netherlands, Belgium	Different kinds of ITs (broiler distribution analysis, environmental sensors, microphones, and algorithm) were combined to assess broiler farm condition, and their data were used to develop a visualization tool to farmers.	Broiler farm	The visualization tool was developed and used by farmers.
Demmers et al.	[81]	2018	UK, China	Algorithm was used to predict broiler`s growth.	Broiler farm	Mean relative error between desired and achieved broiler weight was 1.8%.

Table A1. *Cont.*

Authors	Reference	Year	Country	Its Utilization	Facilities	Main Achievements
Peña Fernández et al.	[50]	2018	Belgium, Italy, Netherlands	Cameras used to monitor broilers in real time and to assess their welfare using algorithm.	Broiler farm	The relation between occupation patterns and footpad lesion scores was positive while, for activity patterns and hock burn scores, was negative.
Naas et al.	[38]	2018	Brazil, Iran	Video cameras and algorithm used to evaluate locomotion deficiencies in broiler.	Experimental	Gait scores 1–3 estimated with 50%, 70%, and 100% of accuracy by using video camera and algorithm.
Stadig et al.	[45]	2018	Belgium, Netherlands	RFID used to detect behaviour alterations, leg health, and performance of broilers using a backpack containing a tag.	Experimental	Behaviour alteration disappeared quickly. No difference for leg health and performance was observed with the wearing of backpack.
Stadig et al.	[71]	2018	Belgium, Netherlands	RFID used to assess broiler location on a free-range farm.	Broiler farm	There was a mean of 68% successful registered positions. More anchors may be able to ameliorate results.
Van Hertem et al.	[53]	2018	Netherlands, Belgium	Flock behaviour used to predict gait score.	Broiler farm	Flock behaviour analysis had potential to identify gait problems.
Zhuang et al.	[69]	2018	China	Broilers images and algorithms used to automatically classify sick and healthy broilers.	Experimental	The algorithms could identify sick and healthy broilers with accuracy up to 99.46%.

References

1. OECD/FAO *OECD-FAO Agricultural Outlook 2019-2028*; OECD Publishing, Paris/Food and Agriculture Organization of the United Nations: Rome, 2019;
2. Buller, H.; Blokhuis, H.; Jensen, P.; Keeling, L. Towards farm animal welfare and sustainability. *Animals* **2018**, *8*, 1–13.
3. Keeling, L.; Tunón, H.; Antillón, G.O.; Berg, C.; Jones, M.; Stuardo, L.; Swanson, J.; Wallenbeck, A.; Winckler, C. Animal Welfare and the United Nations Sustainable Development Goals. *Front. Vet. Sci.* **2019**, *6*, 1–12.
4. Broom, D.M. Animal Welfare: An Aspect of Care, Sustainability, and Food Quality Required by the Public. *J. Vet. Med. Educ.* **2010**, *37*, 83–88.
5. Bessei, W. Impact of animal welfare on worldwide poultry production. *Worlds. Poult. Sci. J.* **2018**, *74*, 211–224.
6. Honorato, L.A.; Hötzel, M.J.; Gomes, C.C.M.; Silveira, I.D.B.; Machado Filho, L.C.P. Particularidades relevantes da interação humano-animal para o bem-estar e produtividade de vacas leiteiras. *Ciência Rural* **2012**, *42*, 332–339.
7. Blokhuis, H.J.; Veissier, I.; Miele, M.; Jones, B. The Welfare Quality ® project and beyond : Safeguarding farm animal well-being. *Acta Agric. Scand Sect. A* **2010**, *60*, 129–140.
8. Horgan, R. Eu animal welfare legislation: current position and future perspectives. *Rev. Electrónica Vet.* **2006**, *7*, 1–8.
9. Welfare Quality ® *Welfare Quality® assessment protocol for poultry (broilers, laying hens)*; Welfare Quality® Consortium. Lelystad, Netherlands, 2009;
10. Miele, M.; Veissier, I.; Evans, A.; Botreau, R. Animal welfare: establishing a dialogue between science and society. *Anim. Welf.* **2011**, *20*, 103–117.
11. Wilhelmsson, S.; Yngvesson, J.; Jönsson, L.; Gunnarsson, S.; Wallenbeck, A. Welfare Quality ® assessment of a fast-growing and a slower-growing broiler hybrid , reared until 10 weeks and fed a low-protein , high-protein or mussel- meal diet ☆. *Livest. Sci.* **2019**, *219*, 71–79.
12. Tuyttens, F.A.M.; Federici, J.F.; Vanderhasselt, R.F.; Goethals, K.; Duchateau, L.; Sans, E.C.O.; Molento, C.F.M. Assessment of welfare of Brazilian and Belgian broiler flocks using the Welfare Quality protocol. *Poult. Sci.* **2015**, *94*, 1758–1766.
13. Vanhonacker, F.; Tuyttens, F.A.M.; Verbeke, W. Belgian citizens ' and broiler producers ' perceptions of broiler chicken welfare in Belgium versus Brazil. *Poult. Sci.* **2016**, *95*, 1555–1563.
14. Gocsik, É.; Brooshooft, S.D.; de Jong, I.C.; Saatkamp, H.W. Cost-efficiency of animal welfare in broiler production systems: A pilot study using the Welfare Quality® assessment protocol. *Agric. Syst.* **2016**, *146*, 55–69.
15. Jukan, A.; Masip-Bruin, X.; Amla, N. Smart Computing and Sensing Technologies for Animal Welfare: A Systematic Review. *ACM Comput. Surv.* **2017**, *50*, 1–27.
16. Carpio, F.; Jukan, A.; Sanchez, A.I.M.; Amla, N.; Kemper, N.; Isabel, A.; Sanchez, M.; Amla, N.; Kemper, N. Beyond Production Indicators: A Novel Smart Farming Application and System for Animal Welfare. In Proceedings of the Fourth International Conference on Animal-Computer Interaction; Association for Computing Machinery (ACM): Milton Keynes, UK, 21-23 November 2017; pp. 1–11.
17. Norton, T.; Chen, C.; Larsen, M.L.V.; Berckmans, D. Review: Precision livestock farming: Building "digital representations" to bring the animals closer to the farmer. *Animal* **2019**, *13*, 3009–3017.

18. Banhazi, T.M.; Lehr, H.; Black, J.L.; Crabtree, H.; Schofield, P.; Tscharke, M.; Berckmans, D. Precision Livestock Farming: An international review of scientific and commercial aspects. *Int. J. Agric. Biol. Eng.* **2012**, *5*, 1–9.

19. De Jong, I.C.; Hindle, V.A.; Butterworth, A.; Engel, B.; Ferrari, P.; Gunnink, H.; Moya, T.P.; Tuyttens, F.A.M.; Reenen, C.G. Van Simplifying the Welfare Quality ® assessment protocol for broiler chicken welfare. *Animal* **2015**, *10*, 117–127.

20. Rushen, J.; Chapinal, N.; Passillé, A.M. Automated monitoring of behavioural-based animal welfare indicators. *Anim. Welf.* **2012**, *21*, 339–350.

21. Webster, A.J.F. The virtuous bicycle: a delivery vehicle for improved farm animal welfare. *Anim. Welf.* **2009**, *18*, 141–147.

22. Costa, L.; Pereira, D.; Bueno, L.; Pandorfi, H. Some aspects of chicken behavior and welfare. *Rev. Bras. Ciência Avícola* **2012**, *14*, 159–164.

23. Dawkins, M.S.; Cain, R.; Roberts, S.J. Optical flow, flock behaviour and chicken welfare. *Anim. Behav.* **2012**, *84*, 219–223.

24. Montis, A.; Pinna, A.; Barra, M.; Vranken, E. Analysis of poultry eating and drinking behavior by software eYeNamic. *J. Agric. Eng.* **2013**, *44*, 166–172.

25. Bright, A. Vocalisations and acoustic parameters of flock noise from feather pecking and non-feather pecking laying flocks. *Br. Poult. Sci.* **2008**, *49*, 241–249.

26. Du, X.; Carpentier, L.; Teng, G.; Liu, M.; Wang, C.; Norton, T. Assessment of laying hens' thermal comfort using sound technology. *Sensors* **2020**, *20*, 1–14.

27. Moura, D.J.; Nääs, I.A.; Alves, E.C.S.; Carvalho, T.M.; Vale, M.M.; Lima, K.A.O. Noise analysis to evaluate chick thermal comfort. *Sci. Agric.* **2008**, *65*, 438–443.

28. Van Hertem, T.; Rooijakkers, L.; Berckmans, D.; Peña Fernández, A.; Norton, T.; Berckmans, D.; Vranken, E. Appropriate data visualisation is key to Precision Livestock Farming acceptance. *Comput. Electron. Agric.* **2017**, *138*, 1–10.

29. Alvino, G.M.; Blatchford, R.A.; Archher, G.S.; Mench, J.A. Light intensity during rearing affects the behavioural synchrony and resting patterns of broiler chickens. *Br. Poult. Sci.* **2009**, *50*, 275–283.

30. Youssef, A.; Exadaktylos, V.; Berckmans, D.A. Towards real-time control of chicken activity in a ventilated chamber. *Biosyst. Eng.* **2015**, *135*, 31–43.

31. Febrer, K.; Jones, T.A.; Donnelly, C.A.; Dawkins, M.S. Forced to crowd or choosing to cluster? Spatial distribution indicates social attraction in broiler chickens. *Anim. Behav.* **2006**, *72*, 1291–1300.

32. Lewis, N.J.; Hurnik, J.F. Locomotion of broiler chickens in floor pens. *Poult. Sci.* **1990**, *69*, 1087–1093.

33. Weeks, C.A.; Danbury, T.D.; Davies, H.C.; Hunt, P.; Kestin, S.C. The behaviour of broiler chickens and its modification by lameness. *Appl. Anim. Behav. Sci.* **2000**, *67*, 111–125.

34. McKeegan, D.E.F.; Reimert, H.G.M.; Hindle, V.A.; Boulcott, P.; Sparrey, J.M.; Wathes, C.M.; Demmers, T.G.M.; Gerritzen, M.A. Physiological and behavioral responses of poultry exposed to gas-filled high expansion foam. *Poult. Sci.* **2013**, *92*, 1145–1154.

35. Webster, A.B.; Collett, S.R. A mobile modified-atmosphere killing system for small-flock depopulation. *J. Appl. Poult. Res.* **2012**, *21*, 131–144.

36. Aydin, A. Development of an early detection system for lameness of broilers using computer vision. *Comput. Electron. Agric.* **2017**, *136*, 140–146.

37. Aydin, A. Using 3D vision camera system to automatically assess the level of inactivity in broiler chickens. *Comput. Electron. Agric.* **2017**, *135*, 4–10.

38. Nääs, I.A.; Lozano, L.C.M.; Abdanan Mehdizadeh, S.; Garcia, R.G.; Abe, J.M. Paraconsistent logic used for estimating the gait score of broiler chickens. *Biosyst. Eng.* **2018**, *173*, 115–123.
39. Aydin, A.; Bahr, C.; Berckmans, D. Automatic classification of measures of lying to assess the lameness of broilers. *Anim. Welf.* **2015**, *24*, 335–343.
40. Nääs, I.A.; Sonoda, L.T.; Romanini, C.E.B.; Morello, G.M.; Neves, H.A.F.; Baracho, M.S.; Souza, S.R.L.S.; Menezes, A.G.; Mollo Neto, M.; Moura, D.J.; et al. Morphological Asymmetry and Broiler Welfare. *Brazilian J. Poult. Sci.* **2008**, *10*, 209–213.
41. Nääs, I.A.; Baracho, M.D.S.; Salgado, D.D.; Sonoda, L.T.; Carvalho, V.R.C.; Moura, D.J.; Paz, I.C.L.A. Broilers' toes asymmetry and walking ability assesment [Assimetria dos pés de frangos de corte e medida de habilidade locomotora]. *Eng. Agric.* **2009**, *29*, 538–546.
42. Nääs, I.A.; Paz, I.C.L.A.; Baracho, M.S.; Menezes, A.G.; Lima, K.A.O.; Bueno, L.G.F.; Mollo Neto, M.; de Carvalho, V.C.; Almeida, I.C.L.; Souza, A.L. Assessing locomotion deficiency in broiler chicken [Medida de deficiência locomotora em frango de corte]. *Sci. Agric.* **2010**, *67*, 129–135.
43. Fontana, I.; Tullo, E.; Scrase, A.; Butterworth, A. Vocalisation sound pattern identification in young broiler chickens. *Animal* **2016**, *10*, 1567–1574.
44. Aydin, A.; Berckmans, D. Using sound technology to automatically detect the short-term feeding behaviours of broiler chickens. *Comput. Electron. Agric.* **2016**, *121*, 25–31.
45. Stadig, L.M.; Rodenburg, T.B.; Ampe, B.; Reubens, B.; Tuyttens, F.A.M. An automated positioning system for monitoring chickens' location: Effects of wearing a backpack on behaviour, leg health and production. *Appl. Anim. Behav. Sci.* **2018**, *198*, 83–88.
46. Cordeiro, M.B.; Tinôco, I.F.F.; Mesquita Filho, R.M.; Sousa, F.C. Digital image analysis for young chicken's behavior evaluation [Análise de imagens digitais para a avaliação do comportamento de pintainhos de corte]. *Eng. Agric.* **2011**, *31*, 418–426.
47. Dawkins, M.S.; Cain, R.; Merelie, K.; Roberts, S.J. In search of the behavioural correlates of optical flow patterns in the automated assessment of broiler chicken welfare. *Appl. Anim. Behav. Sci.* **2013**, *145*, 44–50.
48. Dawkins, M.S.; Lee, H. -j.; Waitt, C.D.; Roberts, S.J. Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait. *Appl. Anim. Behav. Sci.* **2009**, *119*, 203–209.
49. Dawkins, M.S.; Roberts, S.J.; Cain, R.J.; Nickson, T.; Donnelly, C.A. Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption. *Vet. Rec.* **2017**, *180*, 499.
50. Peña Fernández, A.; Norton, T.; Tullo, E.; van Hertem, T.; Youssef, A.; Exadaktylos, V.; Vranken, E.; Guarino, M.; Berckmans, D. Real-time monitoring of broiler flock's welfare status using camera-based technology. *Biosyst. Eng.* **2018**, *173*, 103–114.
51. Roberts, S.J.; Cain, R.; Dawkins, M.S. Prediction of welfare outcomes for broiler chickens using Bayesian regression on continuous optical flow data. *J. R. Soc. Interface* **2012**, *9*, 3436–3443.
52. Silvera, A.M.; Knowles, T.G.; Butterworth, A.; Berckmans, D.; Vranken, E.; Blokhuis, H.J. Lameness assessment with automatic monitoring of activity in commercial broiler flocks. *Poult. Sci.* **2017**, *96*, 2013–2017.
53. Van Hertem, T.; Norton, T.; Berckmans, D.; Vranken, E. Predicting broiler gait scores from activity monitoring and flock data. *Biosyst. Eng.* **2018**, *173*, 93–102.
54. Kashiha, M.; Pluk, A.; Bahr, C.; Vranken, E.; Berckmans, D. Development of an early warning system for a broiler house using computer vision. *Biosyst. Eng.* **2013**, *116*, 36–45.
55. Kristensen, H.H.; Cornou, C. Automatic detection of deviations in activity levels in groups of broiler

chickens - A pilot study. *Biosyst. Eng.* **2011**, *109*, 369–376.

56. Caplen, G.; Hothersall, B.; Murrell, J.C.; Nicol, C.J.; Waterman-Pearson, A.E.; Weeks, C.A.; Colborne, G.R. Kinematic analysis quantifies Gait abnormalities associated with lameness in broiler chickens and identifies evolutionary Gait differences. *PLoS One* **2012**, *7*, 1–11.
57. Ferreira, V.M.O.S.; Francisco, N.S.; Belloni, M.; Aguirre, G.M.Z.; Caldara, F.R.; Nääs, I.A.; Garcia, R.G.; Almeida, P.I.C.L.; Polycarpo, G. V Infrared thermography applied to the evaluation of metabolic heat loss of chicks fed with different energy densities. *Rev. Bras. Cienc. Avic.* **2011**, *13*, 113–118.
58. Nascimento, G.R.; Nääs, I.A.; Baracho, M.S.; Pereira, D.F.; Neves, D.P. Infrared thermography in the estimation of thermal comfort of broilers. *Rev. Bras. Eng. Agric. E Ambient.* **2014**, *18*, 658–663.
59. Nascimento, G.R.; Pereira, D.F.; Nääs, I.A.; Rodrigues, L.H.A. Thermal comfort fuzzy index for broiler chickens [Índice fuzzy de conforto térmico para frangos de corte]. *Eng. Agric.* **2011**, *31*, 219–229.
60. Giloh, M.; Shinder, D.; Yahav, S. Skin surface temperature of broiler chickens is correlated to body core temperature and is indicative of their thermoregulatory status. *Poult. Sci.* **2012**, *91*, 175–188.
61. Moe, R.O.; Bohlin, J.; Flø, A.; Vasdal, G.; Stubsjøen, S.M. Hot chicks, cold feet. *Physiol. Behav.* **2017**, *179*, 42–48.
62. Schwean-Lardner, K.; Fancher, B.I.; Laarveld, B.; Classen, H.L. Effect of day length on flock behavioural patterns and melatonin rhythms in broilers. *Br. Poult. Sci.* **2014**, *55*, 21–30.
63. Schwean-Lardner, K.; Fancher, B.I.; Classen, H.L. Impact of daylength on behavioural output in commercial broilers. *Appl. Anim. Behav. Sci.* **2012**, *137*, 43–52.
64. Mackie, N.; McKeegan, D.E.F. Behavioural responses of broiler chickens during low atmospheric pressure stunning. *Appl. Anim. Behav. Sci.* **2016**, *174*, 90–98.
65. Alves, M.C.F.; Paz, I.C.L.A.; Naas, I.A.; Garcia, R.G.; Caldara, F.R.; Baldo, G.A.A.; Garcia, E.A.; Molino, A. B. Locomotion of commercial broilers and indigenous chickens. *Rev. Bras. Zootec.* **2016**, *45*, 372–379.
66. Giersberg, M.F.; Hartung, J.; Kemper, N.; Spindler, B. Floor space covered by broiler chickens kept at stocking densities according to Council Directive 2007/43/EC. *Vet. Rec.* **2016**, *179*, 124.
67. Mendes, A.S.; Paixão, S.J.; Sikorski, R.R.; Bonamigo, D. V; Morello, M.G.; Ponzoni, R.A.R. Photogrammetry: A non-invasive and objective method for detecting locomotion problems in broiler chickens. *Rev. Bras. Cienc. Avic.* **2016**, *18*, 573–580.
68. Vanderhasselt, R.F.; Sprenger, M.; Duchateau, L.; Tuyttens, F.A.M. Automated assessment of footpad dermatitis in broiler chickens at the slaughter-line: Evaluation and correspondence with human expert scores. *Poult. Sci.* **2013**, *92*, 12–18.
69. Zhuang, X.; Bi, M.; Guo, J.; Wu, S.; Zhang, T. Development of an early warning algorithm to detect sick broilers. *Comput. Electron. Agric.* **2018**, *144*, 102–113.
70. Fontana, I.; Tullo, E.; Butterworth, A.; Guarino, M. An innovative approach to predict the growth in intensive poultry farming. *Comput. Electron. Agric.* **2015**, *119*, 178–183.
71. Stadig, L.M.; Ampe, B.; Rodenburg, T.B.; Reubens, B.; Maselyne, J.; Zhuang, S.; Criel, J.; Tuyttens, F.A.M. An automated positioning system for monitoring chickens' location: Accuracy and registration success in a free-range area. *Appl. Anim. Behav. Sci.* **2018**, *201*, 31–39.
72. Taylor, P.S.; Hemsworth, P.H.; Groves, P.J.; Gebhardt-Henrich, S.G.; Rault, J.-L. Ranging behaviour of commercial free-range broiler chickens 1: Factors related to flock variability. *Animals* **2017**, *7*, 1–14.
73. Taylor, P.S.; Hemsworth, P.H.; Groves, P.J.; Gebhardt-Henrich, S.G.; Rault, J.-L. Ranging behaviour of commercial free-range broiler chickens 2: Individual variation. *Animals* **2017**, *7*, 1–9.
74. Calvet, S.; Carlos Campelo, J.; Estelles, F.; Perles, A.; Mercado, R.; Jose Serrano, J. Suitability Evaluation of

Multipoint Simultaneous CO2 Sampling Wireless Sensors for Livestock Buildings. *Sensors* **2014**, *14*, 10479–10496.

75. Curi, T.M.C.; Conti, D.; Vercellino, R.A.; Massari, J.M.; Moura, D.J.; Souza, Z.M.; Montanari, R. Positioning of sensors for control of ventilation systems in broiler houses: a case study. *Sci. Agric.* **2017**, *74*, 101–109.
76. Lin, T.; Shah, S.B.; Wang-Li, L.; Oviedo-Rondón, E.O.; Post, J. Development of MOS sensor-based NH3 monitor for use in poultry houses. *Comput. Electron. Agric.* **2016**, *127*, 708–715.
77. Coenen, A.M.L.; Lankhaar, J.; Lowe, J.C.; McKeegan, D.E.F. Remote monitoring of electroencephalogram, electrocardiogram, and behavior during controlled atmosphere stunning in broilers: Implications for welfare. *Poult. Sci.* **2009**, *88*, 10–19.
78. Hindle, V.A.; Lambooij, E.; Reimert, H.G.M.; Workel, L.D.; Gerritzen, M.A. Animal welfare concerns during the use of the water bath for stunning broilers, hens, and ducks. *Poult. Sci.* **2010**, *89*, 401–412.
79. Iyasere, O.S.; Edwards, S.A.; Bateson, M.; Mitchell, M.; Guy, J.H. Validation of an intramuscularly-implanted microchip and a surface infrared thermometer to estimate core body temperature in broiler chickens exposed to heat stress. *Comput. Electron. Agric.* **2017**, *133*, 1–8.
80. Hoffmann, G.; Ammon, C.; Volkamer, L.; Sürie, C.; Radko, D. Sensor-based monitoring of the prevalence and severity of foot pad dermatitis in broiler chickens. *Br. Poult. Sci.* **2013**, *54*, 553–561.
81. Demmers, T.G.M.; Cao, Y.; Gauss, S.; Lowe, J.C.; Parsons, D.J.; Wathes, C.M. Neural predictive control of broiler chicken and pig growth. *Biosyst. Eng.* **2018**, *173*, 134–142.
82. Moura, D.J.; Nääs, I.A.; Pereira, D.F.; Silva, R.B.T.R.; Camargo, G.A. Animal welfare concepts and strategy for poultry production: A review. *Rev. Bras. Cienc. Avic.* **2006**, *8*, 137–148.
83. Aydin, A.; Bahr, C.; Berckmans, D. An innovative monitoring system to measure the feed intake of broiler chickens using pecking sounds. In Proceedings of the Precision Livestock Farming 2013 - Papers Presented at the 6th European Conference on Precision Livestock Farming, ECPLF 2013, Leuven, Belgium, 10–12 September 2013; Katholieke Universiteit Leuven: 2013; pp. 926–936.
84. Kaukonen, E.; Norring, M.; Valros, A. Effect of litter quality on foot pad dermatitis , hock burns and breast blisters in broiler breeders during the production period. *Avian Pathol.* **2016**, *45*, 667–673.
85. Toppel, K.; Kaufmann, F.; Sch, H.; Gauly, M.; Andersson, R. Effect of pH-lowering litter amendment on animal-based welfare indicators and litter quality in a European commercial broiler husbandry. *Poult. Sci.* **2019**, *98*, 1181–1189.
86. Çavusoglu, E.; Petek, M.; Abdourhamane, I.M.; Akkoc, A.; Topal, E. Effects of different floor housing systems on the welfare of fast-growing broilers with an extended fattening period. *Arch. Anim. Breed.* **2018**, *61*, 9–16.
87. Tullo, E.; Fontana, I.; Peña Fernandez, A.; Vranken, E.; Norton, T.; Berckmans, D.; Guarino, M. Association between environmental predisposing risk factors and leg disorders in broiler chickens. *J. Anim. Sci.* **2017**, *95*, 1512–1520.
88. Dunlop, M.W.; Moss, A.F.; Groves, P.J.; Wilkinson, S.J.; Stuetz, R.M.; Selle, P.H. Science of the Total Environment The multidimensional causal factors of ‘ wet litter ’ in chicken-meat production. *Sci. Total Environ.* **2016**, *562*, 766–776.
89. Yamak, U.S.; Sarica, M.; Boz, M.A.; Uçar, A. Effect of Reusing Litter on Broiler Performance , Foot-Pad Dermatitis and Litter Quality in Chickens with Different Growth Rates. *Kafkas Univ Vet Fak Derg* **2015**, *22*, 85–91.
90. Martins, R.S.; Hötzel, M.J.; Poletto, R. Influence of in-house composting of reused litter on litter quality,

ammonia volatilisation and incidence of broiler foot pad dermatitis. *Br. Poult. Sci.* **2013**, *54*, 669–676.

91. Çavusoglu, E.; Petek, M. Effects of different floor materials on the welfare and behaviour of slow- and fast-growing broilers. *Arch. Anim. Breed.* **2019**, *62*, 335–344.
92. Steenfeldt, S.; Sørensen, P.; Nielsen, B.L. Effects of choice feeding and lower ambient temperature on feed intake , growth , foot health , and panting of fast- and slow-growing broiler strains. *Poult. Sci.* **2019**, *98*, 503–513.
93. Shim, M.Y.; Karnuah, A.B.; Mitchell, A.D.; Anthony, N.B.; Pesti, G.M.; Aggrey, S.E. The effects of growth rate on leg morphology and tibia breaking strength , mineral density , mineral content , and bone ash in broilers. *Poult. Sci.* **2012**, *91*, 1790–1795.
94. Oviedo-Rondón, E.O.; Wineland, M.J.; Funderburk, S.; Small, J.; Cutchin, H.; Mann, M. Incubation conditions affect leg health in large , high-yield broilers. *J. Appl. Poult. Res.* **2009**, *18*, 640–646.
95. Alves, M.C..; Almeida Paz, I.C..; Garcia, R.G.; Caldara, F..; Baldo, G.A..; Nascimento, G.R.; Felix, G.A.; Garcia, E.A.; Molino, A.R. Equilibrium Condition during Locomotion and Gait in Broiler Chickens. *Brazilian J. Poult. Sci.* **2016**, *18*, 419–426.
96. Clark, B.; Stewart, G.B.; Panzone, L.A.; Kyriazakis, I.; Frewer, L.J. A Systematic Review of Public Attitudes, Perceptions and Behaviours Towards Production Diseases Associated with Farm Animal Welfare. *J. Agric. Environ. Ethics* **2016**, *29*, 455–478.
97. Broom, D.M.; Molento, C.F.M. Bem estar animal: conceito e questões relacionadas - revisão. *Arch. Vet. Sci.* **2004**, *9*, 1–11.
98. Kittelsen, K.E.; Moe, R.O.; Hoel, K.; Kolbjørnsen, Ø.; Nafstad, O.; Granquist, E.G. Comparison of fl ock characteristics , journey duration and pathology between fl ocks with a normal and a high percentage of broilers ' dead-on-arrival ' at abattoirs. *Animal* **2017**, *11*, 2301–2308.
99. Caffrey, N.P.; Dohoo, I.R.; Cockram, M.S. Factors a ff ecting mortality risk during transportation of broiler chickens for slaughter in Atlantic Canada. *Prev. Vet. Med.* **2017**, *147*, 199–208.
100. Schwartzkopf-genswein, K.S.; Faucitano, L.; Dadgar, S.; Shand, P.; González, L.A.; Crowe, T.G. Road transport of cattle , swine and poultry in North America and its impact on animal welfare , carcass and meat quality : A review. *Meat Sci.* **2012**, *92*, 227–243.
101. Minka, N.S.; Ayo, J.O. Physiological responses of food animals to road transportation stress. *African J. Biotechnol.* **2010**, *9*, 6601–6613.
102. Shields, S.J.; Raj, A.B.M. A Critical Review of Electrical Water-Bath Stun Systems for Poultry Slaughter and Recent Developments in Alternative Technologies. *J. Appl. Anim. Welf. Sci.* **2010**, *13*, 281–299.
103. Fraser, D. The globalisation of farm animal welfare. *Rev. sci. tech. Off. int. Epiz* **2014**, *33*, 33–38.
104. von Keyserlingk, M.A.G.; Hötzel, M.J. The Ticking Clock: Addressing Farm Animal Welfare in Emerging Countries. *J. Agric. Environ. Ethics* **2014**, *28*, 179–195.
105. Goldberg, A.M. Farm Animal Welfare and Human Health. *Curr. Environ. Heal. reports* **2016**, *3*, 313–321.
106. Yunes, M.C.; Von Keyserlingk, M.A.G.; Hötzel, M.J. Brazilian citizens' opinions and attitudes about farm animal production systems. *Animals* **2017**, *7*, 1–15.
107. Vizzier Thaxton, Y.; Christensen, K.D.; Mench, J.A.; Rumley, E.R.; Daugherty, C.; Feinberg, B.; Parker, M.; Siegel, P.; Scanes, C.G. Symposium: Animal welfare challenges for today and tomorrow. *Poult. Sci.* **2016**, *95*, 2198–2207.
108. Trienekens, J.H.; Wognum, P.M.; Beulens, A.J.M.; van der Vorst, J.G.A.J. Transparency in complex dynamic food supply chains. *Adv. Eng. Informatics* **2012**, *26*, 55–65.
109. Sassi, N.B.; Averós, X.; Estevez, I. Technology and poultry welfare. *Animals* **2016**, *6*, 1–21.

CHAPTER 4

Technology potentialities based on Brazilian broiler farmers´ opinions on animal welfare

Abstract

A survey was conducted with 184 broiler farmers of Southern Brazil to address two main questions: (i) How do broiler farmers attribute importance to animal welfare and perceive the current level of broiler welfare? (ii) Are broiler farmers´ opinions on broiler welfare linked to their opinions on technologies potentialities and are they willing to adopt technologies? Broiler farmers were asked on the importance and perception of animal welfare using the criteria and principles of Welfare Quality® protocol as a framework. Differences between importance and perception scores were analyzed. The potentialities of technologies on broiler welfare improvements and the willingness of farmers to adopt technologies were assessed. Data were submitted to Kruskal Wallis and Dunn test with p-value adjusted for Bonferroni. Spearman correlation was performed to analyze possible correlations between farmers´ importance/perception attributed to broiler welfare and their opinions on technologies potentialities. In general, broiler farmers attributed great importance to broiler welfare and perceive the current level of broiler welfare as high. Good feeding was the highest scored welfare principle for both importance and perception ($P<0.05$), whereas appropriate behavior was the least scored ($P<0.05$). Importance of welfare principles were higher than perceptions ($P<0.05$), except for appropriate behavior ($P>0.05$). Broiler farmers perceived higher potential of technologies to improve good feeding and good housing when compared to good health and appropriate behavior ($P<0.05$). Positive correlations were observed between importance and technologies potentialities for good feeding, good housing and appropriate behavior and between perception and technologies potentialities for good housing and appropriate behavior. Broiler farmers were willing to adopt technologies aiming at welfare improvements if it did not represent a loss of income. Such findings suggest that broiler welfare is important to broiler farmers and that there is room for welfare improvements. Broiler farmers believe that technologies can assist them on welfare improvements and are willing to adopt technologies aiming on that, even when the adoption did not represent an extra income.

Key words: Innovation, PLF, information technology, poultry welfare, smart sensor

1. INTRODUCTION

Increasingly attention has been given to farm animal welfare worldwide. Studies have focused on this matter, pointing out societal awareness and advocating better conditions for animals lives (BROOM, 2017; FRASER, 2014; GOLDBERG, 2016; HUERTAS; GALLO; GALINDO, 2014; THAXTON et al., 2016; YUNES; VON KEYSERLINGK; HÖTZEL, 2017). The biggest concerns of citizens seem to address mainly the conditions of animals reared under highly intensive systems of production, probably due to high stocking densities (as the commonly used in poultry production) (JONGE; VAN TRIJP, 2013; VANHONACKER et al., 2008, 2009). As a matter of fact, farmers´ attention to the welfare of individuals is impaired by this system, as it is humanely impossible, considering human natural sensors, to assist each broiler in their needs in a poultry house where dozens of thousands of animals are housed.

People have left rural areas and lost contact with animal production, which has changed their relationship with animals (CLARK et al., 2016). In rural areas, animals are an income source whereas in cities animals are seeing as a human company deserving attention and care, which can lead urban people to present more sympathy to farm animals (FRASER, 2003). It does not necessarily imply that farmers are not concerned about animal welfare, as they work with living beings they may feel responsible for animal´s lives, especially when they consider animals as sentient beings (DOCKÈS; KLING-EVEILLARD, 2006). Farmers make their living from the animals, spending a significant amount of their time in close contact with them, in a relationship that can include pleasure, fear, animosity and so on (COLEMAN; HEMSWORTH, 2014); therefore, they play a central role in attending societal demands regarding animal welfare improvements.

Although citizens and farmers generally agree that animal welfare is an important aspect of broiler production, they can disagree about which are the most important welfare principles to be met and to guarantee an appropriate level of animal welfare. Whilst citizens tend to add value to naturalness (YUNES; VON KEYSERLINGK; HÖTZEL, 2017), outdoor access (JONGE; VAN TRIJP, 2013) and opportunities for expressing natural behavior (VANHONACKER et al., 2008), broiler farmers valorize more animal health and comfort aspects (HANSSON; LAGERKVIST, 2012). In fact, broiler farmers tend to have negative opinions on outdoor access as they perceive it is setback to old production practices that can negatively affect animal health, increase labor and costs of production, and decrease profits (TUYTTENS; VANHONACKER; VERBEKE, 2014). The assessment of broiler farmers perceptions on current animal welfare and the importance they allocate to the subject can provide valuable insights on their willingness to adopt welfare practices.

An opportunity to respond to societal demands for better care of farm animals and to assist broiler farmers in this task, is turning the production sector to data-driven farming based on Precision Livestock Farming (PLF) technologies. Such technologies include sensors, cameras, microphones that when coupled with data processing algorithms enable the measurement and control of animal health, welfare and productivity indicators providing clear insights to the farmer. These technologies can be used to monitor animals and their environment in a continuous way, managing their condition 24/7 and providing more information to farmers about their livestock

(BERCKMANS, 2017). Although, there are great efforts to develop technologies to assist broiler farmers on animal welfare improvements (ASTILL et al., 2020; CORKERY et al., 2013; RIOS et al., 2020; ROWE; DAWKINS; GEBHARDT-HENRICH, 2019), little attention has been given to broiler farmers opinion on these technologies.

The present research intends to analyze how important animal welfare is to Brazilian broiler farmers, how they perceive the current level of broiler welfare and how they think PLF technologies can help them in assuring broiler welfare. Because animal welfare can include several aspects of broilers lives, in the present study the principle and criteria present in Welfare Quality® protocol for poultry will be used, since the Protocol is widely accepted by the scientific community as a reference for welfare assessment. To the best of our knowledge, no study has put together farmers´ opinion and perception on broiler welfare and on PLF technologies until now. Tuyttens, Vanhonacker and Verbeke (2014) have assessed Flemish broiler farmers´ opinions on broiler welfare using the Welfare Quality® protocol for poultry as a framework; however, they do not evaluate how it could be linked to farmers expectations on technologies. Additionally, Belgian´s institutional environment and the European system of production can be widely different from Brazilian´s as already stressed out by Tuyttens et al. (2015). Brazil is responsible for supplying approximately 13.8% of the total chicken meat consumed in the world (USDA, 2021) and, according to projections of Brazilian Ministry of Agriculture, Livestock and Supply, Brazilian chicken meat production is expected to increase 28% until the 2030 (BRASIL, 2020). As Brazil is the greatest exporter of poultry meat worldwide, the study is timeless since a significative amount of poultry meat consumed worldwide come from Brazilian farms.

It is possible that broiler farmers who have negative perceptions on current broiler conditions of living or those who give great importance for the subject would be more optimistic about technology potentialities. Additionally, farmers that are more concerned to the welfare level of their animals maybe be more willing to improve broilers´ conditions when these conditions are not in accordance with what is considered as reasonable. If broiler welfare is important to farmers and if they perceive broiler welfare below its level of importance, would they be more willing to take actions aiming at improving animal welfare? This question relies in the Theory of Utility, as it is believed that broiler farmers´ utility would be impaired if the current level of broiler welfare disagrees with farmers´ expectations (they see current broiler welfare status below the level they wish it was) or because farmers´ utility would be higher if animal welfare level could be increased.

This is important to be acknowledged as public and private incentives as well as technical assistance can use this information to formulate approaches to increase the adoption of technologies related to animal welfare benefiting farmers and citizens alike. Therefore, the present research aims to answer two main questions: (i) How do Brazilian broiler farmers attribute importance to animal welfare and perceive the current level of broiler welfare? (ii) Are broiler farmers´ opinions on broiler welfare linked to their opinions on technologies potentialities and their willingness to adopt such technologies?

2. MATERIAL AND METHODS

2.1 DATA COLLECTION AND SAMPLE DESCRIPTIVE ANALYSIS

The importance that poultry farmers allocate to broiler welfare, how they perceive the current rearing conditions, their opinions on technology potentialities and their willingness to adopt them were accessed through a research conducted with broiler farmers from the Southern Brazil, a region composed by Rio Grande do Sul, Santa Catarina and Parana states. The region is noticeably known as the greatest broiler chicken producer of the country, responsible for 64% of all Brazilian broiler meat production and for 84% of Brazilian poultry meat exports (ABPA, 2020). Broiler production is of great socioeconomic relevance in the regions where the survey took place. Data were collected from September to December 2020 through a questionnaire that was answered online (using Google Forms) or in paper.

Before the questionnaire was properly applied, a prequestionnaire was designed using pieces of past researches and elements discussed with 13 experts in broiler production and/or economics. In order to test the adequacy of the questionnaire, a pretest was made with 11 broiler farmers. By their feedbacks, incongruencies and unclear points were adjusted to properly address the objective of each question. The final version of the questionnaire was sent to 200 broiler farmers in paper format with the help of a local poultry company, being 153 answered; however, 18 were disregarded due to incomplete answers. The link to the online format of the questionnaire was sent to other broiler farmers; nonetheless, the precise number cannot be inferred, since the link was sent with the help of another poultry company and these broiler farmers were encouraged to send the link to other broiler farmers. From the online format, 51 answers were obtained, being two of them disregarded also due to incomplete answers. Before answering the questions, farmers had to explicitly agree to participate of the research voluntarily.

The questionnaire consisted of four sections. First, farmers were asked about their socioeconomic and productive characteristics. Information about broiler farmers´ age, income, level of education and about productive characteristic such as broiler weigh at slaughter, mortality rate, number of broiler houses can be visualized in Table 1.

Table 1. Sociodemographic, productive and economic data of broiler farmers in Southern Brazil (n=184)

Sociodemographic data		
Age, years	Mean	n
	43.86 (11.64)	184
Educational level	%	n
Primary school (uncompleted)	21.20	39
Primary school (completed)	28.26	52
Secondary school	35.33	65
Superior	11.41	21
Post-graduation	3.80	7
Brazilian Federal State	%	n
Paraná	71.20	131
Santa Catarina	2.17	4
Rio Grande do Sul	26.63	49
Productive data		
Product	%	n
Griller (~1500g)	38.59	71
Heavy (~3000g)	61.41	113
	Mean	n
Broiler houses, number	1.72 (1.02)	184
Mortality rate, %	3.89 (2.61)	180
Economic data		
Broiler activity income / total income	%	n
25%	20.65	38
26 to 50%	25.54	47
51 to 75%	26.63	49
More than 75%	27.17	50

In the second part of the questionnaire, the importance that animal welfare had to broiler farmers and their perceptions regarding the currently level of broiler welfare were assessed considering the different principles of animal welfare. The Welfare Quality® Assessment protocol for poultry was used as a framework to define the criteria and principles of animal welfare to be evaluated (WELFARE QUALITY®, 2009). In the Protocol, there are four principles to assess animal welfare: good feeding, good housing, good health and appropriate behavior, that when evaluated together produce an overall score of the animal welfare level. To evaluate these principles, 12 criteria are used, being two to define good feeding, three to good housing, three to good health and four to appropriate behavior (Table 2).

In the present research, farmers were asked about how important are the 12 welfare criteria to broiler welfare and about how they perceived the current welfare status of broilers considering each one of them. To infer on this, a five-point Likert scale, ranging from 1 (extremely bad) to 5 (extremely good) was used. Scores of each principle were calculated by weighing the relative importance of each criterion to compose the given principle as previously done by Tuyttens et al. (2010), disregarding the fact that for the criterion "expression social behavior" no objective measurement has been developed by the Welfare Quality® Protocol for broiler chickens so far. The overall welfare level was calculated as the result of the mean score of all principles.

Table 2. Principles and criteria used to evaluate broiler welfare level present in the Welfare Quality® Assessment Protocol for broiler chickens.

Welfare Principles	Welfare Criteria		Criterion relative weight
Good feeding	1	Absence of prolonged hunger	0.41
	2	Absence of prolonged thirst	0.59
Good housing	3	Comfort around resting	0.34
	4	Thermal comfort	0.31
	5	Ease of movement	0.35
Good health	6	Absence of injuries	0.32
	7	Absence of disease	0.39
	8	Absence of pain induced by management procedures	0.29
Appropriate behavior	9	Expression of social behaviors	0.26
	10	Expression of other behaviors	0.22
	11	Good human-animal relationship	0.23
	12	Positive emotional state	0.29

Source: Adapted from Welfare Quality® assessment protocol for poultry (WELFARE QUALITY ®, 2009).

In the third section, farmers were asked about how PLF technologies could improve each one of the four principles of animal welfare as well as the overall broiler welfare. They were asked about their level of agreement with the five following sentences: "broilers reared in more technological broiler houses present higher level of welfare", "broilers eat and drink better when technologies are used in broiler houses", "broilers feel more comfortable when technologies are used in a broiler house", "better broiler health conditions are observed when technologies are used", “broiler express natural behavior more properly in more technological broiler houses”. To infer on this, farmers were asked to attribute their level of agreement with each sentence in a five-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree).

The difference between the importance that broiler farmers allocate to the different animal welfare criteria (how they believe broiler welfare should be) and their beliefs (how they evaluate the current level of broiler welfare) were assessed by subtracting the scores of importance and perception for each one of the principles. In this sense, the greater the difference between them the greater is the divergence between importance and perception. The methodology was according to Vanhonacker et al. (2008), where positive values correspond to aspects that farmers could be more willing to improve; whereas negative values mean low or none willingness to be improved.

In the fourth section of the questionnaire, broiler farmers´ willingness to adopt technologies were assessed. Farmers had to express their agreement in a five-point Likert scale, ranging from 1 (totally disagree) to 5 (totally agree) regarding the three following sentences: “I would use PLF technologies if they could improve broiler welfare and increase my income”, “I would use PLF technologies if they could improve broiler welfare and my investment in the technology was entirely compensated (with no income increase)”, “I would use PLF technologies if they could improve broiler welfare, even if it represents an acceptable decrease in my income”.

2.2 STATISTICAL ANALYSIS

Descriptive statistics were used to evaluate socioeconomic and productive characteristics using Excel. Welfare principles and criteria scores for importance and perception were submitted to Kruskall-Wallis with 5% significance and, whenever significant differences were observed, the Dunn test with p-value adjusted by Bonferroni was applied to discriminate them. Similarly, farmers´ opinions on technologies potentialities to improve the different principles of welfare and their level of (dis)agreement with the three sentences used to measure their willingness to adopt technologies were also submitted to the same statistic tests. Moreover, scores of importance and perceptions that farmers attributed to each principle and criterion were compared by Mann-Whitney test with 5% of significance.

Spearman correlation was used to infer on the possible correlation between the scores given to the importance, perception and importance-perception divergence regarding the different welfare principles and farmers´ opinions on the potentialities that technologies present to improve each welfare principle. Spearman correlation between the opinion on technology potentialities and importance, perception or divergence were made, considering each one of the welfare principles. In this way, we estimated the correlation between technologies that can improve good feeding and the importance good feeding has to animal welfare in broiler farmers´ opinion, also between technologies that can improve good housing and how important good housing is to animal welfare according to broiler farmers, and so on. All statistic tests were performed using R Programming Language (R CORE TEAM, 2021).

Our hypothesis is that the importance that farmers attribute to broiler welfare as well as their perceptions regarding the current level of broiler welfare are linked to their opinions regarding technology potentialities. In addition, greater differences between importance and perceptions would be associated with higher scores on farmers´ opinions regarding technology potentialities as farmers would seek for animal welfare improvements and technologies are being developed to assist them in this task.

3. RESULTS

Results of broiler farmers´ opinion regarding animal welfare importance and how they evaluate the current broiler welfare status considering different principles and criteria of broiler welfare can be visualized in Table 3. In general, broiler producers scored high values to all broiler welfare principles, in terms both of importance and perception, being the calculated overall welfare score at 4.63 and 4.49, respectively. Regarding the comparison among welfare principles within importance and perception, more weigh was allocated to “good feeding” when compared to other welfare principles ($P<0.05$), “appropriate behavior” presented the lowest score ($P<0.05$), whereas “good housing” and “good health” received intermediate values. When analyzed importance and perception for the criteria within welfare principles, no difference was observed between the criteria used to assess “good feeding” neither for importance nor perception. Regarding the criteria for “good housing” assessment, “ease of movement” received lower score compared to “comfort around resting” and “thermal comfort” when analyzed how important these criteria are to animal welfare in broiler farmers´ opinion ($P<0.05$); however, no differences were observed when considered broiler farmers´ perception on the actual level of broiler welfare regarding the same criteria ($P>0.05$). No differences were observed for any variable analyzed when evaluated the criteria within “good health” ($P>0.05$).

Evaluating criteria used to assess “appropriate behavior”, higher scores were allocated to the importance of “good human-animal relationship” when compared to “expression of social behavior” and “expression of other behavior” (P<0.05); however, no difference was observed between “good-animal relationship” and “positive emotional states”. Regarding broiler farmers´ perception of these same criteria, “positive emotional states” presented higher score compared to “expression of other behavior” (P<0.05); nonetheless no differences were observed among “positive emotional states”, “good human-animal relationship” and “expressional of social behaviors” (P>0.05). Similarly, no differences were observed among “expression of other behaviors”, “expression of social behaviors” and “good human-animal relationship” (P>0.05).

Results for differences between importance and perception as well as the importance-perception divergence are shown in Table 3. Broiler farmers allocated higher scores for the importance of “good feeding”, “good housing” and “good health” in the broiler welfare when compared to their scores for the current level of broiler welfare considering the same principles (P<0.05); even though no differences were observed for overall welfare and “appropriate behavior” (P>0.05). Similarly, when considered the scores attributed to importance and perception for each welfare criteria it was observed that, except for the criteria within appropriate behavior and the criterion “ease of movement”, all scores were higher for importance than to perception (P<0.05), which indicate where there are room for welfare improvements on broiler farmers´ opinion.

Divergence between importance and perception assumed negative value for “appropriate behavior”, whereas they were positive to other principles. The divergence results indicate where there are room for broiler welfare improvements in broiler farmers´ opinion: negative values occurs when the importance broiler farmers allocate to a given principle is below their perception and, thus, there is few opportunities for welfare improvements; whereas when divergence is positive, the importance is higher than the perception, presenting more opportunities for broiler welfare improvements.

Table 3. Mean scores of importance, perception and importance-perception divergence for welfare principles and criteria.

Item	Importance	Perception	Divergence	P-value importance X perception
Good feeding	$^{y}4.85^{A}$ (0.56)	$^{z}4.62^{A}$ (0.91)	0.23	0.002
Absence of prolonged hunger	$^{y}4.84$ (0.59)	$^{z}4.61$ (0.92)	0.23	0.002
Absence of prolonged thirst	$^{y}4.85$ (0.56)	$^{z}4.62$ (0.93)	0.23	0.008
Good housing	$^{y}4.69^{B}$ (0.56)	$^{z}4.51^{B}$ (0.72)	0.18	0.039
Comfort around resting	$^{y}4.80^{a}$ (0,54)	$^{z}4.52$ (0.79)	0.29	0.001
Thermal comfort	$^{y}4.78^{a}$ (0.55)	$^{z}4.52$ (0.80)	0.26	0.001
Ease of movement	4.51^{b} (0.78)	4.50 (0.85)	0.01	0.765
Good health	$^{y}4.75^{B}$ (0.51)	$^{z}4.49^{B}$ (0.80)	0.25	0.008
Absence of injuries	$^{y}4.71$ (0.61)	$^{z}4.45$ (0.88)	0.27	0.002
Absence of disease	$^{y}4.81$ (0.52)	$^{z}4.54$ (0.86)	0.27	0.001
Absence of pain induced by management procedures	$^{y}4.70$ (0.68)	$^{z}4.49$ (0.88)	0.21	0.014
Appropriate behavior	4.22^{C} (0.87)	4.34^{C} (0.78)	-0.12	0.263
Expression of social behaviors	4.07^{bc} (1.21)	4.30^{ab} (1.03)	-0.23	0.074
Expression of other behaviors	3.93^{c} (1.30)	4.13^{b} (1.17)	-0.19	0.194
Good human-animal relationship	4.47^{a} (0.82)	4.39^{ab} (0.88)	0.09	0.350
Positive emotional state	4.40^{ab} (0.94)	4.50^{a} (0.78)	-0.10	0.443
Overall	4.63 (0.49)	4.49 (0.65)	0.14	
P-value				
Principle	0.001	0.001		
Criteria within principle				
Good feeding	0.874	0.829		
Good housing	0.001	0.989		
Good health	0.119	0.341		
Appropriate behavior	0.001	0.036		

$^{A-C}$ Means at the same column not sharing the same capital superscript letter differ significantly on Dunn test with p-value adjusted for Bonferroni (P < 0.05).

$^{a-c}$ Means at the same column not sharing the same superscript letter differ significantly on Dunn test with p-value adjusted for Bonferroni (P < 0.05).

$^{y-z}$ Means at the same line not sharing the same capital superscript letter differ significantly on Mann-Whitney test (P < 0.05).

Results of broiler farmers´ opinion on technology potentialities for each welfare principle and for the overall broiler welfare are shown in Table 4. The average score for the potential technologies presents to improve broiler welfare was 4.26. Broiler farmers scored higher values for the potential that technologies present to improve “good feeding” and “good housing” when compared to the “good health” and the “appropriate behavior” principles (P>0.05). Moreover, no differences were observed between “good feeding” and “good housing” (P>0.05) neither between “good health and “appropriate behavior” (P>0.05).

Table 4. Broiler farmers’ opinion on technology potentialities to improve broiler welfare principles.

Item	Technology
Good feeding	4.18^{a} (1.15)
Good housing	4.45^{a} (0.97)
Good health	3.40^{b} (1.44)
Appropriate behavior	3.64^{b} (1.38)
Overall	4.26 (1.08)
P-value	0.001

$^{a\text{-}b}$ Means not sharing the same superscript letter differ significantly on Dunn test with p-value adjusted for Bonferroni (P < 0.05).

Correlations between broiler farmers´ opinion on technology potentialities and the importance they allocate to broiler welfare, their perception on the current level of broiler welfare and the importance-perception divergence are shown in Table 5. It is important to note that the opinion data on technology potentialities is regarding to the potential that technologies present to explicitly improve the given principle. The importance broiler farmers allocated to “good feeding”, “good housing” and “appropriate behavior”, were positively and significantly correlated to their opinions on technology potentialities to improve these welfare principles (P<0.05), although their Rho coefficients were relatively low, being 0.215, 0.150 and 0.260, respectively. No significant correlation was observed between broiler farmers´ opinion on technology potentialities and the importance of overall welfare or “good health”. Regarding broiler farmers´ perception, it was observed that “good housing”, “appropriate behavior” as well as the overall broiler welfare were positively and significantly correlated to broiler farmers´ opinion on technology potentialities aiming at welfare improvements (P<0.05), presenting relatively low Rho coefficient, being 0.178, 0.180 and 0.156, respectively. No significant correlation was observed between the importance-perception divergence and technology potentialities for any welfare principle.

Table 5. Spearman correlations between the importance broiler farmers allocate to broiler welfare, their perception on animal welfare and importance-perception divergence and their opinions on technology potentialities.

Item	Technology potentiality[1]	
	Rho Coefficient	P-value
Importance		
Good feeding	0.215	0.003
Good housing	0.150	0.042
Good health	0.090	0.220
Appropriate behavior	0.260	0.001
Overall welfare	0.110	0.137
Perception		
Good feeding	0.138	0.061
Good housing	0.178	0.015
Good health	0.129	0.080
Appropriate behavior	0.180	0.014
Overall welfare	0.156	0.034
Divergence		
Good feeding	-0.028	0.708
Good housing	-0.094	0.206
Good health	-0.094	0.202
Appropriate behavior	0.084	0.254
Overall welfare	-0.028	0.704

[1] Spearman correlation between the opinions on technology potentialities and importance, perception and divergence were made considering each welfare principles, i.e. broiler farmer´s opinions on technologies that can improve good feeding correlates with how important broiler farmers think good feeding is to broiler welfare, broiler farmer´s opinions on technologies that can improve good housing correlates with how important broiler farmers think good housing is to broiler welfare, and so on.

Results of broiler farmers´ willingness to adopt technologies can be visualized in Table 6. Broiler farmers attributed scores to the sentence “I would use PLF if they could improve broiler welfare, even if it represents an acceptable decrease in my income”, and it was lower when compared to scores for the other two sentences (P>0.05); however, no score differences were observed between the sentences “I would use PLF if they could improve broiler welfare and increase my income” and “I would use PLF they could improve broiler welfare and my investment in the technology entirely compensated (with no income increase)”.

Table 6. Broiler farmer´s willingness to adopt PLF technologies aiming at improving broiler welfare.

Question "I would use PLF if…"	Willingness
…they could improve broiler welfare and increase my income"	4.67[a] (0.91)
…they could improve broiler welfare and my investment in the technology entirely compensated (with no income increase)"	4.58[a] (0.78)
…they could improve broiler welfare, even if it represents an acceptable decrease in my income".	2.54[b] (1.39)
P-value	0.001

[a-b] Means not sharing the same superscript letter differ significantly on Dunn test with p-value adjusted for Bonferroni ($P < 0.05$).

4. DISCUSSION

This study is a first step to elucidate the reasons that lead broiler farmers´ to invest (or not) on technologies that can potentially improve broiler welfare. The motivation for the present study relies on the fact that society pushes farmers to improve animal welfare even when producing with low margins forces them to increase stocking densities, potentially impairing animal welfare. To respond on this, technologies have been developed to assist broiler farmers on animal welfare improvements by enabling the measuring of animal and/or environmental conditions in real-time and transforming these data in useful information to farmers (BERCKMANS, 2017). However, little farmer engagement on these technologies has been observed so far. The assumption of the present research is that the importance broiler farmers allocate to broiler welfare and the way they perceive the current level of broiler welfare is linked to their opinions on technologies potentialities and their willingness to adopt such technologies. Regarding this approach, D´Souza, Cyphers and Phipps (1993) had already stressed out a so called "awareness effect" as an elemental aspect to perform a new behavior and Foguesatto and Machado (2021) recently observed that grain farmers were more willing to adopt technologies when they were more concerned about climate change and environmental issues. Bringing it to the present context, if broiler farmers believe that better than current broiler condition of living is necessary, their utility would be negatively affected, and they will present more positive opinions on technologies that can improve welfare.

It is possible that broiler farmers scored animals´ welfare principles by framing the actual welfare as a medium score and then added points to it as the welfare status overcome this standard. This was suggested by Bracke et al. (2019) in a study involving the application of a questionnaire to experts in broiler production in which they evaluated different broiler production systems. In that way, it can be stated that broiler welfare is important to Brazilian broiler farmers as their average score for broiler welfare importance was 4.63 (scoring above 4.2 for all principles). Also, they perceive the current level of broiler welfare above standard, as they scored 4.49 for their perception on the currently level of broiler welfare (scoring above 4.30 for all principles).

Although it was explicitly informed before they answered the questionnaire that the results would be used for academic purposes only and their personal data would be maintained confidential, it is possible that farmers overscored the importance they attributed to broiler welfare and their perception regarding the actual level of animal welfare because they feared that the information could be used against them. This hypothesis is corroborated by Gocsik et al. (2016) who observed that Dutch broiler and pig farmers were afraid to answer specific questions about animal welfare because they wanted to avoid possible problems from their answers outcomes. Another point to be considered is that farmers could be concerned about being misjudged by other farmers or even by consumers if their broilers were reported to be in low level of welfare as suggested by Hansson and Lagervist (2012), in a study evaluating attitudes of livestock farmers related to animal welfare and health. Although these can represent bias for the present study, we consider the questions represented well opinions and perceptions of broiler farmers on animal welfare and results observed are valuable to answer the research objectives.

Another point to consider is that farmers whose animals present a high level of welfare added more value to welfare than those whose animals are in low level of welfare. It can be explained by the fact that outcome judgements can raise from behaviors successfully executed as explained in more details by Bandura (1982). In this context, if farmers are lesser discounted due to welfare problems or are rewarded due to good animal welfare practices, they will attribute more weigh to broiler welfare than those who are constantly having problems with thermal comfort or discounts due to carcass scratches or leg problems, for example. However, these aspects of production were not assessed in the current study, being this consideration a hypothesis to be explored by future studies.

The importance broiler farmers allocated to the different principles of broiler welfare as well as their perceptions regarding the actual level of broiler welfare were relatively high scored for all principles. “Good feeding” was the highest scored principle for both importance and perception, which is in accordance with Broom (1991) who argued that farmers tend to see animal welfare in a more productive way, i.e. if animal are productive they are in high level of welfare. In corroboration with that Tuyttens, Vanhonacker and Verbeke (2014) observed that “good feeding” was also high scored (6.54 out of 7) by Flemish broiler farmers when asked on the importance of this principle to animal welfare. However, the same authors verified equally high scores to the principle of “good housing” (6.44) and “good health” (6.55), whereas in the present study these principles were scored intermediately. A possible explanation for this, is that in European legislation, stocking densities are dependent on the health indicators of the flock, thus increasing stocking densities are allowed only if previous flocks have presented good health indicators which is mainly achievable with good housing conditions. Along with that, as suggested by Tuyttens et al. (2015) higher level of Brazilian broiler flocks welfare were observed when compared to Belgian´s. It is possible that Brazilian climate and local production practices can explain the fact that broiler health conditions in Brazil are better than in Belgium. This is a possible explanation for the fact that Brazilian broiler farmers are not as concerned with these welfare principles as Belgian broiler farmers.

Least importance was given to “appropriate behavior” particularly when considered the expression of broilers behaviors. Broiler farmers allocated less importance to broiler expression of other behaviors compared to other criteria within this principle. Except for human-animal relationship, other criteria within appropriate behavior presented negative values for importance-perception divergence (broiler farmers attributed a lower score to importance than to perception for the same criterion). Such findings indicate that broiler farmers do not see broiler expression of behaviors and animals´ positive emotional state as a problem for broiler welfare, although many of the broiler behaviors cannot be properly expressed in the conventional production system because the environment does not offer them such possibility (BUTTERWORTH, 2019). Additionally, “naturalness” and the opportunity to express natural behaviors are major citizens priorities when advocating for better farm animal welfare as observed by Yunes, Von Keyserlingk and Hötzel (2017) in a research on attitudes and beliefs of Brazilian citizens regarding animal production systems and animal welfare.

In general, the importance broiler farmers attributed to all principles and criteria were higher than their perceptions on the same principles and criteria, with the exception for the criterion “ease of movement” and those within “appropriate behavior” principle (for which reasons were already addressed). This is interesting to mention as it indicates where there is room for welfare improvements in broiler farmers´ opinion.

The importance that broiler farmers attributed to “good feeding”, “good housing” and “appropriate behavior” were positively correlated to their opinions on technology potentialities to improve such welfare principles. In spite of being a welfare aspect that broiler farmers normally look for improvements as it is strictly related to productive outcomes (TE VELDE; AARTS; WOERKUM, 2002), broiler farmers´ opinion on technology potentialities was relatively low scored for the “good health” principle, which is the main principle addressed by PLF technologies according to Rios et al. (2020). A possible explanation for this, is that more technological broiler houses usually allow for higher stocking densities as environmental conditions can be better controlled (DAWKINS; DONNELLY; JONES, 2004), whereas high stocking densities are often associated with impairments on broiler health due to leg problems (BESSEI, 2006; DOZIER et al., 2005; KARAARSLAN; NAZLIGÜL, 2018) and to disease predisposing (GOO et al., 2019; MUSTAFA et al., 2010; TSIOURIS et al., 2015). In a study involving broiler farmers experiences with PLF technology, Hartung et al. (2017) observed that broiler farmers presented negative opinions regarding increasing stocking densities, although, differently from our findings, they believed that PLF technologies could assist them on broiler health improvements. Thus, it cannot be disregarded a possible bias in this study due to a poor statement of the question that could not capture this information properly, suggesting that future studies evaluate this aspect carefully.

The fact that the importance broiler farmers allocated to appropriate behavior as well as their perception on this principle were positively correlated to their opinions on technology potentialities deserves a highlight. This is an alarming finding, since citizens generally attach great importance to conditions where broilers can display natural behaviors (JONGE; VAN TRIJP, 2013). Efforts should be made to increase farmers adoption of such technologies bridging the gap between consumers and producers. Along with that, farmers´ willingness to adopt technologies aiming at improving animal welfare were high scored even when no extra income would come from their utilization (score 4.58), and a low willingness to adopt technologies was observed only when it represented a loss of their income (score 2.54).

The willingness for technology adoption occurs when farmers evaluate that the change will have more benefits than costs. It is important to be noticed, that benefits and costs are not only restricted to economic ones, but to every positive and negative outcome the changing in the farmer´s behavior will lead to (BORGES; FOLETTO; XAVIER, 2015). There are evidence that moral and social concerns can have a central role to play on the adoption decision. Regarding this, Mzoughi (2011) observed that fruit and vegetables farmers were more willing to adopt an organic farming when they were more concern to societal impressions and when they felt (or would feel) guilty about using the traditional system. Moreover, being aware of a problem can influence the farmer willingness to adopt an innovation that can solve this problem, as demonstrated by D´Souza, Cyphers and Phipps (1993), who observed that farmers´ awareness of ground water contamination increased their probability of adhering to innovations aiming to solve it.

Studies on farmers and/or citizens opinions on animal welfare are vast in the literature (CLARK et al., 2016; KJAERNES; MIELE; ROEX, 2007; VANHONACKER et al., 2009; VANHONACKER; TUYTTENS; VERBEKE, 2016), most of them emphasizing the difficulties of farmers engagement on welfare practices and the differences on how farmers and citizens perceive the current level of animal welfare. For instance, in a study with Dutch farmers and citizens regarding farm animal welfare, Te Velde, Aarts and Woerkum (2002), verified that farmers perceive the current level of welfare as good, whereas citizens tend to perceive it far from optimal. These authors observed that farmers usually perceive improvements on animal welfare as something negative that will imply them to retrocede to old production practices. Similarly, Tuyttens, Vanhonacker and Verbeke (2014) observed that Flemish broiler farmers did not agree that current level of broiler welfare was poor and most of them were not seeking for improvements on animal welfare as they believed it would bring them little advantages. More recently, Albernaz-Gonçalves, Olmos and Hötzel, (2021) verified that Brazilian pig farmers were satisfied with the current level of welfare of their animals and showed no intention to invest on welfare improvements.

In the current study, different results of broiler farmers' opinion were obtained considering welfare compared to the above-mentioned publications. Brazilian broiler farmers are aware on the broiler welfare and are willing to adopt technologies aiming at improving the animal welfare level. Notwithstanding, they do not believe that the actual opportunities for broilers to perform natural behaviors are below the importance they allocated to it and this is a welfare aspect of main societal concern. A possible solution to attend both farmers and citizens interests would be the development/promotion of the use of technologies that could assist farmers improving more than one broiler welfare principle at same time. By way of examples, image technologies could be useful to both analyze behavioral expressions as demonstrated by Schwean-lardner et al. (2014) and to infer on animals´ thermal comfort as shown by Giloh, Shinder and Yahav (2012). Similarly, sound devices as studied by Fontana et al. (2016) could be used to both predict broiler weight and to differentiate between calling and distress calls in young chicks. Such welfare improvements will also imply in better communication between farmers and citizens enabling the latter to be aware on the practices adopted by farmers to improve animal welfare; however, this is a vast area of knowledge which is out of the scope of the present study.

5. FINAL CONSIDERATIONS

Brazilian broiler farmers attributed great importance to animal welfare and considered the principles of “good feeding”, “good housing” and “good health” as the most important to guarantee an adequate level of welfare to broiler chickens. Their perceptions regarding the currently level of broiler welfare was relatively high, although lower than the importance they allocate it, except for “appropriate behavior”, for which the importance-perception divergence presented negative values. Farmers believe that “good feeding” and “good housing” can be better improved using technologies than “good health” and “appropriate behavior”. Both importance and perception on broiler welfare were positively correlated with farmers´ opinions on technology potentialities for all principles, except for good health. Contrary to our assumption, the importance-perception divergences were not correlated to farmers opinions on technology potentialities, indicating that both importance and perception are positively associated with farmers´ opinions on technology potentialities.

The importance of broiler welfare to broiler farmers as well as farmers´ perceptions on the current animal welfare level can be associated to their opinions on PLF potentialities. Moreover, Brazilian broiler farmers indicated that they would use technologies aiming at animal welfare improvements even if it represented no increase in their income. Such findings represent a valuable step to understand factors that influence the adoption of PLF by farmers. Further studies should focus on the determinants of farmers adoption of technologies related to animal welfare and to develop strategies to increase their engagement on welfare practices. The development of technologies aiming at improving different aspects of broiler welfare can be of great value to attend farmers and citizens interests as well as to enhance broiler conditions of living. The understanding of farmers impressions and judgements on broiler welfare are the first step to evaluate the possibilities for broiler farmers´ adoption of PLF technologies related to animal welfare.

REFERENCES

ABPA - ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL. **Relatório anual 2020**. São Paulo: ABPA, 2020.

ALBERNAZ-GONÇALVES, R.; OLMOS, G.; HÖTZEL, M. J. My pigs are ok, why change? – Animal welfare accounts of pig farmers. **Animal**, Cambridge, v. 15, n. 3, [art.] 100154, 2021.

ASTILL, J. *et al*. Smart poultry management: smart sensors, big data, and the internet of things. **Computers and Electronics in Agriculture**, Amsterdam, v. 170, [art.] 105291, [p. 1–8], 2020.

BANDURA, A. Self-efficacy mechanism in human agency. **American Psychologist**, Washington, DC, v. 37, n. 2, p. 122–147, 1982.

BERCKMANS, D. General introduction to precision livestock farming. **Animal Frontiers**, London, v. 7, n. 1, p. 6–11, 2017.

BESSEI, W. Welfare of broilers: a review. **World's Poultry Science Journal**, Ithaca, v. 62, n. 3, p. 455–466, 2006.

BORGES, J. A. R.; FOLETTO, L.; XAVIER, V. T. An interdisciplinary framework to study farmers' decisions on adoption of innovation: insights from expected utility theory and theory of planned behavior. **African Journal of Agricultural Research**, Nairobi, v. 10, n. 29, p. 2814–2825, 2015.

BRACKE, M. B. M. *et al*. Broiler welfare trade-off : a semi-quantitative welfare assessment for optimised welfare improvement based on an expert survey. **PLoS ONE**, San Francisco, v. 14, n. 10, [art.] e0222955, [p. 1–24], 2019.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento (MAPA). Secretaria de Política Agrícola. **Projeções do agronegócio:** Brasil 2019/20 a 2029/30: projeções de longo prazo. Brasília, DF: MAPA, 2020.

BROOM, D. M. **Animal welfare in the European Union**. Brussels: European Parliament Policy Department, Citizen's Rights and Constitutional Affairs, Study for the PETI Committee, 2017.

BROOM, D. M. Animal welfare: concepts and measurement. **Journal of Animal Science**, Champaign, v. 69, p. 4167–4175, 1991.

BUTTERWORTH, A. Effects of high stocking density on broiler chicken and turkeys. **CAB Reviews**, [Wallingford], v. 14, n. 39, p. 1–16, 2019.

CLARK, B. *et al.* A systematic review of public attitudes, perceptions and behaviours towards production diseases associated with farm animal welfare. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 29, n. 3, p. 455–478, 2016.

COLEMAN, G. J.; HEMSWORTH, P. H. Training to improve stockperson beliefs and behaviour towards livestock enhances welfare and productivity Stockperson characteristics affecting animal welfare. **Revue Scientifique et Technique de l'O.I.E**, Paris, v. 33, n. 1, p. 131–137, 2014.

CORKERY, G. *et al*. Incorporating smart sensing technologies into the poultry industry. **Journal of World's Poultry Research**, Erzurum, v. 3, n. 4, p. 106–128, 2013.

D´SOUZA, G.; CYPHERS, D.; PHIPPS, T. Factors affecting the adoption of sustainable agricultural practices. **Agricultural and Resource Economics Review**, Chicago, v. 22, n. 2, p.

159–165, 1993.

DAWKINS, M. S.; DONNELLY, C. A.; JONES, T. A. Chicken welfare is influenced more by housing conditions than by stocking density. **Nature**, London, v. 427, n. 6972, p. 342–344, 2004.

DOCKÈS, A. C.; KLING-EVEILLARD, F. Farmers' and advisers' representations of animals and animal welfare. **Livestock Science**, Amsterdam, v. 103, n. 3, p. 243–249, 2006.

DOZIER, W. A. III. *et al*. Stocking density effects on male broilers grown to 1.8 kilograms of body weight. **Poultry Science**, Champaign, v. 85, n. 2, p. 344–351, 2005.

FOGUESATTO, C. R.; MACHADO, J. A. D. What shapes farmers' perception of climate change? A case study of southern Brazil. **Environment, Development and Sustainability**, Dordrecht, v. 3, p. 1525-1538, 2021.

FONTANA, I. *et al*. Vocalisation sound pattern identification in young broiler chickens. **Animal**, Cambridge, v. 10, n. 9, p. 1567–1574, 2016.

FRASER, D. Assessing animal welfare at the farm and group level: the interplay of science and values. **Animal Welfare**, Hertsmere, v. 12, n. 4, p. 433–443, 2003.

FRASER, D. The globalisation of farm animal welfare. **Revue Scientifique et Technique de l'O.I.E**, Paris, v. 33, n. 1, p. 33–38, 2014.

GILOH, M.; SHINDER, D.; YAHAV, S. Skin surface temperature of broiler chickens is correlated to body core temperature and is indicative of their thermoregulatory status. **Poultry Science**, Champaign, v. 91, n. 1, p. 175–188, 2012.

GOCSIK, É. *et al*. Elicitation of preferences of Dutch broiler and pig farmers to support decision making on animal welfare. **Wageningen Journal of Life Sciences**, Wageningen, v. 76, p. 75–86, 2016.

GOLDBERG, A. M. Farm animal welfare and human health. **Current Environmental Health Reports**, [Switzerland], v. 3, n. 3, p. 313–321, 2016.

GOO, D. *et al*. Effect of stocking density and sex on growth performance , meat quality, and intestinal barrier function in broiler chickens. **Poultry Science**, Oxford, v. 98, p. 1153–1160, 2019.

HANSSON, H.; LAGERKVIST, C. J. Measuring farmers' attitudes to animal welfare and health. **British Food Journal**, Bradford, v. 114, n. 6, p. 840–852, 2012.

HARTUNG, J. *et al*. European farmers' experiences with precision livestock farming systems. **Animal Frontiers**, London, v. 7, n. 1, p. 38–44, 2017.

HUERTAS, S. M.; GALLO, C.; GALINDO, F. Drivers of animal welfare policy in the Americas. **Revue Scientifique et Technique de l'O.I.E**, Paris, v. 33, n. 1, p. 67–76, 2014.

JONGE, J.; VAN TRIJP, H. C. M. The impact of broiler production system practices on consumer perceptions of animal welfare. **Poultry Science**, Champaign, v. 92, n. 12, p. 3080–3095, 2013.

KARAARSLAN, S.; NAZLIGÜL, A. Effects of lighting, stocking density, and access to perches on leg health variables as welfare indicators in broiler chickens. **Livestock Science**, Amsterdam, v. 218, p. 31–36, 2018.

KJAERNES, U.; MIELE, M.; ROEX, J. **Attitudes of consumers, retailers and producers to farm animal welfare**. Cardiff: Cardiff University, School of City and Regional Planning, 2007.

MUSTAFA, M. Y. *et al*. Influence of stocking density on immune response of broilers against newcastle disease virus. **Pakistan Journal of Life and Social Science**, Faisalabad, v. 8, n. 1, p. 7–10, 2010.

MZOUGHI, N. Farmers adoption of integrated crop protection and organic farming: do moral and social concerns matter? **Ecological Economics**, Amsterdam, v. 70, n. 8, p. 1536–1545, 2011.

R CORE TEAM. **The R project for statistical computing**. [*S.l.*], 2021. Available at: https://www.r-project.org/. Accessed: 5 Jan. 2021.

RIOS, H. V. *et al*. How are information technologies addressing broiler welfare? A systematic review based on the Welfare Quality ® assessment. **Sustainability**, Basel v. 12, n. 1413, p. 1–34, 2020.

ROWE, E.; DAWKINS, M. S.; GEBHARDT-HENRICH, S. G. A systematic review of precision livestock farming in the poultry sector: is technology focussed on improving bird welfare? **Animals**, Basel, v. 9, n. 614, p. 1–18, 2019.

SCHWEAN-LARDNER, K. *et al*. Effect of day length on flock behavioural patterns and melatonin rhythms in broilers. **British Poultry Science**, Edinburgh, v. 55, n. 1, p. 21–30, 2014.

TE VELDE, H.; AARTS, N.; WOERKUM, C. V. A. N. Dealing with ambivalence: farmers' and consumers' perceptions of animal welfare in livestock breeding. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 15, p. 203–219, 2002.

THAXTON, Y. V. *et al*. Symposium: Animal welfare challenges for today and tomorrow. **Poultry Science**, Oxford, v. 95, n. 9, p. 2198–2207, 2016.

TSIOURIS, V. *et al*. High stocking density as a predisposing factor for necrotic enteritis in broiler chicks high stocking density as a predisposing factor for necrotic enteritis in broiler chicks. **Avian Pathology**, London, v. 44, n. 2, p. 59–66, 2015.

TUYTTENS, F. A. M. *et al*. Quantitative verification of the correspondence between the Welfare Quality ® operational de fi nition of farm animal welfare and the opinion of Flemish farmers , citizens and vegetarians. **Livestock Science**, Amsterdam, v. 131, n. 1, p. 108–114, 2010.

TUYTTENS, F. A. M. *et al*. Assessment of welfare of brazilian and belgian broiler flocks using the Welfare Quality protocol. **Poultry Science**, Oxford, v. 94, p. 1758–1766, 2015.

TUYTTENS, F.; VANHONACKER, F.; VERBEKE, W. Broiler production in Flanders, Belgium: current situation and producers' opinions about animal welfare. **World's Poultry Science Journal**, Ithaca, v. 70, n. 2, p. 343–354, 2014.

USDA – UNITED STATES DEPARTMENT OF AGRICULTURE. Foreign Agricultural Service. **Livestock and poultry:** world markets and trade. Washington, DC: USDA, 2021.

VANHONACKER, F. *et al*. Do citizens and farmers interpret the concept of farm animal welfare differently? **Livestock Science**, Amsterdam, v. 116, n. 1/3, p. 126–136, 2008.

VANHONACKER, F. *et al*. Societal concern related to stocking density, pen size and group size in farm animal production. **Livestock Science**, Amsterdam, v. 123, n. 1, p. 16–22, 2009.

VANHONACKER, F.; TUYTTENS, F. A. M.; VERBEKE, W. Belgian citizens' and broiler producers’ perceptions of broiler chicken welfare in Belgium versus Brazil. **Poultry Science**, Oxford, v. 95, p. 1555–1563, 2016.

WELFARE QUALITY ®. **Welfare Quality® assessment protocol for poultry (broilers, laying hens)**. Lelystad: Welfare Quality® Consortium, 2009.

YUNES, M. C.; VON KEYSERLINGK, M. A. G.; HÖTZEL, M. J. Brazilian citizens’ opinions and attitudes about farm animal production systems. **Animals**, Basel, v. 7, n. 10, p. 1–15, 2017.

CHAPTER 5

Factors influencing Brazilian broiler farmers' adoption of Precision Livestock Farming technologies

Abstract

Precision Livestock Farming technologies related to animal welfare (PLF-AW) is a promising opportunity to assist farmers on animal welfare improvements. However, little attention has been given to those who decide whether technology will be adopted or not: the farmers. As Brazil has an important role to supply the demand for poultry meat worldwide, the objectives of this study were: (i) to infer on PLF-AW technologies adoption by Brazilian broiler farmers analyzing factors that limit their adoption and (ii) to evaluate factors that influence their adoption of PLF-AW technologies. A survey was conducted in the Southern Brazil with 173 broiler farmers and their socioeconomic and productive characteristics were analyzed as well as their adoption and interest for adopting PLF-AW technologies. Farmers were also asked on their opinions on PLF-AW potentialities in improving animal welfare, farmer welfare, economic/productive indicators and data management. Descriptive analysis of the sample and logistic regression on the determinants for PLF-AW technologies were performed. Most of farmers (78.6%) have adopted at least a climate controller panel. The majors limiting factors for PLF-AW technologies adoption were regarding technology high prices, maintenance requirements and to possible financial consequences with technical problems. Broiler farmers with less experience, producing chicken griller, having another farm activity besides broiler production and presenting high beliefs on animal welfare improvements with the use of PLF-AW technologies were more likely to adopt such technologies. For future studies, we suggest analyzing the level of Brazilian broiler farmers knowledge on PLF technologies and to assess the influence of such technologies on animal welfare improvements.

Key words: Broiler producer, data-driven technology, information technology, poultry welfare, sensors

1. INTRODUCTION

A growing population and rapid urbanization seem to be major drivers for changes in animal production systems (THORNTON, 2010). While there are prospects for the world increasing demand for food, with meat consumption expected to grow by 11% until 2028, being poultry meat the most animal protein consumed (OECD/FAO, 2019), a lack of work force is observed in rural areas due to urbanization. As a result, farmers must raise more animals with less people, which can potentially jeopardize broiler welfare. The high intensively system of production has turned impossible to assist individuals in a house with thousands of broilers without the use appropriate technologies.

Urbanization has also modified the way people perceive animals (CLARK et al., 2016). Whereas, in rural areas, animals are goods that provide rural families income and a way of living, in cities, animals are a human company, demanding a life worth of living. These modifications have led to a social concern on farm animal welfare, with urban people requiring better conditions of living for farm animals (FRASER, 2003). According to McInerney (2004), animal welfare can be considered a common good, since rearing animals below minimum welfare standards can potentially impair humans´ wellbeing. As the goal number two of 2030 Agenda of the United Nations is the ending of hunger by producing food sustainably (UN, 2015), it can be stated that the respect with farm animal´s welfare is a question of sustainability (BROOM, 2010).

The challenge imposed to broiler farmers is how to attend society expectations on broiler welfare with labor force getting each time scarcer and food prices dropping constantly, diminishing product margins. A possible answer for this is the use of PLF technologies. In this regard, new technologies have been developed to assist broiler farmers and help them improve animal welfare, making broiler production more sustainable (RIOS et al., 2020; ROWE; DAWKINS; GEBHARDT-HENRICH, 2019; SASSI; AVERÓS; ESTEVEZ, 2016). Jukan, Masip-Bruin and Amla (2017) state that this technological movement involving the use of information technology can be labelled as the Fourth Industrial Revolution. Authors have already stressed out the importance of these novel technologies in several productive chains to attend the increasing global demand for food with minimum environmental and social impacts (BANHAZI et al., 2012a; BANHAZI; BLACK, 2009; BERCKMANS, 2014, 2017; PIVOTO et al., 2018).

The PLF technologies have been intensively researched and developed to improve animal management, welfare and productivity (ROWE; DAWKINS; GEBHARDT-HENRICH, 2019). These technologies have created a new universe of opportunities for animal production as they allow the measuring and processing a great volume of data in a level never seen before. One of their advantages is the possibility to monitor and control animals and their environment in an automatic and non-invasive way 24/7, providing farmers means to take better care of animals (BERCKMANS, 2017; WATHES et al., 2008). The PLF can automate daily tasks and continuously monitor animals 24/7, reducing laboring time and precisely detecting and analyzing traits of interest. Such technologies can potentially improve farming activities efficiently since the use of information and communication technology can be utilized for taking practical actions in an accurately way (BANHAZI et al., 2012a).

Nonetheless, there is a gap between PLF technologies development and the utilization of these tools by farmers. Whereas technologies are being studied and developed in great velocity, their adoption by farmers seems to happen in a much slower ratio (WATHES et al., 2008). Regarding this, little attention has been given to broiler farmers´ decision for PLF technologies adoption (BERCKMANS, 2017). It is important to keep in mind that farmers are those who take the decision to transform a potential increment on animal welfare in a real one, since they are in closest contact with animals, and therefore, they play a key role on broiler production sustainability.

To the best of our knowledge, no study has been published quantitatively analyzing factors that influence on broiler farmers adoption (or not) of PLF technologies so far. Hartung et al. (2017) assessed the opinions of European farmers on PLF technologies, conducting a research with broiler, pig and dairy farmers; however, they utilized a qualitative approach, interviewing farmers about their experiences with PLF technologies. Moreover, Brazil is the third greatest producer and greatest exporter of poultry meat, being responsible for approximately 14% of the total poultry meat consumed in the world (USDA, 2021). Therefore, analyzing Brazilian broiler farmers' adoption of PLF technologies is of great relevance since they represent a huge market for PLF technologies, besides being responsible for the welfare of a great number of broiler chickens.

According to Souza Filho et al. (2011) there are basically four groups of variables involved with the adoption and diffusion of technologies, namely: socioeconomic, production characteristics, technology characteristics and systemic factors. In the present study, it is aimed to stress out mainly the technology characteristics as a factor for PLF related to animal welfare (PLF-AW) technologies adoption; not disregarding the other variables, however, approaching them with less attention. It is justified because the main intention of this research was to evaluate which characteristics of PLF-AW technologies can influence on broiler farmers adoption and provide information to academia, technology developers and integrators on which kind of technologies should be fostered to increase broiler farmers engagement to technologies related to animal welfare. The choice for PLF-AW technologies is because the societal concern on animal welfare is a major driver pushing to modifications in farm animals´ production practices (ALONSO; GONZÁLEZ-MONTAÑA; LOMILLOS, 2020; BRACKE et al., 2019; BROOM, 2017; JONGE; VAN TRIJP, 2013; MOLNÁR; FRASER, 2020; NIELSEN; ZHAO, 2012; SØRENSEN; FRASER, 2010).

Farmers´ uncertainties are relatively high regarding broiler production as this activity presents several risks that can easily impair animals´ productive performance and reduce farmers´ profits (HARTUNG et al., 2017; SIMÕES et al., 2015). Unexpected issues such as animal diseases, equipment malfunctioning, electric outages and even commercial barriers can negatively affect farmers' income. Thus, it is comprehensive for farmers to present some barriers to innovation and not to expend money in tools they do not fully understand. Despite all potentialities PLF technologies may present, if anything goes wrong with that, farmers will probably be the ones to bear the greatest income loss, since they are the main risk-takers (WATHES et al., 2008).

It is essential to mention that PLF-AW technologies are not restricted to animal welfare improvements only. In fact, they can serve for several purposes. Some of the potentialities of such technologies include: (i) improving animal welfare level by continuously monitoring animals´ behavior and environment; (ii) improving farmers´ welfare by automating routine activities; (iii) improving data management, collecting and analyzing a great volume of data, and translating them into useful information; and (iv) improving productive and economic results, through better controlling health status (BERCKMANS, 2017; HARTUNG et al., 2017; WATHES et al., 2008).

Despite all potentialities PLF-AW technologies can present, they must offer some clear added value in farmers´ point of view to be adopted. Thus, the question emerging from this was: do broiler farmers perceive these potentialities and are they important for the adoption of PLF technologies? If such technologies are claimed to be the future of food production, understanding factors that influence the decision-making process of broiler farmers related to the adoption of technologies is imperative. Therefore, the objectives of the present research were two-fold: (i) to infer on PLF-AW technologies adoption by Brazilian broiler farmers and analyze factors that limit their adoption and (ii) to quantitatively evaluate factors that influence the adoption of PLF-AW technologies by broiler farmers. The present study used an econometric model (logistic regression) to estimate the influence socioeconomic and productive data as well as the influence of Brazilian broiler farmers' opinions about technology potentialities on the likelihood of their adoption of PLF-AW technologies.

2. MATERIAL AND METHODS

2.1 DATA COLLECTION AND SAMPLE ANALYSIS

To infer quantitatively on how socioeconomic and productive factors as well the PLF-AW technologies potentialities are related to farmers adoption of such technologies, a survey was conducted with Southern Brazilian broiler farmers. The Southern region of Brazil corresponds to federal states of Paraná, Santa Catarina and Rio Grande do Sul, which are the greatest producers of poultry meat in the country. Paraná was responsible for 36.7% of total Brazilian production of poultry meat in 2019, Santa Catarina for 15.4% and Rio Grande do Sul for 14.3% (ABPA, 2020). Thus, broiler farming is an important socioeconomic activity in the region.

A pretest was applied to 11 broiler farmers before the survey. Questions of the prequestionnaire were defined based on pieces of past researches and from discussions with 13 experts in broiler production and/or economics. By broiler farmers' feedbacks, adjustments were made in order to properly address the variables of interest. The final version of the questionnaire was applied to broiler farmers with the help of two local industries. Farmers could answer the questionnaire online or in paper format. In total, 204 questionnaires were collected, being 31 disregarded due to incomplete answers, totalizing 173 respondents. The sample was chosen by convenience and data were collected through a questionnaire applied between September and December of 2020. Before answering the questionnaire, broiler farmers had to explicitly inform that they were participating of the research voluntarily.

The final questionnaire consisted of three sections. In part 1, farmers were asked about their socioeconomic and productive characteristics. Such questions were based on pieces of previous researches and from studies of Foguesatto and Machado (2021), Pierpaoli et al. (2013), Pivoto et al. (2019) and Souza Filho et al. (2011). Questions included information on broiler farmers´ age, income and educational level as well as regarding the number of broiler houses in the property, number of farm workers (including family members), broilers´ age of slaughter, for how long they have been farming broiler, for how long they wish to keep farming broilers and if they have another rural activity focused on product commercialization.

In part 2, farmers were presented to pictures of five different technologies that can be related to animal welfare and asked about which technology(ies) they have already adopted and which they wish to adopt. Because PLF technologies comprehend a vast group of technologies, in the questionnaire, only pictures of a digital camera, an infrared camera, a climate controller, an automatic weighing system and an IoT technology were showed to farmers. These technologies were defined based on the review of Rios et al. (2020) and by conversations with industry managers and broiler farmers, as the objective was to define technologies that broiler farmers are acquainted to. It is important to mention that the use of digital camera and/or infrared camera does not necessarily mean that a PLF technology is being used, since it required a more robust system that implies the use of algorithms coupled with such sensors; however, the use of cameras in broiler houses is interpreted as, at least, a first step for the utilization of PLF technology and, in that way, it was considered important to be evaluated in the present study.

In part 3, farmers were asked on the potentialities and barriers for the adoption of the PLF-AW technologies presented to them in part two. Variables regarding farmers´ beliefs on technology potentialities and barriers for technology adoption were based on the studies of Hartung et al. (2017) as well as on studies of Berckmans (2017), Pivoto et al. (2019), Rios et al. (2020) and Wathes (2007). According to Foguesato, Borges and Machado (2020), when studying latent variables, as farmer beliefs, in econometric models it is advisable to use a set of questions, since a unique statement is not the ideal approach to take. In the present study, we used three statements to evaluate each one of the following factors related to PLF technologies potentialities: farmer welfare, animal welfare, economic and management. Farmers had to express their level of agreement with the three statements in a Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree) being the score of such factors calculated as the average of the three questions that compound each one of them. Cronbach's Alpha was used to assess the reliability of these variables. Similarly, barriers for technology adoption were also evaluated and classified in six groups, namely: complexity, insecurity, economic, information, interest, and technical/infrastructure. Regarding to this, farmers were also asked to express their level of agreement in a five-point-Likert scale (1 for strongly disagree and 5 for strongly agree) for 18 questions involving the barriers for PLF-AW technology adoption (three for each barrier group). The group score was calculated as the average score of the three statements. The full questionnaire can be visualized in Appendix 1.

2.2 STATISTICAL ANALYSIS

Data were analyzed by descriptive statistics and logistic regression model using R Programming Language (R CORE TEAM, 2021). To estimate on how socioeconomic, productive and technology potentialities influence broiler farmers adoption of PLF technologies, a logistic regression was used. This regression model was chosen among others due to its relative mathematical simplicity and power to provide significant results (TESFAHUNEGN; MEKONEN; TEKLE, 2016). Logistic models were already utilized to define how factors influence on the adoption/non-adoption of innovations by other studies. By the sake of examples, Pivoto et al. (2019) utilized it to infer on the factors that influence grain farmers adoption of Smart Farming technologies; Carrer, Souza Filho and Batalha (2017) to estimate the factors that influence the adoption of Farm Management Information Systems by citrus farmers; and Mariano, Villano and

Fleming (2012) to analyze the factors that influence the adoption of rice technologies and management practices by Philippines farmers.

In the logistic regression model, the dependent variable is binary. In the present study, the dependent variable is the adoption/non adoption of a technology, which is represented by a dummy variable (0 for non-adoption; 1 for adoption). The model represents the relationship between this dichotomous variable and explanatory variables which can be binary, continuous, discrete or in scales (Table 1). The regression logistic formula of the present study is given by:

$$\ln [P/1 - P] = \beta 0 + \beta 1X1 + \beta 2X2 + \cdots \beta kXk \, , \quad (1)$$

The result of $P/(1 - P)$ is the odds (likelihoods) ratio, being P the probability for broiler farmers adoption of PLF-AW technologies, and $1 - P$ the probability they do not adopt PLF-AW technologies. In the present study, we considered that farmers adopted PLF technologies if they have adopted at least one of the technologies listed in the questionnaire (digital camera, infrared camera, climate controller panel, automatic weighing system and IoT). The intercept is β0; β1, β2,… βk are regression coefficients of the explanatory variables X1, X2,... Xk (socioeconomic, productive and technology potentialities variables). Odds ratio value greater than 1 means a positive relationship between the dependent and the independent variable since the likelihood of the independent variable effect on the dependent variable is increased. On the contrary, odds ratio value lower than 1 indicates negative relationship, whereas odds ratio value of one indicates no relationship (FIELD, 2013). To evaluate the goodness of fit of the logistic regression model, the McFadden Pseudo R^2 was calculated (MCFADDEN, 1977). Correlation analysis of the independent variables was performed before running the logistic model (Appendix 2).

Table 1. Description of explanatory variables on broiler farmers´ adoption of PLF-AW technologies.

Variable	Type¹	Description
Age	C	Age of broiler farmer (years).
Experience	C	Experience on broiler farming (years).
Expected time on keeping producing broilers	O	For how long farmers expect to keep farming broilers. Values ranging from 0 to 4: (0) less than 5 years; (1) next 5 years; (2) 10 years; (3) 15 years; (4) more than 15 years.
Income	C	Monthly total income (R$).
Broiler income/total income	O	How much broiler farming income represents on total income of the property, ranging from 1 to 4: (1) until 25%; (2) 26 to 50%; (3) 51 to 75%; (4) more than 75%.
Another farm activity (for commercialization)	D	If the farmer has another farm activity with commercialization purposes. 1 for NO and 2 for YES.
Workforce	O	Number of persons working in the property (members of family + hired employees
Educational level	O	Values ranging from 1 to 5: (1) elementary school uncompleted; (2) elementary school completed; (3) high school; (4) under graduation; and (5) post-graduation.
Broiler houses	O	Number of broiler houses in the property.
Slaughter weight	D	1 for griller and 2 for heavy broilers.
Farmer welfare	L	All technology potentialities were measured through a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Each technology potentiality is the average score across three statements.
Animal welfare	L	
Economic/productive	L	
Management	L	

No multicollinearity was observed among the explanatory variables (Appendix 3).
¹ C = continuous variable, O = discrete variable, D = dummy variable, L = Likert scale

3 RESULTS

3.1 SAMPLE DESCRIPTIVE ANALYSIS

The descriptive analysis of sample is in Table 2. Regarding workforce, 78.6% of the broiler farm laboring was restricted to family members, while 21.4% presented 1 or more hired employees. When analyzed broiler farmers´ educational level, 48.0% of the sample attended or completed primary school, 36.4% attended or completed high school, 12.1% attended or completed undergraduate courses and 3.5% attended or completed postgraduate studies. When analyzed the expected time broiler farmers´ intend to keep farming broiler chickens, 7.5% affirmed that they intend to stop it in less than 5 years, 15.6% stated that they intend to keep it for more 5 years, 23.1% that they intend to keep it for more 10 years, 17.3% that they intend to keep it for more 15 years, and 36.4% that they intend to keep faming broilers for more than 15 years. In concern to how much the broiler farming activity income represents of the total property income, 21.4% of the broiler farmers stated that it represented less than 25%, 25.4% that it represented between 25 and 50%, 27.2% that it represented between 51 and 75% and 26.0% that it represented more than 75% of total property income.

Broiler farmers´ beliefs on PLF technologies potentialities were measured using a five-point Likert scale. The PLF potentialities regarding animal welfare presented the highest score, followed by farmer welfare, management and economic, respectively. Cronbach´s alpha coefficients were calculated for each technology potentiality, being all values considered adequate (between 0.7 and 0.9).

Table 2. Descriptive analysis of the sample (n=173).

Item	Mean	SD	Min	Max	Cronbach´s alpha
Age	43.95	11.33	18	68	
Experience	13.98	9.40	1	40	
Expected time on keeping producing broilers	2.60	1.32	0	4	
Monthly income (USD)[1]	2229	2304	273	14545	
Broiler income / total income	2.58	1.09	1	4	
Another farm activity	1.77	0.42	1	2	
Workforce	1.71	1.51	1	11	
Educational level	2.50	1.06	1	5	
Broiler houses	4.32	1.02	1	8	
Slaughter age	1.61	0.49	1	2	
Farmer welfare	4.24	0.90	1.3	5	0.74
Animal welfare	4.39	0.90	1	5	0.86
Economic	4.01	0.99	1	5	0.76
Management	4.19	0.92	1	5	0.78

[1] Brazilian reais (BRL) converted to American dollars (USD) using dollar ptax of March 23rd of 2021 as basis.

Broiler farmers´ adoption of PLF technologies as well as their interest in adopting them are shown in Table 3. It is important to mention that the sum of the frequencies can be higher than 100%, because a single farmer can adopt or be interested in adopting more than one technology. When analyzed information on adopters, the climate controller panel was the most adopted technology, being adopted by 78.6% of broiler farmers´ surveyed, distantly followed by IoT (7.5%), digital camera (5.8%), automatic weighing scale (4.6%) and infrared camera (2.9%). For the logistic regression model estimation, farmers were considered adopters if they have adopted at least one PLF technology. Regarding broiler farmers´ interest in adopting PLF technologies, higher frequency was observed for digital camera (46.8%), followed by IoT (45.1%), automatic weighing scale (41.0%), infrared camera (34.7%) and climate controller panel (12.7%). The low frequency of farmers' interest in adopting the climate controller panel is probably because most of them had already adopted this technology.

Table 3. Broiler farmers´ frequencies of adoption and interest of adopting PLF technologies.

Technology	Adopters		Interest in adopting	
	Frequency, %	n	Frequency, %	n
Digital camera	5.8	10	46.8	81
Infrared camera	2.9	5	34.7	60
Climate controller panel	78.6	136	12.7	22
Automatic weighing scale	4.6	8	41.0	71
IoT	7.5	13	45.1	78

3.2 RESULTS ON THE BARRIERS FOR BROILER FARMERS ADOPTION OF PLF-AW TECHNOLOGIES

Results for the barriers for PLF-AW technologies adoption are presented in Table 4. Broiler farmers expressed their level of agreement with different statements in a five-point Likert scale (1 for strongly disagree and 5 to strongly agree). Such statements were grouped three by three according to their nature to form six groups: complexity, insecurity, economic, lack of information, lack of interest and technical/infrastructure. In general, broiler farmers allocated low scores for all barriers related to technology adoption. The highest score was observed for economic (3.19), followed by technical/infrastructure (2.46), complexity (2.45), lack of information (2.28), insecurity (2.23) and lack of interest (1.79). Broiler farmers´ scored values higher than 3 (which is the medium score) for three sentences only: the one about the high prices of such technologies (3.80), on having financial consequences if something goes wrong with such technologies (3.29) and about maintenance requirements (3.24). Only statements regarding lack of interest were scored lower than 2, indicating that farmers are interest in PLF-AW technologies.

3.3 RESULTS ON THE LOGISTIC REGRESSION MODEL

In Table 5, there are findings obtained by the logistic regression model on the determinants of PLF-AW adoption. The model significantly explained the influences of the explanatory variables in the binary variable behavior ($p<0.001$) and the McFadden pseudo-R^2 indicates a fine adjustment of the model (0.259). From the 14 explanatory variables in the model, four of them were significant: experience, product, another farm activity and animal welfare. The other 10 explanatory variables did not influence the likelihood of PLF-AW technology(ies) adoption by broiler farmers. Experience presented a significant negative coefficient, which indicates that more experience represents a negative effect on PLF-AW adoption. Similarly, the slaughter age of the animals also presented a significant negative effect on PLF-AW adoption. Slaughter age is a dummy variable (1 for griller and 2 for heavy broilers), indicating that broiler farmers who produce grillers presents more chances to adopt PLF-AW technologies over those who produce heavier broilers.

Table 4. Barriers for broiler farmers adoption of PLF-AW technologies (n=172)[1]

	Barriers	Score[2]	SD	Mean score
Complexity	Difficulty to use, non-practical	2.46	1.52	2.45
	Difficulty to learn	2.02	1.35	
	Lack of qualified labor	2.87	1.63	
Insecurity	Data insecurity	2.07	1.39	2.23
	Fear of not knowing how to use it	2.25	1.50	
	Neighbors/friends negative opinions	2.37	1.46	
Economic	Too expensive (prices are too high)	3.80	1.37	3.19
	Do not increase income	2.47	1.39	
	Financial consequences if something goes wrong	3.29	1.54	
Lack of information	Ignore these technologies	2.27	1.34	2.28
	Lack of information	2.34	1.35	
	Do not know how to use them	2.24	1.37	
Lack of interest	Change routine activities	1.83	1.34	1.79
	Do not assist on matters of interest	1.81	1.32	
	No advantage(s) with their use	1.73	1.25	
Technical/Infrastructure	Poor internet connection	2.02	1.42	2.46
	Mains instability (power failures)	2.12	1.46	
	Maintenance requirements	3.24	1.47	

[1] One of the respondents did not answer to subsection of the questionnaire.
[2] Scores on a five-point Likert scale, being 1 for strongly disagree and 5 for strongly agree.

Having other activity in the farm for commercialization purposes, besides broiler chickens´ farming, positively influences the adoption of PLF-AW technology(ies), increasing the likelihood of PLF-AW technology(ies) adoption by 4.2 times over those who produce broiler chickens only. Similarly, broiler farmers beliefs on PLF-AW technology(ies) potentialities regarding animal welfare positively influence the likelihood for technology adoption. In this case, 1 additional point in the Likert scale for animal welfare represents 2.4 times more chances of adopting PLF-AW technology(ies).

Table 5. Coefficient estimates of the logistic model on the determinants for PLF-AW adoption

Explanatory variables	Coefficient (β)	S.E.	Sig.	Exp (β)
Intercept	-1.112	2.584	0.667	0.329
Age	0.017	0.022	0.453	1.017
Experience	-0.083	0.028	0.004**	0.921
Farmers´ expectation on keeping producing broilers	0.147	0.209	0.482	1.158
Income	0.001	0.001	0.918	1.000
Broiler income/total income	0.115	0.250	0.644	1.122
Another farm activity (for commercialization)	1.425	0.598	0.017*	4.156
Workforce	-0.168	0.190	0.376	0.845
Educational level	0.138	0.232	0.553	1.148
Broiler houses	0.063	0.254	0.805	1.065
Slaughter age (product)	-2.178	0.648	>0.001**	0.113
Farmer welfare	0.341	0.339	0.315	1.407
Animal welfare	0.877	0.391	0.025*	2.403
Economic	0.151	0.402	0.708	1.163
Management	-0.496	0.408	0.223	0.601
Mcfadden R^2	0.259			
P-Chisquare	>0.001			

Significant levels at: 5%* and 1%**.

4. DISCUSSION

The present study aimed to investigate the frequency of PLF-AW technologies adoption by broiler farmers and to analyze determinants and barriers for such technologies´ adoption. By the application of a questionnaire, information were obtained about socioeconomic and productive characteristics as well as about broiler farmers´ utilization of PLF-AW technologies and their opinions regarding such technologies´ potentialities and on barriers for their adoption. To define the influence of the explanatory variables on the broiler farmers´ adoption of PLF-AW technologies, first, it was necessary to infer on whether these technologies were utilized or not and then use this information as the dependent variable for the logistic regression model. Additionally, possible barriers for technology adoption were measured through a five-point Likert scale, which involved statements on technology complexity, farmers insecurity about PLF utilization, economic aspects regarding PLF utilization, lack of information on technologies, lack of interest in technologies and related to technical/infrastructure issues.

Most adopters use the climate controller panel only and do not adopt other PLF technologies. Climate controller panel is a relatively well-known technology to Brazilian broiler farmers and, at some degree, already widely spread among farmers; whereas PLF technologies that use cameras or IoT, for example, are relatively novel technologies. Nonetheless, broiler farmers´ interest in adopting image technologies is a remarkable finding. According to our results, 46.8% of broiler farmers were interested in adopting digital camera and 37.4% in adopting an infrared camera. Such findings are in line with the results of Rios et al. (2020), who observed that image technologies were the most studied information technology attending broiler welfare. In this regard, it is comprehensive that non-wearable sensors are especially relevant of indoor farming (JUKAN; MASIP-BRUIN; AMLA, 2017). By using non-wearable sensors, such as digital and infrared cameras, it is possible to infer on different broiler welfare aspects, since through the analysis of animals´ behavior and thermal conditions it is possible to have insights on broilers´ health, physiological and cognitive states (SASSI; AVERÓS; ESTEVEZ, 2016).

A relatively high percentage of farmers were interested in adopting PLF-AW technologies, even when they have already adopted one. According to Kassie et al. (2013), the adoption of new technologies can be closely related to farmers´ previous experiences with other technologies. Analyzing the determinants of adoption of sustainable agriculture practices by Tanzanian agriculture farmers, these authors suggested that the adoption of technologies may have a path dependence and that farmers make their decision for innovation adoption taking in consideration a set of innovations and choosing which of them will maximize their utility.

Regarding barriers for PLF-AW technology(ies) adoption, the present findings suggest that the economic aspect is the major limiting factor influencing broiler farmers´ adoption of such technologies. Analyzing determinants and barriers involved with the adoption of smart farming technologies by grain producers in southern Brazil, Pivoto et al. (2019) also found that high technology prices were a major limiting factor expressed by farmers for the adoption of such technologies. In a study evaluating the experience of broiler, swine and dairy farmers with PLF technologies, Hartung et al. (2017) observed that livestock farmers were not willing to improve animal welfare if no economic return would came from this, although farmers judged animal welfare as an important factor of production. The investment on technologies can represent a fragility when analyzed under the perspective of market fluctuations (SOUZA FILHO et al., 2011). In a scenario of restriction and uncertainties imposed by the Covid-19 pandemic, as the one faced during the questionnaire application, it is possible that our results reflect the farmers´ economic concern on technology investments.

Scores for other barriers for PLF-AW technology(ies) adoption were relatively low, except for maintenance requirements. All other statements were scored values below 3, being the least scored those in the group “lack of interest”, indicating that broiler farmers do believe that PLF technologies can be useful tools to attend their purposes. These findings suggest that farmers do not believe that most of the barriers evaluated were important hindrances for technology adoption. Perhaps, because PLF technologies are relatively novel tools it is possible that farmers do not fully understand their characteristics (except those of climate controller panel) and have not perceived such barriers as relevant for the adoption of such technologies. Another possibility is that broiler farmers underscored these limiting factors overestimating their ability to handle PLF-AW technologies. Moreover, it cannot be disregarded the possibility that the statements used to address these barriers were not adequate phrased to properly capture this information.

When analyzing the logistic regression model, four out of 14 explanatory variables significantly influenced the likelihood of farmers adoption of PLF-AW technology(ies), namely: experience, product, another farm activity and animal welfare. Although not significantly influencing the likelihood of broiler farmers´ adoption of technologies, the other explanatory variables were important to increase the reliability of the model.

In the present research, no influence of age on the farmers´ likelihood for adopting technologies were observed. Effects of age on the likelihood for technology adoption can be ambiguous (BORGES; FOLETTO; XAVIER, 2015). There is an evidence that young farmers are more willing to adopt technologies because the risk aversion tend to be higher for elderly people; however, it can be also argued that older farmers have more experience and can assess technology characteristics in a better way (ADESINA; BAIDU-FORSON, 1995). The decision for an innovation adoption is related to farmers objectives and goals, which can vary in time (BORGES; FOLETTO; XAVIER, 2015). For instance, an elder farmer may give more importance to increase their leisure time and spend more time with their family, whereas young farmers may pursue higher profits. By this example, elderly farmers will be more willing to adopt a given technology that can automate processes, whilst the younger will focus more attention on technologies that can reduce costs or improve growth performance. Even though we believe that this is a valuable area of study, the present research did not intend to approach it, being a suggestion for future studies.

A negative influence on the likelihood for technology adoption was observed for farmers' years of experience in broiler farming. On the contrary, years of experience was suggested by Adesina and Zinnah (1993) to positively influence the adoption of technologies by rice farmers as more years will provide them better abilities to obtain, process, and use information relevant to the grain cultivation; however, the same authors did not find any influence of years of experience in their model. A possible explanation for our findings is that broiler farmers with more years of experience may be more reluctant to change their current *modus operandi*, presenting higher aversion to adopt technologies than less experienced farmers; however, this hypothesis was not evaluated in the present study.

Although expected to positively influence the adoption of PLF-AW technologies, farmers´ expectation on keep producing broiler in the next years did not have any significant effect in our model. A possible explanation of our findings is that there are much more variables involved with farmers contentment with broiler production than those related to technology adoption only. Additionally, the year when the questionnaire was applied was an atypical year due to the Covid-19 pandemic and uncertainties on investments and on the willing for keeping producing broilers may have been affected. However, such finding should be better explored by future studies as most studies in the literature have already emphasized the important role of PLF technologies in the future of livestock production (BANHAZI et al., 2012a, 2012b; BERCKMANS, 2014, 2017; RIOS et al., 2020; ROWE; DAWKINS; GEBHARDT-HENRICH, 2019; WATHES et al., 2008).

No influence of farmers´ income and of broiler/total income on the likelihood for PLF-AW technology adoption was observed. In this regard, it was expected that higher income or higher contribution of broiler production on the total farmer income would increase the likelihood for PLF-AW adoption as farmers would have more capacity for investments and/or would allocate greater importance to broiler production. Studying dairy farmers attitudes towards animal welfare, Hansson and Lagerkvist (2012) observed that full-time farmers were less willing to adopt improvements on animal welfare than part-time farmers, which could be explained by the excessive economic pressure full-time farmers may experience. In our findings, however, we observed that having another farm activity for commercialization purposes positively and significantly influenced the likelihood for technology adoption. The fact that PLF-AW technologies enable the automatization of processes is a possible explanation for our findings, as with their use, broiler farmers´ would have more time to dedicate to other activities. Thus, it is likely that the effect of having another farm activity on the adoption of technologies depends on the technology characteristics.

The number of persons working in the property was expected to have a negative influence on the likelihood for PLF-AW technologies adoption, as having more people working would decrease the necessity of technologies for monitoring animals. However, in our findings no significant influence was observed. In this regard, Hartung et al. (2017) observed that livestock farmers did not believe that PLF technology could replace "the eyes of the farmer" in their routine activities. It was expected a positive influence on the likelihood for PLF-AW technology(ies) adoption in concern to educational level as the complexity of PLF technologies can be high (VAN HERTEM et al., 2017) and higher education level would mitigate the issues of technology complexity. Nevertheless, no influence was observed for this explanatory variable on farmers' adoption of PLF-AW technologies, which can be explained by the relatively low score observed in the present research for technology complexity as a barrier for PLF-AW adoption.

Our findings suggest that there is no influence of the number of broiler houses on the likelihood for PLF-AW technologies adoption. Nevertheless, in a study assessing the level of technology adoption by broiler farmers, Ithika et al. (2013), observed a positive correlation between production size and the use of technologies. Regarding this, Souza Filho et al. (2011) state that small farmers present higher risk aversion than bigger ones, especially when their present living costs depend on the current production results. Age of slaughter negative influence on the likelihood of PLF-AW adoption probably because of the higher densities utilized in griller production. PLF technologies enables the monitoring of animals in much better way than farmers natural sensors (BERCKMANS, 2017) and their advantages may be better perceived by broiler farmers who house more birds per square meter. In addition to that, it is possible that marginal benefits provided by technology will be higher for farmers who have more birds housed and this can justify the technology investment.

Concerning to the influence of broiler farmers´ opinions on potentialities of PLF technologies over the likelihood for technology adoption it was expected that all four potentialities evaluated would have a positive effect in our model, notwithstanding only animal welfare presented a positive significant effect. Such findings suggest that opinions about animal welfare may play a more important role on farmers decisions for welfare improvements than farmers have expressed in previous studies (ALBERNAZ-GONÇALVES; OLMOS; HÖTZEL, 2021; TUYTTENS; VANHONACKER; VERBEKE, 2014; VANHONACKER; TUYTTENS; VERBEKE, 2016). A possible explanation for the farmers´ unwillingness of engagement on better welfare practices observed by such studies may be because farmers believe that animal welfare improvements imply in returning to more traditional ways of farming (TE VELDE; AARTS; WOERKUM, 2002). However, in the present case, PLF-AW technologies are means of improving animal welfare whilst modernizing production management, which can explain our findings.

The benefits and costs evaluated by the farmers when deciding for the adoption of a technology may be not restricted to economics, although there is evidence that livestock farmers are seeking for higher profits, less working hours and better data management (HARTUNG et al., 2017). According to Borges, Foletto and Xavier (2015), farmers balance the positive and negative outcomes of their behavioral changing when deciding for adopting a new practice related to farming animals. The same authors stated that social pressure can play an important role on that, since individuals may shape their behavior based in a reference group. In accordance with that, Mzoughi (2011) observed that French fruit and vegetables farmers that were more concern to societal impressions or feeling guilty about traditional farming were more willing to adopt an organic system. Bringing it to our context, as animal welfare is a societal concern, it is possible that farmers do not want to be pictured as someone who is not concerned to the subject and that their opinions on animal welfare can play an important role for their adoption of PLF-AW technologies.

Moreover, farmers´ decision for improving animal welfare level and/or adopting technologies related to it can occur to the extend they feel their utility is affected by these improvements or because of indirectly aspects such as altruistic concern about other persons´ behavior or about the animals themselves (HANSSON; LAGERKVIST, 2012). Several authors have argued that there is a social cost attributed to rearing animals below the level of welfare acceptable by society (ANOMALY, 2014; BROOM, 2010; MCINERNEY, 2004). A so called “license to produce” is of great importance for livestock farmers as observed by Te Velde, Aarts and Woerkum (2002), who define such license as farmers´ search for legitimacy within society for the way they work. In this context, rearing broilers in conformity with the level of welfare demanded by society (or even by the farmer themselves) will avoid such costs and make the activity more socially sustainable which can explain the results observed in our model.

It must be kept in mind that the results observed by the present research are restricted to this data collection and any kind of results generalization must be done with caution. The present study has some limitations that must be taken in account for. For instance, we stress out that: broiler farmers of only two distinct broiler companies were assessed by the survey, broiler farmers were from three different federal states of Brazil only and the sample was chosen by convenience; thus, the results may not be representative even from the Brazilian Southern region. Moreover, it is not disregarded the fact that the Covid-19 pandemic and the recent truck drivers´ strike occurred in Brazil have influenced broiler farmers´ responses, especially about their interest in adopting PLF technologies and their opinions on the PLF potentialities and barriers for adoption. Furthermore, the model results can be widely different if other explanatory variables and/or PLF technologies are analyzed. Nonetheless, in the present research, it was tried to mitigate all these limitations by strictly following the methodology procedures, and we understand that the results observed are reliable for the analyzed sample.

5. FINAL CONSIDERATIONS

Most of broiler farmers have adopted climate controller panel, whilst great interest in image technologies adoption were observed. In general, farmers allocated low scores for the barriers related to PLF adoption, except for those related to economic issues and to technology maintenance requirements. Less experienced chicken griller farmers that have other farm activities and that believed on the potentialities of PLF-AW in improving broiler welfare were more likely to adopt PLF-AW technologies.

Results suggest that animal welfare is an important factor influencing the likelihood of PLF-AW technology(ies) adoption. This is an alarming finding since farmers are often judged as not caring on animal welfare in the same way as consumers. Such results indicate that farmers are concern to broiler welfare and willing to take actions for improving animals´ conditions of living. Contrary to our initial assumption, farmers opinions on economic, management and farmer welfare benefits with the adoption of PLF-AW technologies did not influence farmers´ likelihood for technology adoption. It is possible that broiler farmers do not fully understand the potentialities of such technologies as most of them are not commercially available or are relatively new in the market. However, this was not assessed in the present research, being the subject recommended for future studies.

The simple fact of adopting PLF technologies related to broiler welfare does not guarantee that the animal´s living condition will be enhanced. The PLF technologies are tools for farmers and their potentialities can only be achieved if farmers use them properly. In the core, PLF technologies are getting data from a limited number of variables and transferring them into a mathematical model for controlling and monitoring specific traits of interest. It is the farmer´s role to interpret and take decisions based on this information. Thus, for future studies it is suggested to evaluate the level of broiler welfare where PLF technologies were adopted and compare it with the welfare level of broilers reared with less technology.

APPENDIX 1 – Questionnaire

Part 1

1. General characteristics (socioeconomic and productive data)

1.1 Age:

1.2 Years of experience in broiler farming:

1.3 For how long do you intend to keep producing broilers?

( ) Stop it in less than 5 years

( ) Keep it for 5 years

( ) Keep it for 10 years

( ) Keep it for 15 years

( ) Keep it for more than 15 years

1.4 Monthly income (R$):

1.5 How much broiler income represents of total income?

( ) Less than 25% ( ) 26 e 50% ( ) 51 e 75% ( ) more than 75%

1.6 Do you have another farm activity for commercialization purposes, besides producing broilers? ( ) yes ( )

1.7 How many persons work in the property (including family members)?

1.8 Level of education:

( ) Elementary school uncompleted

( ) Elementary school completed

( ) High school

( ) Under graduation

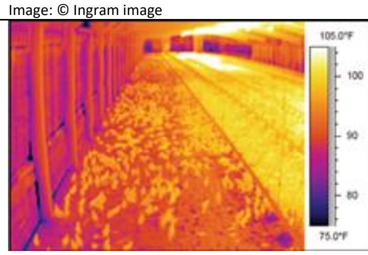
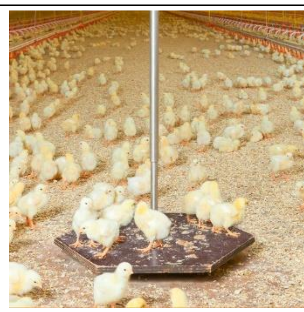
( ) Post-graduation

1.9 How many broiler houses do you own?

1.10 Slaughter weight:

Part 2

Mark an X on the Technologies do you use OR wish to adopt

Technology	Illustration	I use this technology	I want to adopt this technology
Digital camera	 Image: © Ingram image		
Infrared camera	 Image: BigHerdsman		
Climate controller panel	 Image: Plasson		
Automatic weighing system	 Image: BigDutchman		
IoT	 Image: BigDutchman		

Part 3

3.1 Having in mind the Technologies listed in Part 2, please mark according to your opinion (1 = strongly disagree, 2 =disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

Item/Score	1	2	3	4	5
Using technologies can reduce my workload					
Using technologies can increase my spare time					
Using technologies can make routine activities more					
Using technologies can improve animal welfare					
Using technologies improve control over animal welfare					
Using technologies make animals more comfortable					
Using technologies can increase my income					
Using technologies help with detecting problems earlier					
Using technologies can improve broiler performance					
Using Technologies improve control over flock performance					
Using Technologies provide more information on productive					
Technologies assist on handling with so many information and data					

3.3 Having in mind the Technologies listed in Part 2, please mark according to your opinion on the limiting factors for such technologies adoption (1 = strongly disagree, 2 =disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

Item/Score	1	2	3	4	5
It is difficult to use technologies (non-practical)					
It is difficult to learn how to use them					
I have no qualified labor to work with technologies					
I am afraid that data will be explored without my					
I am afraid of not knowing how to use them					
My neighbors/friends have negative opinions about these					
They are too expensive (prices are to high)					
They do not increase my income					
I will face financial consequences, if something goes wrong					
I do not know these technologies					
I do not have enough information about these technologies					
I do not know how to use these technologies					
Using these technologies will change my routine and I do					
These technologies cannot assist me on matter of my					
I can see no advantages by using these technologies					
I have poor internet connection					
Mains instability (power failures)					
Technologies will demand too many maintenance					

APPENDIX 2. Correlation matrix of explanatory variables

Variables	Age	Work-force	Income	Educatio-nal level	Broiler houses	Experien-ce	Slaughter weight	Expected time keep producing broilers	Another farm activity	Broiler income/ Total income	Farmer welfare	Animal welfare	Economic/ productive	Manage-ment
Age	1													
Workforce	0.098	1												
Income	-0.006**	0.054	1											
Educational level	-0.374**	-0.111	0.003	1										
Broiler houses	-0.068	0.455**	0.111	0.049	1									
Experience	0.303**	0.064	-0.101	-0.248**	0.009	1								
Slaughter weight	-0.218**	0.041	-0.052	0.143	0.066	-0.385**	1							
Expected time keep producing broilers	-0.390**	0.087	0.106	0.188*	0.116	-0.218**	0.342**	1						
Another farm activity	-0.049	-0.013	0.040	0.060	-0.140	0.085	0.082	0.044	1					
Broiler income/ Total income	-0.144	-0.068	-0.011	0.014	0.141	-0.170*	-0.025	0.191*	-0.399**	1				
Farmer welfare	0.001	0.066	0.085	0.077	0.077	-0.161*	-0.034	0.107	-0.003	-0.119	1			
Animal welfare	0.035	0.168*	0.011	-0.054	0.075	-0.179*	0.036	0.130	-0.023	0.000	0.656**	1		
Economic/ productive	-0.068	0.072	-0.047	-0.037	0.072	-0.237**	0.049	0.132	-0.003	0.013	0.650**	0.766**	1	
Manage-ment	-0.015	0.087	-0.056	-0.016	0.096	-0.174*	0.128	0.191*	0.009	-0.102	0.605**	0.688**	0.780**	1

* Significant correlation at the level of 5%
* Significant correlation at the level of 1%

APPENDIX 3. Multicollinearity coefficients

Variable	Coefficient
Age	1.454
Workforce	1.400
Income	1.102
Educational level	1.269
Broiler houses	1.404
Experience	1.475
Slaughter weight	1.404
Expected time on keep producing broilers	1.463
Another farm activity	1.261
Broiler income/Total income	1.454
Farmer welfare	2.184
Animal welfare	2.956
Economic/productive	3.876
Management	3.020

REFERENCES

ABPA - ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL. **Relatório anual 2020**. São Paulo: ABPA, 2020.

ADESINA, A. A.; BAIDU-FORSON, J. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso. **Agricultural Economics**, Amsterdam, v. 13, p. 1–9, 1995.

ADESINA, A. A.; ZINNAH, M. M. Technology characteristics, farmers' perceptions and adoption decisions: a Tobit model application in Sierra Leone. **Agricultural Economies**, Amsterdam, v. 9, p. 297–311, 1993.

ALBERNAZ-GONÇALVES, R.; OLMOS, G.; HÖTZEL, M. J. My pigs are ok, why change? – Animal welfare accounts of pig farmers. **Animal**, Cambridge, v. 15, n. 3, [art.] 100154, 2021.

ALONSO, M. E.; GONZÁLEZ-MONTAÑA, J. R.; LOMILLOS, J. M. Consumers' concerns and perceptions of farm animal welfare. **Animals**, Basel, v. 10, n. 385, p. 1–13, 2020.

ANOMALY, J. What's wrong with factory farming? **Public Health Ethics**, Oxford, v. 8, n. 3, p. 246–254, 2014.

BANHAZI, T. M. *et al*. Precision livestock farming: precision feeding technologies and sustainable livestock production. **International Journal of Agricultural and Biological Engineering**, Beijing, v. 5, n. 4, p. 54–61, 2012a.

BANHAZI, T. M. *et al*. Precision livestock farming: an international review of scientific and commercial aspects. **International Journal of Agricultural and Biological Engineering**, Beijing , v. 5, n. 3, p. 1–9, 2012b.

BANHAZI, T. M.; BLACK, J. L. Precision livestock farming: a suite of electronic systems to ensure the application of best practice management on livestock farms. **Australian Journal of Multi-disciplinary Engineering**, Barton, v. 7, n. 1, p. 1–14, 2009.

BERCKMANS, D. Precision livestock farming technologies for welfare management in intensive livestock systems. **Revue Scientifique et Technique de l'O.I.E**, Paris, v. 33, n. 1, p. 189–196, 2014.

BERCKMANS, D. General introduction to precision livestock farming. **Animal Frontiers**, London, v. 7, n. 1, p. 6–11, 2017.

BORGES, J. A. R.; FOLETTO, L.; XAVIER, V. T. An interdisciplinary framework to study farmers' decisions on adoption of innovation: insights from expected utility theory and theory of planned behavior. **African Journal of Agricultural Research**, Nairobi, v. 10, n. 29, p. 2814–2825, 2015.

BRACKE, M. B. M. *et al*. Broiler welfare trade-off : a semi-quantitative welfare assessment for optimised welfare improvement based on an expert survey. **PLoS ONE**, San Francisco, v. 14, n. 10, [art.] e0222955, [p. 1–24], 2019.

BROOM, D. M. Animal welfare: an aspect of care, sustainability, and food quality required by the public. **Journal of Veterinary Medical Education**, Toronto, v. 37, n. 1, p. 83–88, 2010.

BROOM, D. M. **Animal welfare in the European Union**. Brussels: European Parliament Policy Department, Citizen's Rights and Constitutional Affairs, Study for the PETI Committee, 2017.

CARRER, M. J.; SOUZA FILHO, H. M.; BATALHA, M. O. Factors influencing the adoption of Farm Management Information Systems (FMIS) by brazilian citrus farmers. **Computers and Electronics in Agriculture**, Amsterdam, v. 138, p. 11–19, 2017.

CLARK, B. *et al.* A systematic review of public attitudes, perceptions and behaviours towards production diseases associated with farm animal welfare. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 29, n. 3, p. 455–478, 2016.

FIELD, A. **Discovering statistics using IBM SPSS statistics**. 4th ed. Los Angeles: Sage, 2013.

FOGUESATTO, C. R.; MACHADO, J. A. D. What shapes farmers' perception of climate change? A case study of southern Brazil. **Environment, Development and Sustainability**, Dordrecht, v. 3, p. 1525-1538, 2021.

FRASER, D. Assessing animal welfare at the farm and group level: the interplay of science and values. **Animal Welfare**, Hertsmere, v. 12, n. 4, p. 433–443, 2003.

HANSSON, H.; LAGERKVIST, C. J. Measuring farmers' attitudes to animal welfare and health. **British Food Journal**, Bradford, v. 114, n. 6, p. 840–852, 2012.

HARTUNG, J. *et al*. European farmers' experiences with precision livestock farming systems. **Animal Frontiers**, London, v. 7, n. 1, p. 38–44, 2017.

ITHIKA, C. S.; SINGH, S. P.; GAUTAM, G. Adoption of scientific poultry farming practices by the broiler farmers in Haryana, India. **Iranian Journal of Applied Science**, Rasht, v. 3, n. 2, p. 417–422, 2013.

JONGE, J.; VAN TRIJP, H. C. M. The impact of broiler production system practices on consumer perceptions of animal welfare. **Poultry Science**, Champaign, v. 92, n. 12, p. 3080–3095, 2013.

JUKAN, A.; MASIP-BRUIN, X.; AMLA, N. Smart computing and sensing technologies for animal welfare: a systematic review. **ACM Computing Surveys**, New York, v. 50, n. 1, p. 1–27, 2017.

KASSIE, M. *et al*. Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. **Technological Forecasting and Social Change**, New York, v. 80, n. 3, p. 525–540, 2013.

MARIANO, M. J.; VILLANO, R.; FLEMING, E. Factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines. **Agricultural Systems**, Barking, v. 110, p. 41–53, 2012.

MCFADDEN, D. **Quantitative methods for analyzing travel behavior of individuals:** some recent developments. New Haven: Cowles Foundation for Research in Economics at Yale University, 1977. (Cowles Foundation Discussion Paper, n. 474).

MCINERNEY, J. **Animal welfare, economics and policy**. London: Defra, 2004.

MOLNÁR, M.; FRASER, D. Protecting farm animal welfare during intensification: farmer perceptions of economic and regulatory pressures. **Animal Welfare**, Hertsmere, v. 29, n. 2, p. 133–141, 2020.

NIELSEN, B. L.; ZHAO, R. Farm animal welfare across borders: a vision for the future. **Animal Frontiers**, London, v. 2, n. 3, p. 46–50, 2012.

OECD/FAO. **OECD-FAO Agricultural Outlook 2019-2028**. Paris: OECD Publishing; Rome: Food and Agriculture Organization of the United Nations, 2019.

PIERPAOLI, E. *et al*. Drivers of precision agriculture technologies adoption: a literature review. **Procedia Technology**, Amsterdam, v. 8, p. 61–69, 2013.

PIVOTO, D. *et al.* Scientific development of smart farming technologies and their application in Brazil. **Information Processing in Agriculture**, Amsterdam, v. 5, n. 1, p. 21–32, 2018.

PIVOTO, D. *et al*. Factors influencing the adoption of smart farming by Brazilian grain farmers. **International food and agribusiness Management Review**, Stamford, v. 22, n. 4, p. 571–588, 2019.

R CORE TEAM. **The R project for statistical computing**. [*S.l.*], 2021. Available at: https://www.r-project.org/. Accessed: 5 Jan. 2021.

RIOS, H. V. *et al*. How are information technologies addressing broiler welfare? A systematic review based on the Welfare Quality ® assessment. **Sustainability**, Basel v. 12, n. 1413, p. 1–34, 2020.

ROWE, E.; DAWKINS, M. S.; GEBHARDT-HENRICH, S. G. A systematic review of precision livestock farming in the poultry sector: is technology focussed on improving bird welfare? **Animals**, Basel, v. 9, n. 614, p. 1–18, 2019.

SASSI, N. B.; AVERÓS, X.; ESTEVEZ, I. Technology and poultry welfare. **Animals**, Basel, v. 6, n. 62, p. 1–21, 2016.

SIMÕES, D. *et al*. Economical and financial analysis of aviaries for the integration of broilers under conditions of risk. **Ciência e Agrotecnologia**, Lavras, v. 39, n. 3, p. 240–247, 2015.

SØRENSEN, J. T.; FRASER, D. On-farm welfare assessment for regulatory purposes: Issues and possible solutions. **Livestock Science**, Amsterdam, v. 131, p. 1–7, 2010.

SOUZA FILHO, M. H. *et al*. Condicionantes da adoção de inovações tecnológicas na agricultura. **Cadernos de Ciência e Tecnologia**, Brasília, DF, v. 28, n. 1, p. 223–255, 2011.

TE VELDE, H.; AARTS, N.; WOERKUM, C. V. A. N. Dealing with ambivalence: farmers' and consumers' perceptions of animal welfare in livestock breeding. **Journal of Agricultural and Environmental Ethics**, Dordrecht, v. 15, p. 203–219, 2002.

TESFAHUNEGN, G. B.; MEKONEN, K.; TEKLE, A. Farmers' perception on causes, indicators and determinants of climate change in northern Ethiopia: implication for developing adaptation strategies. **Applied Geography**, Sevenoaks, v. 73, p. 1–12, 2016.

THORNTON, P. K. Livestock production: recent trends, future prospects. **Philosophical Transactions of the Royal Society B: Biological Sciences**, London, v. 365, n. 1554, p. 2853–2867, 2010.

TUYTTENS, F.; VANHONACKER, F.; VERBEKE, W. Broiler production in Flanders, Belgium: current situation and producers' opinions about animal welfare. **World's Poultry Science Journal**, Ithaca, v. 70, n. 2, p. 343–354, 2014.

UN - UNITED NATIONS. General Assembly.**Transforming our world:**the 2030 agenda for sustainable development. New York: United Nations, 2015. 35 p.

USDA – UNITED STATES DEPARTMENT OF AGRICULTURE. Foreign Agricultural Service. **Livestock and poultry:** world markets and trade. Washington, DC: USDA, 2021.

VAN HERTEM, T. *et al*. Appropriate data visualisation is key to precision livestock farming acceptance. **Computers and Electronics in Agriculture**, Amsterdam, v. 138, p. 1–10, 2017.

VANHONACKER, F.; TUYTTENS, F. A. M.; VERBEKE, W. Belgian citizens' and broiler producers' perceptions of broiler chicken welfare in Belgium versus Brazil. **Poultry Science**, Oxford, v. 95, p. 1555–1563, 2016.

WATHES, C. M. *et al*. Is precision livestock farming an engineer’s daydream or nightmare, ananimal’s friend or foe, and a farmer’s panacea or pitfall? **Computers and Electronics in Agriculture**, Amsterdam, v. 64, n. 1, p. 2–10, 2008.

WATHES, C. M. **Precision livestock farming for animal health, welfare and production**. *In:* INTERNATIONAL CONGRESS IN ANIMAL HYGIENE, 2007, Tartu. **Proceedings** [...]. Tartu: Estonian University of Life Science, 2007. p. 397–404.

CHAPTER 6

ADDITIONAL CONSIDERATIONS

The present thesis provides novel insights on PLF technologies related to broiler welfare (PLF-AW) analyzing the potentialities and limitations of their development (Chapter 3), identifying opportunities to increase their adoption (Chapter 4) and inferring on their adoption by broiler farmers in Southern Brazil, analyzing determinants and limiting factors influencing technologies adoption (Chapter 5). In a first methodological step, studies about PLF-AW development were analyzed through a literature review to identify which are these technologies and to analyze how they address the different principles of broiler welfare. In the second step, broiler farmers´ opinions on animal welfare and on PLF-AW potentialities as well as on the determinants for the adoption of such technologies were assessed through an empirical research.

Most of PLF technologies identified in the literature review involved the use of image technologies, which is comprehensive since they are especially suitable for indoor farming, being relatively cheap and capable of monitoring a great number of animals. The health principle of broiler welfare was the main focus of PLF technologies, indicating a high scientific concern on lesions (especially footpad dermatitis and hockburn) and diseases. The great majority of PLF technologies described in the literature are not yet available for commercialization and were only experimentally tested. The development of ready-to-use PLF-AW is complex and involves a series of technical difficulties.

PLF technologies are complex to produce as they involve the modelling of bio responses of CITD organisms as detailed in Chapter 2 (item 2.2.1). Summing it up with the difficulties imposed by a real environment which presents several other variables than those in experimental installations/conditions, it is possible to picture the hindrances of developing such technologies. The technology should be able to inform farmers on what is happening in their broiler houses, giving them alarms when a potential problem is detected, some advice or action possibilities when some attitude must be taken, and automate responses when needed. However, the more robust is technology the more difficult it is to be produced and sometimes to be understood by farmers. Besides, there is a huge path between the development of such technologies and their availability in the market, which the present thesis did not intend to address in-depth.

It does not matter how difficult and elaborated is to develop a new technology if it does not provide any additional value to farmers. Thus, analyzing farmers opinions and behaviors towards such technologies is a valuable step to develop new technologies and foster their adoption. Results reported in Chapter 4 indicated that there is room for welfare improvements in broiler farmers´ opinions, especially to feeding, house and health conditions. Brazilian broiler farmers also expressed optimism on the potentialities of technologies in improving animal welfare and high willingness for technology adoption aiming at improving animal welfare, even when it represented no extra income to them. This is an alarming finding, indicating that the use of technologies by broiler farmers can be the link to attend social expectations regarding broiler welfare level. Broiler farmers should be better listened by technology developers, including research groups.

The findings of Chapter 5 regarding farmers likelihood of PLF-AW adoption deserve to be highlighted. Farmers who believe on PLF potentialities regarding broiler welfare improvements were more likely to adopt such technologies than those who do not. The common sense points out that technology's economic potentialities would be relevant for the likelihood of technologies adoption and that animal welfare improvements would be secondary. Both assumptions were not observed in the present research. Such finding indicate that broiler farmers believe that welfare improvements can be achieved with technologies and that opinions on animal welfare improvements with the use of PLF-AW influences the likelihood of PLF adoption. It is completely novel information that should be better explored by future studies. It is important to mention that economic barriers such as the high prices of technologies were a major limiting factor for PLF-AW adoption expressed by broiler farmers. It is suggested that future studies focus on the return over the investment on different technologies and analyze the economics involving with technologies adoption more in-depth.

The fact that most of the PLF-AW technologies identified in the literature review were restricted to experimental environment only, added some constrains to the empirical research, especially when analyzed the determinants and limiting factors influencing technologies adoption by broiler farmers. Assuming that broiler farmers did not know PLF-AW technologies by their technical functioning, pictures of such technologies were shown. PLF-AW image technologies were illustrated with a picture of digital/infrared camera, although the simple fact of using camera does not necessarily means that a PLF technology is being utilized (a limitation addressed in more details in Chapter 5). However, climate controller panel is widely acknowledged by broiler farmers and was by far the most adopted technology by the sample evaluated. Thus, it is believed that the findings related to the determinants and limiting factors influencing broiler farmers adoption of PLF-AW technologies are reliable for the sample analyzed.

Farmers´ opinions on free range chicken's welfare and their PLF technologies adoption were not assessed in the present thesis, although recognized by the author as an extremely important field to be explored. Consumers of animal friendly products tend to valorize the naturalness aspect of farm animals´ lives more than other aspects; however, it does not necessarily mean that free range chickens experience better live conditions than those reared in conventional broiler houses. The PLF technology adopted by those farmers will be probably different than those assessed in the present thesis as will probably be their motivations/limitations to adopt them and their opinions on broiler welfare. Therefore, the lack of information about free range broiler producers is considered a limitation of the present study faced due time and resources scarcity.

PLF technologies can be complementary. The gathering of data from different sensors and algorithms in a single remote technology constitutes a real opportunity for adding value to farmers. The aim of these technologies is to transform the caretaker-farmer in a farm manager, who is getting several information from their broiler houses in real-time being also able to take actions remotely if needed. To implement such PLF technology it is necessary to integrate data from different sources. The improvements can be adopted once at a time if the sensors used in a broiler house are compatible to each other. This is a relevant factor to take in consideration by farmers when deciding to adopt PLF technologies; the farmer must be aware that it is real possibility for a near future and then decide to adopt technologies that permit such improvements in their systems. Analysis on how the complementarity among different PLF technologies influence the adoption or the intention of adopting technologies by farmers is suggested for future studies.

The thesis explores an up-coming broiler farming reality and it is hoped that the findings reported here can be useful to trace future scenarios for broiler welfare improvements and to elaborate plans of action to increase the level of technology adoption by farmers. It is believed that PLF technologies can potentially increase both animal and human welfare. Several challenges are yet to be overcome and many issues will probably emerge in a near future. Most of PLF technologies are still in the development phase or/and starting to be adopted. It is observed a huge potentiality for such technologies to address broiler welfare and to mitigate the social and economic pressures faced by broiler farmers.

APPENDIX A – FIRST PAGE OF PUBLISHED PAPER

sustainability

MDPI

Review

How Are Information Technologies Addressing Broiler Welfare? A Systematic Review Based on the Welfare Quality® Assessment

Heitor Vieira Rios [1,2,*], Paulo Dabdab Waquil [3], Patrícia Soster de Carvalho [2,4] and Tomas Norton [2,*]

1 Center for Studies and Research in Agribusiness, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS 91540-000, Brazil
2 Department of Biosystems, Division Animal and Human Health Engineering, Group M3-BIORES: Measure, Model & Manage of Bioresponses, KU Leuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium; paty_soster@hotmail.com
3 Department of Economics and Foreign Affairs and Center for Studies and Research in Agribusiness, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS 91540-000, Brazil; waquil@ufrgs.br
4 Departament of Zootechny, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS 91540-000, Brazil
* Correspondence: heitorvieira_rios@hotmail.com (H.V.R.); tomas.norton@kuleuven.be (T.N.)

Received: 23 December 2019; Accepted: 12 February 2020; Published: 14 February 2020

check for updates

Abstract: This systematic review aims to explore how information technologies (ITs) are currently used to monitor the welfare of broiler chickens. The question posed for the review was "which ITs are related to welfare and how do they monitor this for broilers?". The Welfare Quality® (WQ) protocol for broiler assessment was utilized as a framework to analyse suitable articles. A total of 57 studies were reviewed wherein all principles of broiler welfare were addressed. The "good health" principle was the main criteria found to be addressed by ITs and IT-based studies (45.6% and 46.1%, respectively), whereas the least observed principle was "good feeding" (8.8%). This review also classified ITs and IT-based studies by their utilization (location, production system, variable measured, aspect of production, and experimental/practical use). The results show that the current focus of ITs is on problems with conventional production systems and that less attention has been given to free-range systems, slaughterhouses, and supply chain issues. Given the valuable results evidenced by the exploitation of ITs, their use in broiler production should continue to be encouraged with more attention given to farmer adoption strategies.

Keywords: information technology; precision livestock farming; welfare quality

1. Introduction

1.1. General Overview and Objectives

The world population growth is putting pressure on all food production sectors and, in particular, demanding agricultural chains to be more productive, efficient, and sustainable. Poultry meat is currently the main source of animal protein produced worldwide and is expected to comprise approximately 38% of global demand for animal protein (excluding fish) by 2028 [1]. At the same time, ethical and moral concerns about the way we produce our food have gained prominence in contemporary society. Societal concern regarding the welfare of farm animals and the sustainability of animal production systems has provoked important discussions and has emerged as an important point in the agenda of many scientific debates [2].