Sustainable Agriculture Reviews 54

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Sustainable Agriculture Reviews 54

Animal Biotechnology for Livestock Production 1

Springer

Sustainable Agriculture Reviews

Volume 54

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Sustainable agriculture is a rapidly growing field aiming at producing food and energy in a sustainable way for humans and their children. Sustainable agriculture is a discipline that addresses current issues such as climate change, increasing food and fuel prices, poor-nation starvation, rich-nation obesity, water pollution, soil erosion, fertility loss, pest control, and biodiversity depletion.

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ISSN 2210-4410 ISSN 2210-4429 (electronic)
Sustainable Agriculture Reviews
ISBN 978-3-030-76528-6 ISBN 978-3-030-76529-3 (eBook)
https://doi.org/10.1007/978-3-030-76529-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Many developed countries are actually facing a ban of animal food products, promoted mainly by urban and vegetarian activists who have never experienced living in farms and who do not acknowledge that their modern way of life is largely the result of hard work of their elders with the help of farm animals. However, since the start of society, animal production has been an essential agricultural sector worldwide providing food, labor, aesthetics and social values, and even today many farmers would not survive without animals. This book entitled 'Animal Biotechnology for Livestock Production 1' is our first volume providing advanced knowledge on biotechnological methods to improve the livestock production, with focus on animal reproduction, health, diagnosis and nutrition. Chapter 1 presents on artificial insemination in cattle, with focus on physiology aspects of the estrous cycle, estrus synchronization program, ovulation synchronization program for timed artificial insemination, strategies for improving fertility and use of sexed semen in artificial insemination. Chapter 2 reviews biotechnological applications for production of dromedary camels, with details on camel herd reproduction, reproduction control and artificial insemination. Sperm dilution, thawing, conservation, and insemination techniques are also discussed. Recent biotechnological applications for livestock production are summarized in Chap. 3, with emphasis on somatic cell nuclear transfer, artificial insemination, embryo transfer, embryonic stem cell technology and marker assisted selection.

Cattle production in France. Copyright 2021 Eric Lichtfouse

Chapter 4 reviews applications of stem cells in livestock, with emphasis on mesenchymal stem cells. Immunomodulatory, antimicrobial activity, migration and reparative functions of stem cells are detailed. Chapter 5 presents techniques for profiling proteins and metabolites associated with feed efficiency in dairy cattle. Recent findings on key metabolites and proteins of metabolic pathways are also disclosed. Chapter 6 focuses on processing, packaging, and safety of dairy products. Applications of biotechnologies in food diagnosis are also explained. Chapter 7 reviews 'on-farm point-of-care' diagnostic technologies in animals. This chapter covers various point-of-care and on-farm diagnostic technologies for monitoring animal health and disease with focus on molecular, electrochemical-biosensors diagnostics. Chapter 8 presents biotechnological applications in the poultry industry. This chapter covers the concepts and developments of biotechnologies for poultry production, breeding, feed and nutrition. This chapter also discusses applications in poultry vaccines, biologics, disease diagnosis and food processing**.**

We express our thanks to all authors who have contributed high quality chapters. Our special thanks are due to the Indian Council of Agricultural Research (ICAR), the Government of India and the Director of the ICAR National Dairy Research Institute (NDRI), Karnal, India for providing the institutional support. We would like to acknowledge Dr. Sudarshan Kumar, Scientist, ICAR-NDRI, Karnal, India for his help in choosing contributors and reviewers. We would like extend our thanks to the staff of Springer Nature, for their generous assistance, constant support, and patience in initializing and publication of this book. We acknowledge our thanks to

Department of Biotechnology, Government of India for providing financial support from “DBT-RA Program in Biotechnology & Life Sciences”.

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Vinod Kumar Yata is an interdisciplinary researcher working at National Dairy Research Institute, Karnal, India. Previously, he worked as an Assistant professor at the Department of Biotechnology, Dr. B R Ambedkar National Institute of Technology Jalandhar, Punjab, India. He received his Ph.D. in Biotechnology from Indian Institute of Technology Guwahati. He specializes in interdisciplinary research which includes Nanotechnology, Microfluidics, Animal Biotechnology, Cancer biology and Bioinformatics. He has developed a microfluidic device for the separation of live and motile spermatozoa form cattle semen samples. He opened up a new avenue to prodrug enzyme therapy by introducing the nanocarriers for the delivery of non-mammalian prodrug activating enzymes. He elucidated the structural features and binding interactions of several bio molecules by in silico methods. He has published three books as an editor and one book as an author with Springer Nature publisher. He has published several research papers in peer reviewed international journals and presented papers in several international conferences.

Ashok Kumar Mohanty is a principal scientist at Animal Biotechnology Centre, ICAR-National Dairy Research Institute, Karnal, India. His group is involved in various basic and applied research related to animal production systems. His research group has made pioneering contributions in the field of Animal Biotechnology, with emphasis on Gene cloning, Expression and Functional characterization of Animal Proteins, Proteomics in Animal Production, Cell and Molecular Biology and Structural Biology of Proteins. His group has developed a Buffalo Mammary Epithelial cell line for the first time which can be used a model system to understand lactation biology in animal as well as human. His team has also developed a pregnancy diagnostic kit for the early detection of pregnancy cattle and buffalo. His group is also extensively involved in developing low cost technology for semen sexing in cattle. He has organized a number of national and international workshops and international conferences. He is a recipient of several awards which includes, DBT Overseas Associateship by Ministry of Science & Technology, Govt. of India., Jawaharlal Nehru Award (gold medal) by Indian Council of Agricultural Research (ICAR), New Delhi for outstanding postgraduate research in the field of Animal Biotechnology and Young Scientist Award sponsored by International union of Crystallography (IUCr) and Dept. of Science and Technology (DST), Govt. of India for attending IUCr congress at Geneva, Switzerland. He is the Fellow of National Academy of Dairy Sciences, India and executive member of proteomics society of India and associate fellow of National Academy of Veterinary Science, India. He has supervised more than 50 graduate, PhD students and post docs. He published more than 200 peer reviewed research and review papers. He has also authored 8 book chapters in the areas of animal and food biotechnology published by in national and international publishers.

Eric Lichtfouse is a professor of environmental sciences and scientific writing at Aix Marseille University and Xi'an Jiaotong University. He has invented carbon-13 dating, a molecular-level method allowing to study the dynamics of organic compounds in temporal pools of complex environmental media. He has discovered temporal pools of individual substances in complex media such as soils. He is Chief Editor and founder of the journal Environmental Chemistry Letters, and the book series Sustainable Agriculture Reviews and Environmental Chemistry for a Sustainable World. He is the author of the book Scientific Writing for Impact Factor Journals, which includes an innovative writing tool: the micro-article. He has awards in analytical chemistry and scientific editing.

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Chapter 7
On-Farm Point-of-Care Diagnostic Technologies for Monitoring Health, Welfare, and Performance in Livestock Production Systems

Mohamed Zeineldin, Ahmed A. Elolimy, P. Ravi Kanth Reddy, Mohamed Abdelmegeid, Miguel Mellado, Mona M. M. Y. Elghandour, and Abdelfattah Z. M. Salem

Abstract The occurrence of infectious diseases has a significant adverse effect on livestock health and production efficiency. Current diagnostic approaches in veterinary practice are primarily focused on the observation of changes in physical, clinical, behavioral, or performance of individual or groups of animals. In recent years, these diagnostic approaches have markedly improved livestock profitability during their production cycle. This is mainly achieved by using reliable and conveniently available on-farm and point-of-care diagnostic technologies for the rapid and accurate management of animal health. The availability of on-farm and point-of-care technology is rapidly changing decisions for bovine practitioners on both individual sick cows and herd health level. Early detection of infectious diseases using quick,

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V. K. Yata et al. (eds.), *Sustainable Agriculture Reviews 54*, Sustainable Agriculture Reviews 54, https://doi.org/10.1007/978-3-030-76529-3_7

effective, low-cost, automated technologies will allow timely detection of infected animals, thus reducing the economic loss and associated abuse of antimicrobial therapy. Here we review the currently available on-farm and point-of-care diagnostic technologies for health surveillance and disease detection in livestock production systems. We additionally review the advantages and disadvantages of each methodology, concerning their possible effect on the improvement of animal welfare and productivity of farm animals.

Keywords Bovine · Disease · Diagnosis · On-farm · Point-of-care · Technology

7.1 Introduction

Infectious diseases are a major source of livestock production inefficiency and cause significant economic losses to the global livestock industry due to associated morbidity, mortality, and treatment costs (Craft 2015). The presence of infectious agents, and related therapeutic and antibiotic residues, has serious consequences for the public perception of livestock production, food safety, and human health (Daszak et al. 2000). Although disease control and prevention are critical elements for mitigating the effect of disease on animal health and production efficiency, disease-free production systems are unrealistic (Schwabe 1982). Since diseases are an unavoidable component of modern livestock production systems, on-farm and point-of-care diagnostics for the accurate detection and diagnosis of affected animals are vital for minimizing morbidity, optimizing recovery, and maintaining profitability. Early and accurate disease detection plays an important role in reducing mortality, preventing disease transmission, and avoiding the long-term effects of disease on production, welfare, and profitability (Bisson et al. 2015). Early detection and diagnosis of infectious diseases in livestock also help to avoid irreversible pathologies, prevent the production of antibiotic-resistant bacteria, reduce public health concerns and optimize the action of antimicrobial therapy (Hennessy and Wolf 2018).

Compared to human medicine, current diagnostic approaches in veterinary practice have primarily focused on observation of changes in the physical, clinical, behavioral, or performance status of individual or groups of animals. Although these findings have historically been made by animal caretakers and animal health professionals, there has been an increased interest in the use of cow-side diagnostic tests to improve the sensitivity, precision, and timeliness of disease detection (Berckmans 2014a). The investment in rapid, selective, accurate, and cost-effective tests and the recognition among clinicians and animal stakeholders of the value of quick and accurate diagnosis of disease have resulted in rapid progress in point-of-care and on-farm diagnostics for rapid on-site testing of animals (Helwatkar et al. 2014). Similarly, technology adaptation and implementation are being used to

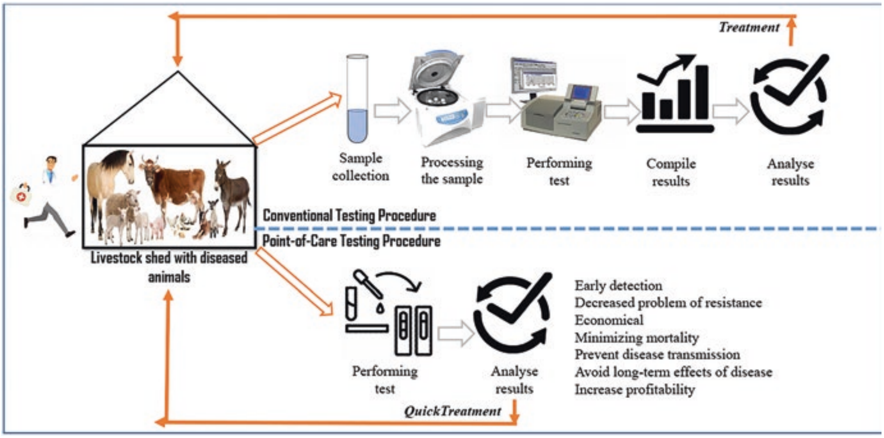

Fig. 7.1 Advantages of point-of-care diagnostic techniques compared to conventional diagnostic methods

create more robust systems for measuring animal growth, production, and the physical environment of animals, all to improve individual or group performance and production efficiency (Lokhorst and Ipema 2010). To date, most of the available diagnostic tests in humans and farm animals focus on the rapid identification of non-infectious conditions (e.g. blood glucose, β-hydroxybutyrate, and hemoglobin concentration, diagnosis of cardiac markers, detection of blood gas and electrolytes, etc.) (Tschandl et al. 2019; Sargeant and O'Connor 2020). On-farm and point-of-care diagnostics also provide an alternative for monitoring livestock health, which has a high potential for increasing the performance of livestock production systems, eliminating subjectivity the management decision-making, and maximizing the efficacy of unskilled or inexperienced labor in animal health management (Helwatkar et al. 2014). Advantages of point-of-care diagnostic techniques compared to conventional diagnostic methods are shown in Fig. 7.1.

In this chapter, we review the currently available on-farm and point-of-care diagnostic technologies for health and performance monitoring in livestock production systems. Additionally, we review the advantages and disadvantages of each approach, in particular regarding its possible effect for improving animal health and productivity.

7.2 Characteristics of an Ideal Point-of-Care and On-Farm Diagnostic Technologies

The list of available point-of-care and on-site diagnostic tests in both human and animal medicine has expanded steadily over the last few years. The global diagnostic market for veterinary diagnostic testing is projected to increase at an average annual growth rate of 8.6% from 2016 to 2021, to hit US$ 6.71 billion by 2021 (Commission 2011). This massive market potential is driven by the availability of quick, portable veterinary diagnostic devices to track animal health disorders (Helwatkar et al. 2014). Ideal technology should be developed as durable, low-cost, reliable, and effective explaining the intrinsic biological process (Frost et al. 2003). Moreover, it should be easily converted into a professionally tested and easy-to-maintain relevant action (Bolboacă 2019). The selection of the appropriate point-of-care and on-farm diagnostic technology is affected by many factors, including the frequency and type of measurement, the labor needed to conduct the test, the conditions of the livestock management system, and the costs of the technology (Berckmans 2014a). The idealized diagnostic technologies are challenged by the sample volumes of the complex structure of biological materials, the processing time of the sampling, and the diagnostic capacity and accuracy of the instrument (Gubala et al. 2012). The design of an ideal point-of-care and on-farm diagnostic should therefore depend not only on the development of technology but also on the design of the biological measurement goals and the surrounding livestock farming system.

7.3 Categories of Point-of-Care and On-Farm Diagnostic Technologies

Successful management of animal diseases depends on the timely identification of clinically infected animals through laboratory and clinical examination, along with an understanding of the factors influencing the epidemiology of the causative agent (Bisson et al. 2015). There is a wide variety of easier and more cost-effective diagnostic techniques, including point-of-care technologies for disease surveillance in both human medicine and veterinary practice (Helwatkar et al. 2014; Yanase and Triantaphyllou 2019; Mohr et al. 2020). Generally, each diagnostic tool measures a specific parameter related to the physiological state of the animal, performance or existence of infectious agents in an individual or group of animals, a change that entails an intervention to alleviate the disorder detected (Lokhorst and Ipema 2010). Besides, there may be relevant algorithms and computer programs necessary to understand an animal's health status, which may need to be coupled with other data (e.g, financial input) before an appropriate and effective decision can be taken (Das et al. 2015). This obstacle can be better tackled by the advancement of point-of-care and on-farm automated technology in a revolutionary way to provide fast and effective identification of animal health threats (Neethirajan et al. 2017). In this context, point-of-care diagnostics are valuable tools for detecting small sample volumes and low concentrations of biological components and infectious agents (Theurer et al. 2013). Practically, all the available technologies for the livestock industry fall into one of four broad categories related to their proximity (attached or non-attached) and association (invasive or non-invasive) with the animals themselves (Helwatkar et al. 2014). Attached technologies include those that can be fixed to the outside the animal's body (non-invasive) (Krieger et al. 2019) or those that are fitted inside the body (invasive) (Rose-Dye et al. 2011). This category includes some of the most reliable technologies for continuously monitoring animal health throughout the day and comprises accelerometers, pedometers, vibration sensors, thermometers, and rumen temperature bolus. Non-attached technologies are those that animals pass by, over, or through for health monitoring (Stone et al. 2017). These devices are often set at fixed locations in the animal's environment (e.g, surveillance cameras (regular or thermographic), and video and audio recording systems). Similarly, point-of-care diagnostic technologies are also achieved with the use of unattached, transportable, and hand-held equipment and test kits to obtain blood samples and provide results in a very short time, so that decisions are taken very rapidly.

7.4 Molecular Diagnostic Technologies for Monitoring Animal Health and Disease

Traditionally, diagnostic approaches in veterinary practice have focused primarily on clinical evaluation of the behavior of individual animals or groups of individuals and the reaction to certain conditions of the disease (Van Veen 1997). These conventional approaches rely on animal history and visual clinical signs and can only be used to diagnose a small percentage of sick animals. Because of the multifactorial disease control and the wide variety and complexity of the livestock farming environment, these conventional methods are not sufficient to improve the sensitivity, precision, and timeliness of disease diagnosis (Saegerman et al. 2011). The usefulness of molecular and high-performance sequencing technologies for tracking the health and disease of livestock has been highlighted for accurate disease control (Reuter et al. 2015; Kumar et al. 2019). The recent application of molecular diagnostic approaches to livestock has shown the importance of these platforms for improving livestock management systems and limiting the spread of diseases (Shirley et al. 2010). Also, the existing use of molecular diagnostic techniques has demonstrated the complexity of disease-causing agents (Zeineldin et al. 2017a, b) and proven associations between early disease detection and livestock health and productivity (Naqvi 2007). Numerous molecular-based techniques are presently used to determine disease-causing agents, including immunohistochemistry, fluorescent in situ hybridization (FISH), marker-assisted selection, cloning, flow cytometry, RNA dot blotting hybridization, ELISA, and quantitative real-time PCR assays (Walker and Subasinghe 2000). Meanwhile, the field of molecular diagnostics has shown dramatic developments over the last few years in the use of low-cost high-density single-nucleotide polymorphism (SNP) technology in the genotyping of individuals at the SNPs level (van Arendonk 2011). Among these technologies, immunohistochemistry and fluorescent in situ hybridization have been used to show the presence and characteristics of species in complex biological samples (Cheon and Chae 2000). Also, qPCR and FISH have been the most effective approaches used to amplify and quantify particular DNA or RNA sequences in complex biological samples from different hosts (Elelu et al. 2016). While these molecular techniques are appropriate for a plethora of different biological samples and provide reliable information on some agents, they do not provide the direct sequence of the infectious agent. Also, the use of these methods includes advanced awareness of the causative agents. These shortcomings eventually led to the development and widespread implementation of high-performance sequencing technologies in veterinary diagnostic reference laboratories, which can sequence all genomic material present in biological samples and produce thousands of sequences of previously unknown biological materials (Zeineldin et al. 2019b). In addition, next-generation technology has the ability to provide an unbiased sequencing platform for several microbial genomes and their antibiotic resistance genes in near-real time, which bring several possible advantages to create diagnostic reference laboratories for rapid diagnostic decision making (Zeineldin et al. 2019a). Recently, the current high-throughput sequencing technologies used in veterinary practice are primarily Illumina sequencing platforms (San Diego, CA, USA), Nanopore technology, and 454 pyrosequencing platforms (Ambardar et al. 2016; Singh et al. 2019). In the coming years, the cost of this sequencing technology is expected to be reduced and sequencing platforms will be available and used on a wide scale in livestock. The entire genome sequencing technology has recently been applied in a variety of studies to improve diagnostic methods accuracy in the veterinary field (Glaser et al. 2016). For example, the use of sequencing technologies for the genetic characterization of viral infectious agents has provided a much deeper and more detailed view of viral capsid and virus genetic material (Chappell et al. 2019). This knowledge is important for a deeper understanding of the genotypes of viruses and will help to identify viruses and the future production of vaccines. More recently, developments in mass spectrometry science, including metaproteomics, metabolomics, and metatranscriptomics, have improved diagnostic technologies to enhance animal health (Elolimy et al. 2020). Although valuable information is given by these techniques, the use of this technology in veterinary practice is minimal. Due to the associated high costs, access to these advanced technologies in developing countries is limited (Zumla et al. 2014). In addition, some enhancements are still required before the next generation and mass spectrometry technologies are used as a point-of-care and on-farm diagnostic testing.

7.5 Electrochemical Point-of-Care Biosensor Technology

The term point-of-care biosensors include instruments that can measure the physiological, immunological, and behavioral responses of animals, as well as the monitoring of the animal environment (Wang 2006). Electrochemical point-of-care is a flexible biosensor with a point-of-care functionality used to generate an electrochemical signal measured using a detector and a data analyzer (Dai and Liu 2019).

These instruments are not only extremely precise and sensitive to the parameters being analyzed, but are also accurate and easy to use and can improve the clinical assessment (Wang 2006). The emerging use of point-of-care biosensors in livestock management offers major benefits and applications in the monitoring of animal productivity, health monitoring, and disease detection, as well as monitoring of animal physiological conditions (Gattani et al. 2019; Robinson et al. 2020). The implementation of this technology is expected to enhance animal health and productivity of the livestock industry in the future, as well as to reduce the impact of the livestock industry on the environment (Gattani et al. 2019). In addition, the implementation of point-of-care biosensors in the livestock sector would contribute to social competitive advantage and organizational benefits for the global economy. The latest existing point-of-care biosensors in the veterinary field focus on the use of the available knowledge of animal physiology, nature, biology, nutrition, and the environment, and the incorporation of this knowledge into an effective and real-time diagnostic method (Neethirajan et al. 2017). Different established sensors and their locations in farm animals are presented in Fig. 7.2.

The key point-of-care biosensing devices rely mainly on identifying the desired biological biomarker (e.g, DNA, RNA, enzymes, hormones, metabolites, tissue, blood, cells, etc.) unique to a particular biological agent using a bioreceptor sensor (Wang 2006). The bioreceptor sensor is a key structure in the point-of-care biosensor device since it is crucial for the distinction between various biomarkers and molecules present in the same biological samples. The association between the bioreceptor sensor and the specific biomarker results in specific signals that allow qualitative and quantitative biomarker measurements (Vidic et al. 2017). A detailed overview of the theory and function of the electrochemical point-of-care biosensors has been reviewed elsewhere (Wang 2006; Dai and Liu 2019; Sun and Hall 2019).

The criteria for an ideal point-of-care biosensor in the veterinary sector is similar to that commonly used in human medicine but may vary concerning the particular needs of livestock farming (Kumar et al. 2020). Although designed for human application, respiratory rate sensors were evaluated successfully in cattle to measure thoracic and abdominal movements (Neethirajan 2020). Laser distance sensor while milking is another system for monitoring the respiratory rate of cows (Pastell and Kujala 2007). Sensor-equipped holters (belt-like device on an animal's chest) have been tested to measure the heart rate in dogs (Lahdenoja et al. 2019). Similarly, den Uijl et al. (2017) analyzed the results of behavioral traits such as headshake, walk, sleep, trot, canter, eat, and drink, using a neck collar-embedded with an accelerometer and validated through clinical setting. Several point-of-care diagnostic platforms are currently available in veterinary practice (Table 7.1), and these tools provide automatic readout results greatly reducing the time of diagnosis. However, the complete adoption and application of such innovations and their effective use in diagnostic procedures in livestock clinical practice imply further progress in the robustness of bioassay production and biomarker detection.

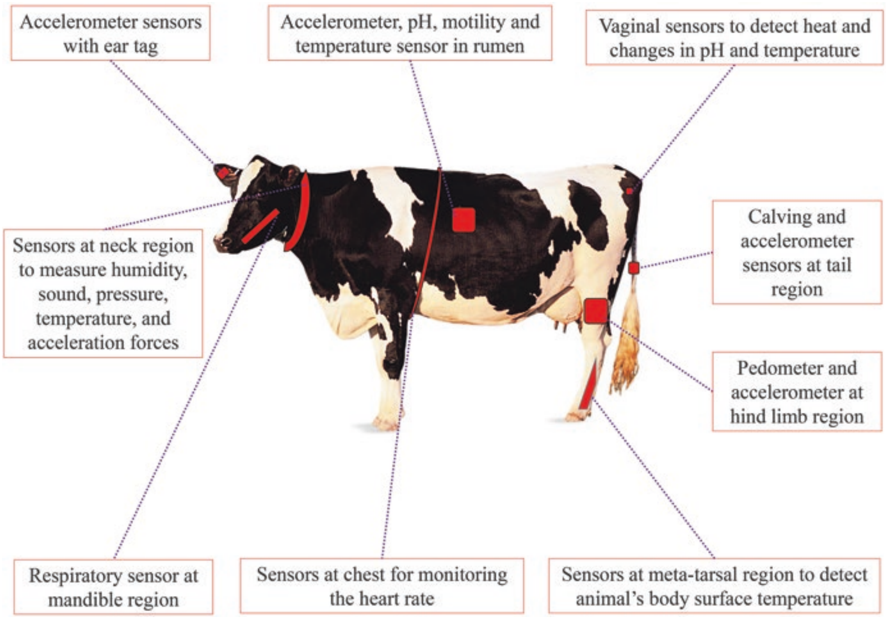

Fig. 7.2 Different established sensors being used in farm animals

7.6 On-Farm Diagnostic Technologies

7.6.1 On-Farm Video Surveillance and Digital Images Analysis Technologies

The frequency of animal behavior changes is often correlated with stress, anxiety, and pathological conditions (Von Holst 1998). These changes in behavior are cost-effective and easy to track via careful observation of individual animals or through the use of video surveillance devices on the farm (Zin et al. 2016). Simultaneous monitoring of these behavioral changes that occur on more than one animal for 24 h a day may be difficult to interpret for the farm observer (Ishiwata et al. 2007). The use of video monitoring systems to track these behavioral activities enables researchers to examine animal activity at their location in real-time (Zin et al. 2016). Further, the availability of digital imaging and the latest innovation of computer programs that can interpret and analyze these data has expanded the use of this technology in the livestock industry to track animal health without distracting the animals (Nilsson et al. 2015). For example, on-farm video monitoring and digital image processing tools have been commonly used for recording particular areas used by individual animals as they get up or lay down to make suggestions on stall size (Ceballos et al. 2004). Moreover, it was also used to track the thermoregulatory clumping of the animal to determine the efficacy of the pen temperature (Shao and Xin 2008). Another example of the use of on-farm video surveillance and digital image

Table 7.1 Some examples of point-of-care diagnostic technologies currently used in livestock husbandry system

Point-of-care test	Health status	Metabolites and agents	Animal species	Sample type	Reference
Protein G-based milk dipstick	Brucellosis	Brucella	Dairy cattle	Blood	Revathi Poonati et al. (2020)
Indirect enzyme-linked immunosorbent (iELISA) assays	Brucellosis	Brucella	Dairy cattle	Blood	Revathi Poonati et al. (2020)
Visual color-based serum phosphorous detection kit	Hypophosphatemia	Phosphorous	Cattle	Blood	D'souza (2020)
Handheld portable lactate analyzer	Bovine respiratory disease	L-lactate concentration	Cattle	Blood	Zeineldin et al. (2017a, b)
Handheld portable lactate analyzer	Healthy	L-lactate concentration	Cattle	Blood	Karapinar et al. (2013)
Portable blood lactate analyzer	Bovine respiratory disease	Plasma lactate	Cattle	Blood	Coghe et al. (2000)
β-hydroxybutyrate hand-held meter	Ketosis	β hydroxybutyrate	Dairy cattle	Blood	Iwersen et al. (2009)
Portable glucometer	Healthy	Blood glucose	Cattle and sheep	Blood	Katsoulos et al. (2011)
Lactate meters	Healthy	L-lactate concentration	Cattle	Blood	Karapinar et al. (2013)
Electrochemical glucose meter	Periparturient healthy cattle	Glucose	Dairy cattle	Blood and plasma	Megahed et al. (2015)
Portable ion-selective electrode meters	Periparturient healthy cattle	Potassium	Dairy cattle	Blood, plasma, milk, and abomasal fluid	Megahed et al. (2016)
Portable somatic cell count-based test	Healthy and sub-clinical mastitis	Somatic cell count	Dairy cows	Milk samples	Iraguha et al. (2017)
FreeStyle Precision Neo™	Healthy	β-hydroxybutyrate and glucose	Dairy cow	Blood samples	Macmillan et al. (2017)

(continued)

Table 7.1 (continued)

Point-of-care test	Health status	Metabolites and agents	Animal species	Sample type	Reference
β-hydroxybutyrate electrochemical meter	Periparturient healthy cattle	β hydroxybutyrate	Dairy cattle	Blood and plasma samples	Megahed et al. (2017)
Point-of-care glucometer	Healthy	Glucose	Goat	Blood samples	Quandt et al. (2018)
Epocal point-of-care analyzer	Healthy	Ionized calcium	Dairy cattle	Blood samples	Mahen et al. (2018)
Erythrocyte osmotic fragility assessment at field level	Stress-related disorders	Erythrocyte membrane	Sheep and goats	Blood samples	Reddy et al. (2019)
Cobalt chloride-impregnated device	Stress-related disorders	Moisture	Cattle	Sweat samples	Pereira et al. (2010)
Leukocyte esterase (LE) test strips	Subclinical endometritis	Leukocyte esterase	Dairy cow	Vaginal discharge	Van Schyndel et al. (2018)
Brix refractometry	Subclinical endometritis	Total solid percentage	Dairy cow	Vaginal discharge	Van Schyndel et al. (2018)
Colorimetric ammonium point-of-care test	Periparturient Holstein-Friesian cows	Ammonium	Dairy cow	Urine sample	Megahed and Constable (2020)

processing technology is the tracking of lameness problems in dairy cows by measuring the shift in animal gait characteristics as they pass to the milking parlor (Berckmans 2014b). The key drawbacks of on-farm video monitoring and digital image processing technologies are the difficulty in detecting the behavior of a large number of animals at the same point over a long period (Von Holst 1998). The challenge of recording in low ambient light and the labor needed to evaluate and display the frequency of such behaviors in individual animals over a long period impedes the application of this technology on a wide scale (Fleishman et al. 1998). Despite current limitations, on-farm video surveillance and digital image processing technologies may be used as a reference framework for other behavior tracking technologies in livestock management system.

7.6.2 On-Farm Audio Surveillance Systems for Sound Detection

Animal vocalization has been commonly used as a significant predictor of animal health status (Manteuffel et al. 2004). Sound monitoring technology has been implemented in the livestock industry to track and regulate animal health and welfare (Wathes et al. 2005; Handcock et al. 2009). The animal sound provides details not only about the abnormal state of the animal but also about the personality of the animal (Manteuffel et al. 2004). Automatic detection of irregular animal behaviors using bioacoustics, such as cough sounds, achieved maximum efficiency and minimal costs at a precision level of over 94% in the livestock industry (Anderson et al. 2011). For example, the use of sound recognition devices in the pig and dairy cattle industry provided an earlier diagnosis of respiratory distress (Exadaktylos et al. 2008; Ferrari et al. 2010). Respiratory diseases in the livestock sector have resulted in significant economic losses due to high mortality and morbidity rates (Zeineldin et al. 2016). Coughing is the primary clinical symptom of respiratory diseases in both cattle and pigs (Carpentier et al. 2018). Monitoring coughing as an indicator of respiratory disease can identify early clinical cases before the occurrence of serious complications and thereby reduce the risk of respiratory diseases in the livestock industry (Ferrari et al. 2010). It is well recognized that existing diagnostic methods for respiratory diseases in livestock are expensive and not very precise. Several attempts have therefore been made to classify the coughing characteristics in various animal species as a sign of respiratory diseases. Since coughing sound during respiratory distress has unique characteristics, the clinical use of on-farm audio surveillance systems to investigate cough sounds may be beneficial for real-time monitoring (Chung et al. 2013). Several algorithms have been validated for various cough sounds characterization in the livestock industry (Berckmans 2014b).

The advantage of using on-farm audio monitoring systems for sound detection is that the non-invasive nature of this device does not interfere with the daily activities of animals (Ferrari et al. 2008). In addition, this technology may be used to track multiple individuals at the same time. However, this may result in overlapping and less coherent sounds in a commercial setting (Carpentier et al. 2018). Despite the usefulness of this technology in early disease detection and tracking animal sounds, more consideration needs to be given to the realistic application and avoid drawbacks of these technologies in the veterinary field.

7.6.3 On-Farm Accelerometers and Pedometer for Walking and Standing Behavior Monitoring

Several automated technologies have been used in the livestock industry to track animal walking and standing activity as well as to record step frequency, including the use of accelerometers and pedometers placed on animals employing various wearable devices such as collars, ear tags, leg or tail bands (Rushen et al. 2012). Over the last few years, accelerometers are probably the most promising technology for providing accurate data on activity tracking, body orientation, and complex posture behaviors (Sala et al. 2011). These instruments have been used to remotely assess animal walking distance and animal orientation (Rothwell et al. 2011; Ringgenberg et al. 2010; Enstipp et al. 2011). Besides, accelerometers have been used to track lying down activity, rumination, feeding, sleep pattern, approaching parturition, and lameness in dairy cows (Martiskainen et al. 2009). Similarly, pedometers are an inexpensive, simple, portable electronic system used to measure the number of distance traveled and the status of the animal's behavior using a mechanical sensor (Shepley et al. 2017). Recently, pedometer devices have also shown strong predictability when used to classify estrus behavior (Løvendahl and Chagunda 2010). Furthermore, a pedometer can assess several cow activities, including locomotion behavior (Alsaaod and Büscher 2012) and approaching calving time (Felton et al. 2013). The application of accelerometers and pedometers in livestock involves using three main components: the main device, the receiving system, and the software program. The receiving system collects animal activities from the attached sensor and transmits these data in real-time through the receiving system to the software program (Brehme et al. 2008). The advantage of on-farm accelerometers and pedometer technologies is the continuous monitoring of animals in commercial systems, particularly when paired with other portable techniques (Moreau et al. 2009; O'Leary et al. 2020). The pitfalls of using these instruments for behavioral tracking include the expense of accessing sensor data and data processing. The risk of damage to sensor boxes due to continuous movements of the animal in the barn and growing labor demand for fixing and removing equipment from livestock are another disadvantage (Norling 1991). However, further modification including increasing battery life, memory capacity, and reducing the device size to be conveniently attached to the animal can efficiently transform on-farm accelerometers and pedometer technologies into functional behavioral measurements technologies.

7.6.4 On-Farm Global Positioning Systems (GPS) for Position Monitoring

On-farm GPS technology is designed to monitor the animal's location and remotely track the movement of the animal within a given area of the farm (Moen et al. 2001). The detailed methodology of GPS collars functioning is presented in Fig. 7.3. The GPS is designed to additionally inform the animal keeper of the distribution of animals on pastures (Griffin 2009). It can also track animal movement using a digital map for easy monitoring and submit information on animal status, such as animal behavior, delivery time, and position (Tang and Abplanalp 2014). Recently, low-cost GPS positioning sensors have been used in veterinary practice to assess the position status of animals (Godsk and Kjærgaard 2011). GPS sensors are attached to the animal collars to detect possible changes in animal behavior, such as feeding, walking, lying down, and standing, which may be associated with stressful situations or changes in animal health (Tang and Abplanalp 2014). Advances in GPS technology have produced lighter and more precise receivers, but the identification of numerous animals in various geographical regions is still difficult (Davis et al. 2011; Foley and Sillero-Zubiri 2020). The drawbacks of GPS technology include costs, battery life, and the frequency of animal location updates. Current technology enables the animal's location to be changed every second, but this rate exceeds the capacity resources available in most animal tracking barns (Tomkiewicz et al. 2010). These limitations restrict the ability to use GPS systems in behavioral tracking for longer periods and limit their use in small local zones. Furthermore, attaching the GPS to the animal collars may have an adverse effect, such as decreased power, tissue damage, and the death of the animal. Therefore, there is still much research needed to improve this technology concept and components used in these devices to be widely used on large scale.

7.6.5 On-Farm Automatic Milking Robot System for Monitoring Leg Health

The milking robot technology was used to track the leg health of the dairy animal in which the sensors were attached to the amplifier and the data was collected on a computer using advanced processing software (Pastell and Kujala 2007). This

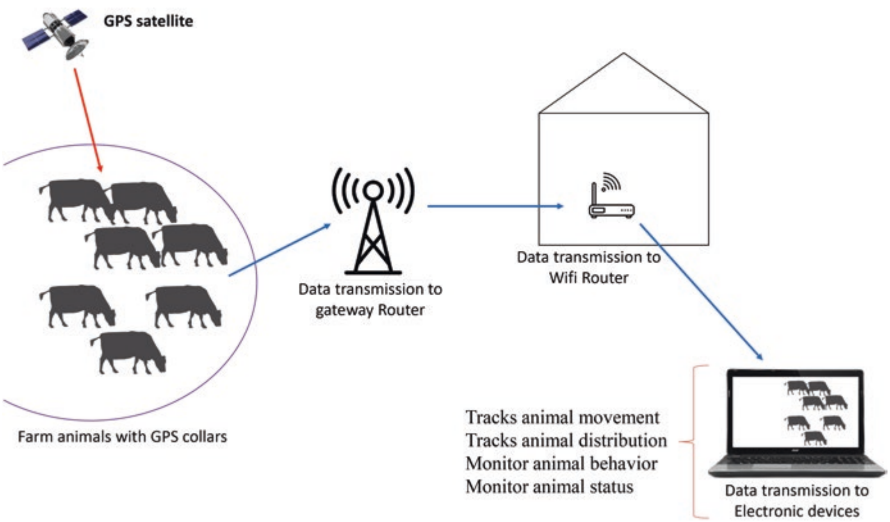

Fig. 7.3 Methodology of GPS collars functioning

technology can be used to automatically detect kick frequency during milking, which warns the operator of potential hoof diseases and other leg problems, but more work is required to improve accuracy (Borderas et al. 2008). Automated milking robots automatically collect data during the milking process and track poor health conditions in a regulated, confined barn up to three times a day. For example, lameness in dairy cows is evident in a reduced frequency of visits to robot system technology (Bach et al. 2007), but this appears to have a low specificity as many other cows are not lame (Borderas et al. 2008). Research focused on the weight distribution between the limbs and the probabilistic neural network showed that automated weight distribution measurements could classify lame cows markedly faster than those obtained by visual inspection applying gait score systems (Pastell et al. 2006). Moreover, these weight distribution steps are responsive to the degree of discomfort associated with lameness (Visen et al. 2002; Chapinal et al. 2011), but the relationship between input and output values is difficult to translate into mathematical representation (Visen et al. 2002). Therefore, the impact of different management factors and their interaction with the robot utilization should be carefully considered together to improve the system efficiency in livestock.

7.6.6 On-Farm Automated Feeder for Monitoring Feeding Behavior

Farm animals are increasingly housed in groups where disease is challenging to identify, leading to increased morbidity and care costs. Automatic detection of feed, water, and frequency of particular behaviors of animals, typically through radio frequency recognition, can be used for early identification of animals that are ill and can provide insight into potential improvements in the pain conditions of animals (Weary et al. 2009). Sick animals spend more time in the feed bunk than healthy ones, particularly the newly received animals (González et al. 2010). Data from such feeders can help recognize morbid animals from healthy ones based on differences in feeding behaviors (Sowell et al. 1999). Recording variations in feed behavior can also help track dairy cows suffering from periparturient diseases such as metritis, ketosis, or lameness (Proudfoot et al. 2010). Current limitation in monitoring the animal feeding behavior is the setup requirement, system maintenance, and the associated cost (Brown-Brandl and Eigenberg 2011). All of these possible drawbacks must be addressed when assessing automated feed intake and behavioral monitoring systems.

7.6.7 On-Farm Physical Inspection for Monitoring Health and Stress-Related Disorders

Any health and stress-related problems are reflected in the physiological parameters such as rectal temperature, pulse rate, and respiratory rate. Simple evaluation of these variables with physical or visual inspection for few minutes may explain the underlying health-related issues. However, quantification of these parameters involves animal contact, restraint, and human-interface (Jorquera-Chavez et al. 2019). Besides, monitoring these activities in large flocks is time-consuming, labor-intensive, and subjective, being inappropriate at the field level. Reddy et al. (2019) projected panting score as the facile measure for quantifying health problems, especially respiration-related issues. They attributed the technique's eminence to its non-invasive functioning of direct observation from two or three meters away from the animal (Nejad and Sung 2017). Therefore, digitalization of diagnostic technology to stress-related disorders through precision livestock farming technologies has the potential to address many aspects of animal health and related to animal welfare and public health.

7.6.8 On-Farm Monitoring Change in Core Body Temperature

Body temperature is the most useful measure of animal reactions to physical-environmental stimuli, occurrence of diseases, and physiological functions such as diet, lactation, and reproduction (Galan et al. 2018). Remote temperature monitoring may help to rapidly detect diseases, minimizing associated treatment costs, and improving animal efficiency (Liang et al. 2013). Core body temperature is determined by many factors such as health status, physiological status, environmental temperature, humidity, water consumption, and feed intake (Davis et al. 2003). Core body temperature can be measured using a variety of methods, such as rectal probe, tympanic membrane, implanted transmitter, infrared thermography, and rumen temperature bolus (Firk et al. 2002). These approaches reflect mechanized technologies, but we must ensure that they are the most reliable, practical, and economical (Firk et al. 2002). Rectal probe is an alternative to conventional rectal thermometers since thermometers are labor-intensive and time-consuming (Godyń et al. 2019). Measurement of body temperature using a rectal probe is useful by continuous measurement of changing temperature over time; however, existing measurement methods are only suitable for single or short-term continuous measurements (Reuter et al. 2007). The rectal probe approach causes the loss of certain data while removing it out of the rectum. Hence, the probe must be connected to the animal in a manner that is not feasible for large-scale use. On the other hand, tympanic temperatures are a reliable indicator of heat stress in cattle, with scales somewhat close to rectal temperatures (Gasim et al. 2013). To measure the tympanic temperature, thermistor is connected to the data logger and then inserted several cm down the ear canal until the tip is located near the tympanic membrane; nevertheless, the implementation of these techniques requires trained staff (Mader et al. 2002). The tympanic temperature procedure can only be used for limited numbers of animals and should not be used for long periods (Goodwin 1998). Animals with tympanic membrane recorders should also be closely monitored for infection at the insertion site (Davis et al. 2003).

Other methods for tracking core body temperature are infrared thermography (IRT) and rumen temperature bolus. Thermography imaging was used to detect nasal mucosal temperatures in a non-invasive manner (Willatt 1993) and corneal surface temperatures (Stewart et al. 2008). In bovine medicine, IRT is used mainly for diagnostic purposes, animal health evaluation, and feed quality monitoring (Montanholi et al. 2010). It has also been used for the prediction and early diagnosis of mastitis and lameness in dairy cattle (Hovinen et al. 2008; Alsaaod and Büscher 2012; Stokes et al. 2012). Additionally, IRT has been used for bovine respiratory disease diagnosis at an earlier stage (Schaefer et al. 2007). The key drawbacks of these technologies are that images must be obtained in direct sunlight, and animal hair coats must be free of soil, moisture, and foreign material (Stewart et al. 2005). Other drawbacks of infrared thermography include the cost of infrared cameras, size, angle of measurement, and animal activity (Johnson et al. 2011). Therefore, IRT requires some adjustment before it becomes practical for the livestock industry.

Developing rumen temperature bolus for tracking core body temperature can be the most appropriate way for producers to monitor body temperature. These boluses could also periodically collect data at different time intervals to monitor sudden or subtle changes in the ruminal environment (Edwards 2010). The benefit of rumen temperature bolus over other approaches is the quick administration without side effects to the animal and the potential to track the large flock at once (Ipema et al. 2008). Rumen bolus is delivered by a baling gun and can be safely recovered after slaughter and does not irritate the epithelium of the reticulo-rumen wall (Ghirardi et al. 2006). This approach may have the longest duration in the body. Nonetheless, it may present some challenges for recovery in commercial harvesting facilities and the dynamics of rumen makes it susceptible to changes in the temperature from water intake and the type of diet due to fermentation (Timsit et al. 2011; Makinde 2020).

7.7 The Future Direction and Challenges of On-Farm and Point-of-Care Diagnostic Technologies

Advances in on-farm and point-of-care diagnostic technology have been linked to acceleration of mechanization, which could promote diagnostic validation, strengthen veterinary surveillance systems, increase livestock efficiency and improve animal welfare (Jones et al. 2019). Therefore, the potential effect of using this diagnostic technology depends on the number of livestock farming systems and the number of animals in each system to which these technologies will apply. These new devices will encourage investment and will support our society (Abuelo and Alves-Nores 2016). The biggest challenge for global economies is to bring new products that meet customer needs in a cost-effective and productive manner. Other critical problems currently faced by on-farm diagnostic technologies are the sluggish usage of these technologies on a broad commercial scale and lack of harmonization between the use of these technologies and the large-scale implementation of data analysis (Busin et al. 2016). The key explanation for this is the abundant data produced and the available technology's inability to promptly turn the ample data into useful knowledge that could be used in the decision-making process. Additional work on the system using these technologies will also contribute to implementing the next generation of an economical and appropriate health monitoring system, which will capture additional behavioral changes related to the level of operation and connect the collected animal data to predict animal health events. The new technology has now reached a stage where its application to biological processes has become practical. Moreover, the livestock industry requires a large number of animals and procedures, making it possible to manufacture personalized, applied low-cost technology (Berckmans 2014a). Of course, no major advancement in precision livestock medicine come without disadvantages. Point-of-care and on-farm diagnostic technologies are still in the early stages of implementation particularly in veterinary medicine, and several major issues will need further research before these techniques become practical with a wide application in livestock management systems.

7.8 Summary and Conclusion

This chapter explains basic on-farm and point-of-care diagnostic technologies as a valuable way of monitoring animal health, welfare, and disease in the livestock industry. The promise of using this technology is valid; however, some drawbacks need to be tackled. Advances in on-farm diagnostic technology will increase the market's efficiency and make these technologies more competitive in the livestock sector. This chapter outlines the attached and unattached type of technologies for tracking physiological and behavioral responses that are important for evaluating animal welfare. The choice of the appropriate diagnostic method depends on the anticipated gain relative to the cost of the device used. Behavioral evaluation must also be selected based on their importance to animal welfare rather than their ability to be reported automatically. Further work on the system using these types of technologies will contribute to creating a next-generation, feasible, and cost-effective animal health monitoring system to detect other critical activities that will enable producers to introduce prevention and treatment protocols against diseases at earlier times.

Conflicts of Interest The authors declare no conflict of interest.

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