Precision livestock farming in the context of meat safety assurance system

I Nastasijevic\textsuperscript{1}, I Brankovic Lazic\textsuperscript{1} and Z Petrovic\textsuperscript{1}

\textsuperscript{1} Institute of Meat Hygiene and Technology. Kacanskog 13, 11040 Belgrade

E-mail: ivan.nastasijevic@inmes.rs

Abstract. The food chain continuum ‘from farm to fork’ should be managed to provide the appropriate level of consumer protection. Healthy animals are the essential precondition for obtaining a safe food supply. A science-based risk assessment includes the information about prevalence and concentration of major public health hazards of zoonotic origin (Salmonella, Campylobacter, Listeria monocytogenes, Yersinia, Verotoxin-producing E. coli/VTEC) and chemical contaminants (residues of veterinary drugs, dioxins, mycotoxins) in all modules along the food (meat) chain: farm-transport-slaughterhouse-meat processing-distribution-retail-consumers. The effective monitoring of biological or behavioural symptoms related to animal health and welfare can be achieved by Precision Livestock Farming (PLF). PLF emerged as a farm management approach based on information and communication technology (ICT). It can enable the early disease detection system using electronic information transfer from biosensors, in optimising animal health, production and management processes on farm. PLF can deliver added value to the integrated meat safety assurance system (MSAS) by providing real-time evidence of animal health and welfare status. This will strengthen understanding of all three major aspects of MSAS that must be monitored: biological hazards (farm-slaughterhouse continuum), animal health and welfare (Food Chain Information (FCI) quality and flow), and contaminants (prioritisation in monitoring based on FCI information).

1. Introduction

The food chain continuum “from farm to fork” should be managed to provide the appropriate level of consumer protection (ALOP). This can be achieved by science-based risk assessment which includes information about prevalence and concentration of major public health hazards of zoonotic origin (Salmonella, Campylobacter, Listeria monocytogenes, Yersinia, Verotoxin-producing E. coli/VTEC) in all modules along the food (meat) chain: farm-transport-slaughterhouse-meat processing-distribution-retail-consumers. Since hazards can enter the food chain at multiple points, the risk assessment should be carried out to provide knowledge about the most effective control measures which should be typically applied in a synergistic way to minimise the occurrence of food safety hazards in the food chain. Healthy animals are the essential precondition for obtaining a safe food supply. It is of the utmost importance to apply effective control measures on-farm with the aim to reduce the load of contamination in subsequent modules along the food chain. Recently, Precision Livestock Farming (PLF) emerged as a farm management approach based on information and communication technology (ICT) that is having a rapidly growing impact on the methods used in livestock production [1]. PLF can enable the early disease detection system by facilitating detection of clinical signs or symptoms (either biological or behavioural) that the animals exhibit. These signs can easily be picked up at a very early stage, to limit or avoid the occurrence of diseases, hence to avoid the use of antimicrobials, as well as to monitor animal welfare.

1.1. Precision Livestock Farming concept

PLF applies principles of control engineering using electronic information transfer, e.g. from biosensors, in optimising animal health, production and management processes on farm. PLF consists of measuring variables on the animals (good health, welfare, behavioural changes, good productive
performance, good reproductive performance) [2], modelling these data to select information, and then using these models in real time for monitoring and control purposes. PLF is based on the philosophy that fully automated, continuous monitoring of animals enables farmers to monitor the health and welfare status of their animals continuously and automatically and help them make quick and evidence-based decisions to adjust to changes in animal requirements, e.g. in-built collar sensors to detect specific behavioural parameters, sound or visual technologies in pig farms, that allow the continuous monitoring of behavioural/respiratory symptoms, nanobiosensors integrated with Internet-of-Things (IoT) technology for rapid and real-time monitoring of infections/animal diseases on farm. PLF supports intelligent management of animal health including rapid alert systems to meet the growing demand for animal proteins, while guaranteeing animal health and welfare, the future sustainability of animal farming, as well as improved food safety [3].

The main purpose is to obtain real-time, valid information regarding both (i) animal health (e.g. production diseases) and associated economic gains or losses, and (ii) food (meat) safety (e.g. zoonotic food borne pathogens – *Salmonella*, Verotoxin-producing *E. coli*/VTEC, *Campylobacter*, *Yersinia*) and associated consumer health issues affecting public health. Therefore, PLF is currently considered as a state-of-the-art engineering endeavour towards sustainability in (primary) food production improving, consequently, consumers’ health through the more effective public health protection. The application of PLF allows optimal use of knowledge and information in the monitoring and control of processes on farm. In addition, such approach allows extension to the further step in the meat chain regarding defining the most effective control measures and risk mitigation strategies at the abattoir level. Therefore, PLF can be used strategically to support Food Chain Information (FCI) flow in the farm-to-chilled carcass continuum, as well as to facilitate decision-making by the risk managers, e.g. official veterinarian and/or authorised auxiliary appointed by the food business operator (FBO) in terms of the scope and type of the ante-mortem and post-mortem inspection. Overall, PLF can serve effectively in supporting a risk-based meat safety assurance system.

2. **Main challenges in the livestock and meat sector**

It is predicted the worldwide increase of animal products will be around 70% by 2050, which could present mankind with some serious problems [4], and the worldwide demand for meat and animal products is expected to increase by at least 40% in the next 15 years [5]. Many opinions given by the scientific community stated that the solution lies in stopping or reducing meat consumption [3]. However, it is not easy to stop or forbid people from eating meat and change their habits in a rapid manner, and these facts should not be neglected. Therefore, feasible solutions and alternatives to mitigate growing problems should be found. A major challenge within the next 10 years is how to enable continuous monitoring of animal health within big groups of animals [3]. Due to the increasing number of animals and the decreasing number of farmers, every farm will house more animals. In the future, a single farm (or animal city) could see 25,000 milking cows, 200,000 fattening pigs, or a few million broilers. Infections in such big groups can have disastrous economic and public health consequences [3]. This is also in relation to the prudent use of antibiotics in food animals and the pressure for antibiotic reduction, since overuse of antibiotics can lead to development of antimicrobial resistance in humans, associated with the food (meat) consumption [6]. For example, in the European Union (EU), study of *Salmonella* from humans, as well as *Salmonella* and *E. coli* isolates from fattening pigs and calves of less than one year of age, showed high proportions of isolates were resistant to ampicillin, sulphonamides and tetracyclines, while resistance to third-generation cephalosporins was uncommon; in *Campylobacter* isolated from humans, high to extremely high proportions of isolates were resistant to ciprofloxacin and tetracyclines [7]. In the EU in 2017, there were 643 strong-evidence food borne outbreaks (12.7% of total outbreaks), with 60% of them associated with food of animal origin, in particular meat and meat products (i.e. including meat from poultry, pork, bovine, sheep and other unspecified red meats and their products) [8], with more than 246,000 people being affected by food borne diseases, including the significantly increased antimicrobial resistance outbreaks from 10.4% in 2014 to 14.9% in 2017 [7].
While the reduction of antibiotic use is a primary challenge, the development of vaccines will take time, and the efficiency of applying vaccines in big herds must be monitored to improve them [3]. Having in mind all abovementioned issues it is evident that the animal health is a top priority in relation to human health.

3. Precision Livestock farming and meat safety assurance system

PLF can serve effectively as a powerful management tool to support the integrated meat safety assurance system (MSAS). Namely, the European Food Safety Authority (EFSA) has recently proposed a generic framework for a modern, flexible and dynamic risk-based meat safety assurance system. Implementation of such a system is expected to be a slow and careful process across the EU and it would involve thorough development, fine-tuning and testing its practical feasibility, as well as general impacts [9].

3.1. Meat safety perspective

The safety of meat can be jeopardised by numerous biological, chemical and physical hazards. To tackle them, meat controls have traditionally been based on official meat inspection and/or on laboratory end-product testing. The system of traditional post-mortem meat inspection, comprising visual inspection, palpation and incision of carcasses and organs of slaughtered animals, was developed in the nineteenth century to deal with zoonotic diseases of importance at that time, e.g. trichinellosis, brucellosis, tuberculosis and cysticercosis/taeniasis. Since these diseases were relatively prevalent in Europe 150 years ago, this meat inspection was, indeed, originally risk-based. During recent decades, the scope of meat inspection has been substantially extended. Other public health issues have attracted attention, such as the presence of residues of veterinary medicines or other chemical substances, as well as TSE/BSE controls (Specified Risk Material), but also animal health and welfare protection, meat quality assurance, control of slaughter by-products and protection of the environment. Such a multi-purpose framework of control measures should provide valuable contributions to public health protection. However, many diseases for which meat inspection procedures were initially developed, 150 years ago, are rare today or even eradicated in many European countries. Meanwhile, other meat-borne diseases have emerged. Although the nature of the problems in meat safety have obviously significantly changed over time, the system of meat inspection has practically remained unchanged in Europe until modern times [10, 11]. The traditional meat inspection is not designed to deal with the currently most relevant meat-borne hazards such as Salmonella, Campylobacter, Yersinia enterocolitica, verocytotoxigenic Escherichia coli (VTEC) or Toxoplasma gondii, including associated antimicrobial resistance (AMR), nor with chemical hazards (residues of veterinary drugs, mycotoxins, dioxins, etc.), as these hazards usually do not cause clinical disease or result in macroscopic lesions in animals. On the contrary, the presence of lesions resulting from an infection months earlier will in many cases lead to condemnation of the meat/carcass, although the food safety burden is negligible [9].

3.2. The integrated meat safety assurance system concept

A novel concept of MSAS will be risk-based and will encompass the most relevant aspects in the farm-to-slaughterhouse continuum, as follows: (i) Biological hazards i.e. define clear targets for main hazards in/on carcasses and obtaining new data on biological hazards; develop the most effective control options for the main hazards, at both farm and slaughterhouse level; categorise herds/farms and slaughterhouses according to the magnitude of risk posed by biological hazards; and omit routine palpation or incision techniques in post-mortem inspection, (ii) Animal health and welfare i.e. design meat inspection, ante-and post-mortem, as a valuable tool for surveillance and monitoring of specific animal health and welfare conditions [12]; introduce only visual post-mortem inspection and compensate the potential loss of information regarding surveillance of animal disease and welfare with other approaches; improve the FCI quality and flow, (iii) Contaminants i.e. monitor chemical residues and contaminants based on risk of occurrence and using prioritisation based on FCI information,
introduce more flexible control programmes based on test results and addressing emerging hazards, introduce more integrated sampling, testing and intervention protocols for monitoring chemicals in the food chain and environmental contaminants [9].

3.3. Interface between Precision Livestock Farming and Meat Safety Assurance System

PLF can be successfully integrated in a novel concept such as the Meat Safety Assurance System (MSAS). As a multidisciplinary approach, PLF requires collaboration among animal scientists, physiologists, veterinarians, ethologists, engineers, and information and communication technology (ICT) experts. Such an approach can serve well as support for the FCI flow and communication in the farm-slaughterhouse continuum. This, in turn, can facilitate decision-making by the risk manager (e.g. official veterinarian with assistance of authorised auxiliaries from meat business operator). Based on FCI, supplemented with valid and real-time information obtained by the PLF system, the risk manager can respond in a timely and risk-based manner, defining the scope and type of necessary meat inspection protocol in relation to the health and welfare status of incoming animals from respective farms (e.g. ante-mortem and post-mortem inspection – to omit palpation/incision or not).

Therefore, PLF can deliver added value to the MSAS by providing automatic detection (via biosensors) of a variety of animal health and welfare conditions. Disturbed animal health and welfare can lead to increased faecal shedding of zoonotic food (meat) borne pathogens and consequently to increased probability for cross-contamination of animals’ hides/skins/feathers on-farm/transportation/lairage, as well as carcasses at the slaughter line, and presents a food safety threat to consumers. PLF can contribute by providing real-time evidence of animal health and welfare status, which leads to better understanding of all three major aspects of MSAS: biological hazards (farm-slaughterhouse continuum), animal health and welfare (FCI quality and flow), and contaminants (prioritisation in monitoring based on FCI information) (Figure 1).

For example, the PLF approach can provide real-time (automatic) detection for the wide range of conditions related to animal health and welfare on farm [13], such as: detecting lameness in solipeds using acceleration data from ear tags, automatic 3D vision locomotion monitoring for cows, monitoring of physiological and behavioural stress in animals, monitoring of vocalisation sounds to assess response of broilers to environmental variables, pig cough monitoring as indicator of respiratory disease and environmental conditions, drinking behaviour of animals, automatic detection of health (body temperature) with a video-based infrared thermography camera, evaluating hormone profiles to improve automated oestrus detection.

From the meat safety perspective, rapid detection of major zoonotic food (meat) borne pathogens (e.g. Salmonella, Campylobacter, Cl. perfringens) is of the utmost importance. This can be done by the application of innovative biosensing systems (biosensors) based on specific biomarkers for pathogens affecting animal health, such as DNA receptors, glycan, aptamers and antibodies [13]. A biosensor recognises a target biomarker characteristic for a respective pathogen, via an immobilised sensing element – bioreceptor (monoclonal antibody, RNA, DNA, glycan, lectin, enzyme, tissue, whole cell). The specific biochemical interaction between the biomarker and the bioreceptor is then converted into a measurable signal by the transducer (Figure 2). Especially, paper-based platforms (microarrays) can be effectively used on-farm as affordable, rapid and easy to conduct sensing systems for implementation in field conditions [14].
**Figure 1.** Interface of Precision Livestock Farming (PLF) and Meat Safety Assurance System (MSAS)
Figure 2. Principle of biosensor based on biochemical interaction between the biomarker and the bioreceptor (adapted from [14])

4. Conclusion
The food chain continuum “from farm to fork” should be managed to provide the appropriate level of consumer protection (ALOP). This can be achieved by science-based risk assessment which includes the information about prevalence and concentration of major public health hazards of zoonotic origin (Salmonella, Campylobacter, Listeria monocytogenes, Yersinia, Verotoxin-producing E. coli/VTEC) in all modules along the food (meat) chain: farm-transport-slaughterhouse-meat processing-distribution-retail-consumers. Healthy animals are the essential precondition for obtaining a safe food supply. PLF emerged as a farm management approach based on ICT that is having a rapidly growing impact on the methods used in livestock production. PLF can enable the early disease detection system by facilitating detection of clinical signs or symptoms (either biological or behavioural) that the animals exhibit. These signs can easily be picked up at a very early stage, to limit or avoid the occurrence of diseases, hence to avoid the use of antimicrobials, as well as to monitor animal welfare. PLF applies principles of control engineering using electronic information transfer, e.g. from biosensors, in optimising animal health, production and management processes on farm. PLF consists of measuring variables on the animals (good health, welfare, behavioural changes, good productive performance, good reproductive performance), modelling these data to select information, and then using these models in real time for monitoring and control purposes. PLF enables farmers to monitor the health and welfare status of their animals continuously and automatically and help them make quick and evidence-based decisions to adjust to changes in animal requirements. The main purpose is to obtain real-time, valid information regarding both (i) animal health (e.g. production diseases) and
associated economic gains or losses, and (ii) food (meat) safety (e.g. zoonotic food borne pathogens) and associated consumer health issues affecting public health. Therefore, PLF is currently considered as a state-of-the-art engineering endeavour towards sustainability in (primary) food production, consequently improving consumer health through the more effective public health protection it provides. Since the worldwide increase of production of animal products will be around 70% by 2050, this will present mankind with some serious problems, and the worldwide demand for meat and animal products is expected to increase by at least 40% in the next 15 years. New challenges regarding meat safety that have arisen over the previous decades are different from the classic zoonotic diseases that were relevant in the nineteenth century (trichinellosis, brucellosis, tuberculosis, cysticercosis/taeniasis); instead, emerged, current meat safety threats are associated with zoonotic meat-borne pathogens (Salmonella, Campylobacter, Yersinia enterocolitica, VTEC, Toxoplasma gondii and AMR) and chemical contaminants (residues of veterinary drugs, dioxins, mycotoxins). However, the current meat inspection system was designed more than 150 years ago and is ineffective in detecting and controlling the aforementioned emerged meat-borne threats now relevant. Therefore, there is a strong need for re-design of the meat inspection system and development of the novel concept of integrated MSAS, which will encompass all relevant modules along the meat chain, from farm to consumer. PLF can deliver added value to the MSAS by providing automatic detection (via biosensors) of a variety of animal health and welfare conditions. Such an approach can contribute, by providing real-time evidence of animal health and welfare status, to better understanding of all three major aspects of MSAS that should be monitored: biological hazards (farm-slaughterhouse continuum), animal health and welfare (FCI quality and flow), and contaminants (prioritisation in monitoring based on FCI information). PLF also facilitates the decision-making of risk managers (veterinary inspectors, assisted with official auxiliaries) when it comes to the scope and type of ante-mortem and post-mortem inspection at slaughterhouse level. Therefore, PLF can serve as a powerful tool for evidence-based and risk-based MSAS which should increase the public health protection, as well as reduce the economic burden to all stakeholders in the meat industry (farmers, meat business operators and consumers)

Acknowledgment
This paper is prepared with reference to ongoing COST action 18105: Risk-based meat inspection and integrated meat safety assurance (RIBMINS).

References
[1] Berckmans D 2008 Precision livestock farming (PLF) Comput. Electron. Agric. 62 1
[2] Tullo E Finzi and A Guarino M 2019 Review: Environmental impact of livestock farming and Precision Livestock Farming as a mitigation strategy Sci. Total Environ. 650 2751–60
[3] Berckmans D 2017 General introduction to precision livestock farming Animal Frontiers 7(1) 11–1
[4] FAO 2009 Global agriculture towards 2050. High-level Expert Forum: How to feed the world 2050, Rome 12-13 October 2009. http://www.fao.org/fileadmin/templates/wsf5/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf (accessed on 9 May 2019)
[5] OIE 2014 Precision livestock farming technologies for welfare management in intensive livestock systems Rev. Sci. Tech. Off Int. Epiz. 33(1) pp 189–96
[6] WHO 2011 Tackling antibiotic resistance from a food safety perspective in Europe. ISBN 978 92 890 1422 9 (ebook). http://www.euro.who.int/__data/assets/pdf_file/0005/136454/e94889.pdf?ua=1 (accessed on 9 May 2019)
[7] ECDC 2018 Surveillance of antimicrobial resistance in Europe – Annual report of the European Antimicrobial Resistance Surveillance Network (EARS-Net) 2017. Stockholm: ECDC. ISBN 978-92-9498-279-7. DOI 10.2900/230516
[8] EFSA 2018 EU summary report on zoonoses, zoonotic agents and food-borne outbreaks 2017. *EFSA J.* **16**(12) 5500

[9] EFSA 2013 Scientific Opinion on the public health hazards to be covered by inspection of meat (solipeds). Scientific Opinion on the public health hazards to be covered by inspection of meat (bovine animals). Scientific Opinion on the public health hazards to be covered by inspection of meat from sheep and goats. Scientific Opinion on the public health hazards to be covered by inspection of meat from farmed game. *EFSA J.* **11**(6) 3263-6

[10] Regulation (EC) 854/2004 laying down specific rules for the organization of official controls on products of animal origin intended for human consumption. [https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004R0854&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004R0854&from=EN) (accessed on 11 May 2019)

[11] Regulation (EU) 2017/625 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products. [https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0625&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0625&from=EN) (accessed on 11 May 2019)

[12] Nastasijevic I, Lakicevic B, Raseta M, Djordjevic V, Jankovic V, Mrdovic B and Brankovic Lazic I 2018 Evaluation of pig welfare in lairage and process hygiene in a single abattoir. *Meat Technol.* **59**(1) 8–22

[13] Halachmi I 2015 Precision livestock farming applications. Wageningen Academic Publishers. ISBN: 978-90-8686-268-9. https://doi.org/10.3920/978-90-8686-815-5

[14] Vidic J Manzano M Chang C M and Jaffrezic-Renault N 2017 Advanced biosensors for detection of pathogens related to livestock and poultry. *Vet. Res.* **48**(11) 1–22