

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable production of poultry meat

Volume 1: Safety, quality and sustainability

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Introduction

Poultry meat production faces a range of challenges. To meet growing demand, the FAO has estimated that the world poultry production needs to grow by 2.5% per year up to 2030, and by as much as 3.4% in developing countries. Much of the increase in output already achieved has been as a result of improvements in commercial breeds combined with rearing in more intensive production systems. However, these systems face a number of problems in achieving further sustainable increases in production. More intensive systems and complex supply chains have increased the risk of rapid transmission of zoonoses, which remains a significant challenge (including the risk of pathogens developing antibiotic resistance). At the same time consumers' expectations of sensory and nutritional quality have never been higher. Consumers' attitudes now also encompass wider concerns such as the environmental impact and sustainability of poultry production. These challenges are addressed in this collection: *Achieving sustainable production of poultry meat Volume 1: Safety, quality and sustainability*.

Poultry meat safety

The first part of the book reviews continuing challenges in ensuring the safety of poultry meat. Chapter 1 begins by reviewing current research on *Campylobacter*, which is emerging as the leading cause of bacterial foodborne illness related to poultry products in many countries. Despite stringent biosecurity on farm and control measures during processing, the number of cases of *Campylobacter* has continued to rise each year in countries such as the United Kingdom. Unlike *Salmonella*, currently no effective vaccine for *Campylobacter* spp. has been discovered for either the human or the poultry populations. As the chapter shows, farm interventions including biosecurity, altering the diet, use of prebiotics and probiotics, and additives have not been found to be consistently effective. Other techniques during processing such as rapid chilling, surface washes and irradiation have also had limited success in controlling the pathogen without affecting quality. In addition, having traditionally been seen as a commensal of broiler chickens, *Campylobacter* is increasingly regarded as potentially pathogenic to poultry. As the chapter points out, there is a need for more research on *Campylobacter* pathogenesis to develop more effective interventions. There is also a need to explore the biology of *Campylobacter* in chicken to better understand the effect it has on the health, welfare and performance of broilers.

Chapter 1 is complemented by Chapter 10, which discusses in more detail where we are in achieving effective control of *Campylobacter*. The chapter reviews ways by which *Campylobacter* can spread around farms and how effective biosecurity measures are in reducing horizontal transmission. It also discusses key findings in the use of antimicrobial therapy, including the relative ineffectiveness of probiotics against *Campylobacter*, as well as studies of the potential use of botanicals. Finally, it summarises progress in developing vaccines, including DNA vaccines. Like Chapter 1, it underlines the need for more research on this pathogen in the context of poultry meat production.

Chapter 2 provides an authoritative review of the state of the art in control of *Salmonella*, which remains the major cause of poultry-related foodborne illness in countries such as the United States, including emerging risks associated with new serovars. The chapter

summarises our current understanding of the invasion and transmission mechanisms of *Salmonella*. As it indicates, further research is needed to understand the complete roles of humoral and cell-mediated immunity.

The chapter also reviews the wide range of methodologies for the sampling and bacteriological detection of *Salmonella* in poultry flocks, their weaknesses and strengths, and the development of new techniques, including polymerase chain reaction-based techniques with greater sensitivity, specificity and reduced assay time. Finally, the chapter discusses the wealth of techniques used for control of *Salmonella* on the farm. Although vaccination has been the primary cause of reduction of *Salmonella* incidence all over the world, the efficacy of vaccines depends on several factors and they are not universally effective. This has placed the emphasis on other strategies based on diet modulation and feed supplementation.

The chapter reviews the diverse dietary strategies that have been investigated to reduce *Salmonella* in the gastrointestinal (GI) tract, such as feeding whole cereals or mash diet to improve intestinal resistance, the use of exogenous enzymes to reduce the amount of substrate remaining in the gut for pathogenic microorganisms or the use of bioactive compounds with immunomodulatory properties. Other techniques to boost immune response include feeding maternal antibodies to hatchlings, the use of antimicrobial peptides, the potential acidification of feed or water by short-chain fatty acids to reduce *Salmonella* colonisation of broilers, essential oils and competitive exclusion treatments such as the use of probiotics, prebiotics and synbiotics. The chapter also discusses newer techniques such as bacteriophages and the increasing interest in ways of combining of different dietary treatments allowing potential addition, complementarity, or even synergism, of protagonist effects directly at the gut level.

Chapter 2 is complemented by Chapter 9 on the control programme for *Salmonella* in Sweden, which has focused on pre-harvest and harvest interventions and which has largely eliminated *Salmonella* from fresh poultry meat. This remarkable achievement is based on the following key steps: preventing contamination of the breeding pyramid (by compulsory sampling of grandparent and parent flocks, including hatcheries), strict biosecurity on farm sites; preventing *Salmonella* contamination in feed given to broiler flocks (e.g. through HACCP systems based on heat treatment), detailed surveillance of the production chain at critical control points to detect *Salmonella* contamination and immediate action to remove *Salmonella* from the food chain if detected. Given the decision not to use vaccination as a control measure, the chapter reviews the effectiveness of other approaches such as competitive exclusion treatments as well as biosecurity arrangements. The chapter also discusses the various cost–benefit analyses of the *Salmonella* control programme, including the balance of responsibilities and costs faced by farmers and others such as feed manufacturers in achieving a very high level of safety whilst sustaining a viable business.

Chapter 2 refers to increasing concern over the past 30 years regarding the worldwide emergence of multidrug-resistant phenotypes among *Salmonella* serotypes such as *S. Typhimurium*, *S. Enteritidis* and *S. Newport*. This problem is discussed in Chapters 4 and 5. Chapter 4 highlights public health concerns associated with a strong link between antibiotic use in food production and the rise of antibiotic-resistant pathogens that affect public health, for example ciprofloxacin-resistant and erythromycin-resistant *Campylobacter*. Antibiotics have been conventionally used in food animals to treat clinical disease (therapy), to prevent and control common disease events (prophylaxis and metaphylaxis) and to enhance animal growth (growth promoter), though the latter use has now been banned in many countries. The chapter discusses the range of initiatives to reduce

antibiotic use, exemplified by the World Organisation for Animal Health (OIE), which has identified the following targets: tracking rates of veterinary antibiotic use, resistance and residues through a nationwide surveillance and monitoring system; changing incentives to discourage unnecessary antibiotic use in animals; educating farmers, veterinarians and consumers on the dangers of antibiotic resistance; and phasing out the sub-therapeutic use of antibiotics in animals. The chapter also highlights the shift to methods that reduce reliance on antibiotics, for example, efficient biosecurity and hygiene protocols, the use of prebiotics and probiotic bacteria for competitive exclusion, bacteriophages, additives such as organic acids, genetic resistance, vaccination, and organic and antibiotic-free farming. It also highlights recent reductions in antimicrobial-resistant *Salmonella* associated with *Salmonella* control programmes adopted by the poultry industry, linking back to the kinds of intervention reviewed in Chapter 2.

Building on the overview in Chapter 2, Chapter 5 reviews in detail the range of prebiotics and related compounds used in competitive exclusion treatments. These include non-digestible carbohydrates, fructooligosaccharides, yeast-derived components and mannan derivatives, galactooligosaccharides and guar gum. The chapter reviews the latest research into their mode of action and effectiveness in control of pathogens such as *Salmonella*. It highlights where further research is needed, for example in how well these treatments work on less-studied pathogens such as *Campylobacter* as well as the growing interest in combining probiotics and prebiotics into synbiotics which offers the opportunity to enhance the growth of beneficial bacteria in a more controlled way. It highlights the need for more research to understand the GI tract microbiome and its mechanisms of action in dealing with pathogens, host animal responses, pathogen resistance and variability among strains within a pathogen species. There also needs to be more research in such areas as multifunctional carriers (e.g. nanoparticles) to optimise delivery of compounds.

Chapters 3, 6, 7 and 8 review safety control measures at different stages in the poultry meat supply chain. Echoing Chapter 9, Chapter 3 discusses farm safety management. As it points out, producing and maintaining a healthy flock requires good husbandry practices, backed by effective procedures, training, monitoring and record keeping. These practices start with the selection, housing and management of healthy chicks coming into a flock. They then cover quarantine and other biosecurity measures such as pest control, housing, stocking and diet as well as waste management and health monitoring.

Chapter 6 discusses processing operations from live transportation of birds and slaughter to post-chill processing, and considers the effects of these operations on carcass contamination. The chapter starts with transportation and handling of live birds, including physical separation between flocks, keeping the birds clean and dry during transport and unloading, reducing cross-contamination risks and minimising stress associated with feed withdrawal and confinement during transport. It then reviews current research on the effects of processing steps such as scalding and evisceration on pathogen survival and spread, as well as the role of prerequisite and HACCP systems for effective management of slaughterhouse operations. Finally, it reviews the effectiveness of the range of antimicrobial treatments: chemical, physical (such as washing, chilling, the use of ozone or irradiation) and biological treatments such as bacteriophages. Throughout it highlights the importance of a pre-harvest pathogen control approach is crucial as a key part of an overall food safety programme.

Chapter 7 looks at good practice in official inspection of slaughterhouses, highlighting the need for more research on ways of optimising compliance. As chilling is critical in storage, transport and sale of fresh poultry meat, Chapter 8 reviews research on its

effectiveness in the context of the range of decontamination techniques available, as well as emerging techniques such as the use of natural antimicrobials and edible coatings in preservation.

The chapters in Part 1 show what can be achieved in controlling pathogens such as *Salmonella* in poultry, including appropriate interventions at each point in the supply chain that systematically reduce the pathogen load. They also highlight the continuing challenges faced in dealing with other pathogens such as *Campylobacter*. These include a deeper understanding of pathogen behaviour, further improving detection techniques, a better knowledge of the GI tract microbiome, and the use of that foundation to better understand and extend the range of methods to control pathogens in the GI tract, as well as ways of combining techniques to create a series of hurdles which, in combination, keep the pathogen under effective control.

Poultry meat quality

Poultry meat quality can be defined in many different ways. Chapter 11 provides an overview of these different aspects of quality, which range from safety (discussed in Part 1) to nutritional value and from physiological and processing qualities such as water-holding capacity and shelf life to sensory properties such as colour, juiciness, tenderness and flavour. Consumption quality is based on an assessment of subjective sensory qualities and nutritive value. In contrast, processing quality is mainly based on objective physical and/or chemical properties. This chapter highlights recent research on defining, measuring and enhancing poultry meat quality attributes, including the use of indicators of meat maturation such as pH or conductivity and ways of enhancing nutritional value.

Building on the overview in Chapter 11, Chapter 12 reviews current research specifically on enhancing the nutritional quality of poultry meat. It discusses current research on understanding lipid metabolism and carcass lipid deposition. The chapter then summarises methods for the nutritional enrichment of poultry meat to increase polyunsaturated fatty acid content, particularly long chain *n*-3, using differing feed ingredients such as marine, plant and, more recently, algal ingredients. However, it has been found that such enrichment can be accompanied by the potential for increased oxidation of muscle lipids, the major contributor to the decline in meat quality during storage. The chapter therefore also reviews ways of reducing tissue lipid oxidation, for example, through use of antioxidants.

Flavour is an essential attribute of poultry meat quality and is discussed in Chapter 13. It reviews the wealth of research on the complex chemistry of flavour compounds and precursors underpinning poultry meat flavour as well as the process of flavour formation during cooking. The chapter also discusses the relative importance of factors influencing the formation of flavour and off-flavour in poultry meat, including breed/strain of chicken, diet and type of production system, and what this means for strategies to preserve or enhance the flavour of poultry meat.

The colour of poultry meat is often the first thing used by consumers to assess meat quality, and so it plays a vital role in purchasing decisions. Chapter 14 begins by surveying the extensive literature on meat pigments, including the types and chemistry of haeme pigments. It then considers what determines the colour of different types of poultry meat, starting with factors affecting the colour of fresh meat such as sex, diet, bird management and pre-slaughter stress as well the mechanisms of discolouration in poultry meat, and

how discoloration can be prevented. It also reviews the colour of cooked, cured and irradiated poultry meat. Finally, recent developments in methods for objective colour measurement of meat products are reviewed.

Chapter 15 discusses how the characteristics of texture and tenderness are affected by the post-slaughter processing of poultry carcasses. It reviews what we know about the changes that occur in poultry muscle after slaughter, including pH decline and the development of rigor mortis. The chapter shows how the quality of poultry meat is influenced by chilling type, temperature and time, and how processing techniques can improve the quality of the meat and reduce the incidence of defects such as pale, soft and exudative meat.

Freshly processed poultry meat may be contaminated by microorganisms carried into the processing facility by live birds and by microorganisms that contaminate the carcass during processing. Chapter 16 focusses on the range of spoilage bacteria, conditions favouring their growth and how they can be controlled through techniques such as modified atmosphere packaging.

All these chapters in Part 2 highlight both how far back in the supply chain quality traits can be shaped and how critical a holistic approach is in seeking to optimise quality at each step in the process. Chapters in Part 2 also show that there is still much to learn, for example, about the genetic basis of individual quality attributes, the role of dietary interventions and the ways managing birds up to the point of slaughter affects final meat quality.

Sustainability

Increasingly quality for consumers is not just about sensory properties but broader issues such as the environmental impact of production, which is the focus of the final part of the book. As Chapter 17 shows, intensive poultry production systems face a number of environmental challenges. These systems are very much dependent on external feed production, especially protein sources such as soya, the production of which has raised environmental concerns. Another issue is nitrogen emissions, for example in the forms of ammonia emissions to air, nitrous oxide emissions that contribute to global warming and nitrate leaching contributing to eutrophication. This chapter reviews recent studies applying life cycle assessment modelling to quantify the contribution of different sub-systems of poultry production (production of feed, housing emissions, manure management, etc.) to the overall environmental impact of poultry production and to suggest measures which could make the intensive poultry production more environmentally friendly. These include improving feed efficiency, for example by using additives such as enzymes in feed or alternatively improving the efficiency of the birds through genetic selection, use of alternative feed ingredients, such as locally grown protein crops and agricultural by-products, and other management options such as improving poultry housing and new strategies for manure management.

Given its importance in the overall environmental impact of poultry production, Chapter 18 focuses on poultry feed. As it shows, the potential to reduce the adverse environmental impact of intensive poultry production through precise feed formulation and manufacturing is extensive, as new additives and supplements are developed to increase nutrient retention and decrease nutrient excretion, enhance performance and prevent diseases. The chapter starts by reviewing research on processing issues such as

improving nutrient uniformity, particle size and pelleting as well as ways of optimising nutrient density and the use of multiphase feeding. It shows how formulating diets with low dietary crude protein and supplementation with highly digestible synthetic amino acids can reduce the excretion of excess nitrogen. The addition of exogenous enzymes, probiotics and prebiotics has also been shown to increase nutrient bioavailability, reduce nutrient variation of ingredients, enable the use of potentially less expensive ingredients and reduce the excretion of excess nitrogen and phosphorus. However, more needs to be discovered about the mechanism of action of these new additives given that the response of poultry to these products is highly variable, depending on the substrate, additive source, concentration and chemical relationship with other feed components.

Chapters 19 and 20 review recent research on measuring and reducing energy and water use, as well as the management of by-products and waste, in conventional poultry processing operations, focussing on processes such as bleed out, scalding, defeathering and evisceration. The following chapter reviews the growing sector of organic poultry production, with sections covering housing and nutrition requirements for organically reared poultry, the management of farm resources and bird health, ensuring food safety and the oversight of poultry meat processing and product labelling. It identifies the need to develop new organic ingredients able to provide required levels of non-essential amino acids as well as further research into appropriate use of probiotics, prebiotics, essential oils and organic acids.

As the final chapter in the book, Chapter 22 looks at sustainability in the context of the small-scale family poultry farming practiced by a large proportion of smallholder families in the rural and peri-urban areas of most of the world's developing countries. It shows that by enabling improvements in disease control, breeding and genetics, bird management and nutrition through smallholder poultry development projects, we have the potential to impact very meaningfully on poverty alleviation, household nutrition and food security, the health and education of children and the empowerment of women as the principal poultry keepers. This is shown via case studies from Myanmar, Tanzania and Zambia. The chapter suggests how the complex nature of the mixed farming systems and value chains incorporating family poultry production will increasingly benefit from inter- and transdisciplinary research in such areas as identifying the composition and nutritional value of alternative feedstuffs as well as better feed formulation.

Summary

This collection shows how interdependent questions of safety, quality and sustainability are. As an example, it demonstrates the central role of diet in such areas as food safety (e.g. in the control of *Salmonella*), aspects of quality (such as nutritional value, colour and flavour) and sustainability, whether in reducing the environmental impact of intensive systems or supporting smallholder poultry production. It also demonstrates the importance of an interdisciplinary approach in addressing issues of safety, quality and sustainability in an integrated way. The book shows the benefits of researchers collaborating to ensure synergies across the supply chain, for example by combining enhanced biosecurity with other interventions to combat pathogens in a way that is less reliant on the use of antibiotics. It is hoped that this collection will help support such an integrated approach.

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