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

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**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. [13] 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.
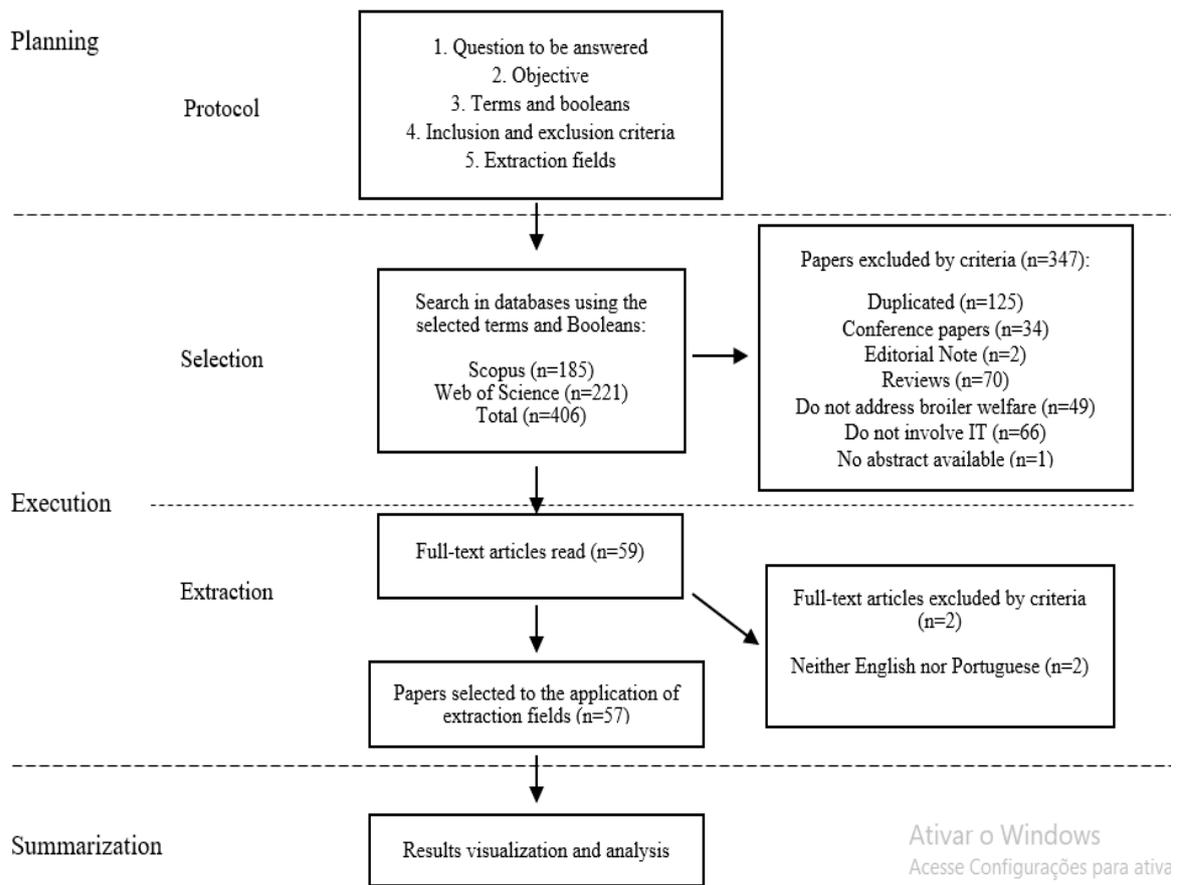
**Figure 1.** Processes adopted in the present systematic review.

## 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.
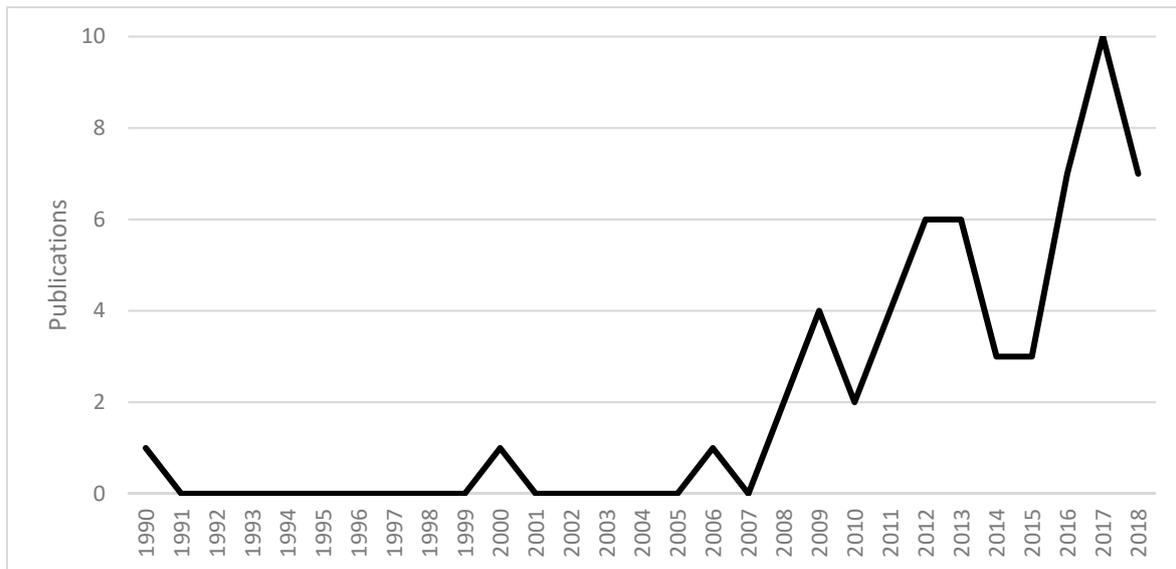


**Figure 2.** Temporal distribution of publications.

### *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.

### 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].

**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 |
| (Cont.) | | | | |
| 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 |
| 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.

### 3.1.4. 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.

**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 |

### 3.2.1. 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%).

### 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.

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.

**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<br>Good housing<br>Good health<br>A. behaviour[2]<br>H. slaughter[3] | 11.1<br>27.8<br>44.4<br>22.2<br>11.1 | Farm | 100 | Conventional<br>Free-range | 88.9<br>11.1 | Animal/flock<br>Both | 88.9<br>11.1 | Technical aspect | 100 | Practical<br>Experimental | 27.8<br>72.2 |
| | Broiler´s distribution (n = 13) | Good feeding<br>Good housing<br>Good health<br>A. behaviour | 7.7<br>15.4<br>61.5<br>15.4 | Farm | 100 | Conventional | 100 | Animal/flock | 100 | Technical aspect | 100 | Practical | 100 |
| | Thermal image (n = 9) | Good housing<br>Good health<br>A. behaviour<br>H. slaughter | 44.4<br>22.2<br>22.2<br>11.1 | Farm<br>S. house | 88.9<br>11.1 | Conventional<br>Both | 77.8<br>22.2 | Animal/flock<br>Both | 88.9<br>11.1 | Technical aspect | 100 | Practical<br>Experimental | 44.4<br>55.6 |
| | Image analyses (n = 5) | Good housing<br>Good health | 20.0<br>80.0 | Farm<br>S. house | 80.0<br>20.0 | Conventional<br>Both | 80.0<br>20.0 | Animal/flock | 100 | Technical aspect | 100 | Practical<br>Experimental | 60.0<br>40.0 |
| | Image display tool (n = 1) | Good feeding<br>Good housing<br>Good health<br>A. behaviour | 100<br>100<br>100<br>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<br>Good housing<br>Good health<br>A. behaviour | 20.0<br>20.0<br>20.0<br>40.0 | Farm | 100 | Conventional | 100 | Animal/flock | 100 | Technical aspect | 100 | Practical | 100 |
| (Cont.) | | | | | | | | | | | | | |

| IT type | Subtype | Welfare principle | %[1] | Level | %[1] | System | %[1] | Target | %[1] | Aspect | %[1] | Study type | %[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<br>Good health | 50.0<br>50.0 | Farm | 100 | Conventional | 100 | Animal/flock | 100 | Technical aspect | 100 | Experimental | 100 |
| Environmental sensor (n = 8) | | Good housing<br>H. slaughter | 62.5<br>37.5 | Farm<br>S. house | 87.5<br>12.5 | Conventional<br>Free-range<br>Both | 75.0<br>12.5<br>12.5 | Environmental | 100 | Technical aspect | 100 | Practical<br>Experimental | 87.5<br>12.5 |
| Animal sensor (n = 9) | ECG and EEG (n = 3) | H. slaughter | 100 | Farm<br>S. house | 33.3<br>66.7 | Conventional<br>Both | 66.7<br>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<br>Good housing | 50.0<br>50.0 | Farm | 100 | Conventional<br>Both | 50.0<br>50.0 | Animal/flock | 100 | Technical aspect | 100 | Experimental | 100 |
| | Telemetry-logging system (n = 3) | Good housing<br>H. slaughter | 33.3<br>66.7 | Farm<br>S. house | 66.7<br>33.3 | Conventional<br>Both | 33.3<br>66.7 | Animal/flock | 100 | Technical aspect | 100 | Experimental | 100 |
| Algorithm (n = 23) | | Good feeding<br>Good housing<br>Good health<br>A. behaviour | 13.0<br>21.7<br>69.6<br>8.7 | Farm<br>S. house | 95.7<br>4.3 | Conventional<br>Both | 95.7<br>4.3 | Animal/flock<br>Environmental<br>Both | 91.4<br>4.3<br>4.3 | Technical aspect<br>Both | 95.7<br>4.3 | Practical | 100 |

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

### 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.

**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. |
| 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. |
| 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. |

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| 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. |
| 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. |

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| 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. |
| 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 | Experimental | The real-time monitoring tool could efficiently detect lameness in broilers from gait score 3. |

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| | | | | effects of gait score on speed, step length, step frequency, and lateral body oscillations. | | |
| 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. |
| 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%. |
| 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. |
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| 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%. |

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