BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Embryo development and hatchery practice in poultry production

Edited by Dr Nick French

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Introduction

It is widely recognised that developments in the chick embryo have a profound effect on hatchability and the subsequent health and productive capacity of poultry. With a stronger focus on welfare, prevention of disease and more sustainable poultry production, understanding these early stages has never been more crucial. This volume addresses the key stages and factors in embryo development in poultry to optimise hatchability and chick health.

The book is split into three parts: chapters in Part 1 examine parental influences and embryo development, focusing on areas such as the use of genetic selection to improve reproductive traits and management of breeder poultry flocks to optimise hatchability and chick health. Chapters on the development of defences against pathogens in the chicken egg, assessing poultry semen quality, the key stages of embryo development, chicken egg storage and transport, in ovo sexing in poultry chicks and in ovo vaccination of chicken eggs are also included. Part 2 chapters focus on incubation, specifically drawing attention to incubator design, the effects of incubator temperature, light as well as humidity and air composition on chick development. Chapters also address the role of egg turning in embryo development as well as the importance of incubation conditions on embryo skeletal development. Chapters in Part 3 focus on managing the hatching stage, highlighting the use of alternative hatching systems, the importance of managing the poultry hatcher environment as well as emphasising current key issues in transportation of broiler and layer chicks.

Part 1 Parental influences and embryo development

Part 1 opens with a chapter that reviews genetic selection to improve reproductive traits in chickens. Chapter 1 begins by first focusing on the layer breeding programme structure, then moves on to discuss areas such as egg production, liveability, resilience and adaptability. It also examines how genetic selection can affect egg quality, nesting behaviour and various reproduction traits as well as hatchability, fertility and sperm quality. A section on the molecular tools used is also included, before the chapter concludes with an overview of potential future research trends in the area as well as a section that emphasises the importance of improving reproductive traits to further improve animal health.

The subject of Chapter 2 is managing breeder poultry flocks to optimise hatchability and chick health. The chapter begins by providing an overview of different forms of mating behaviour, such as natural mating behaviour and

mating behaviour in a broiler breeding house. It moves on to review housing systems and the methods that can be used to improve hatchability and chick health. A section on male-to-female ratio is also provided, focusing specifically on common male-to-female ratio practice and adjusted male-to-female ratio. The chapter reviews the use of spiking methods such as spiking young males and intra-spiking. A section on improving broiler breeder nutrition is also provided, followed by an overview of feed restriction and feeding programs. The importance of bodyweight management in female and male broiler breeders is also described, before concluding with an overview of why good feather cover quality is important during the production period.

The next chapter focuses on advances in understanding the development of defences against pathogens in the chicken egg. Chapter 3 starts by providing an overview of the basic components of the egg, followed by a breakdown of the key events that occur during the egg's formation. The chapter provides a summary of how antimicrobial proteins and peptides contribute to the egg's defence, followed by an overview of how each egg component can also contribute to the egg's defence with a special focus on the cuticle through the inclusion of a case study. The chapter also describes the embryo derived structures that are involved in the egg's defence.

Chapter 4 discusses assessing poultry semen quality by examining some of the semen evaluation techniques and fertility determination procedures currently used on breeder farms. The chapter begins by examining the biology of fertilisation, focusing on fertilisation versus fertility and how eggs are formed during fertilisation. It moves on to analyse the importance of semen evaluation and provides an analysis of how semen evaluation techniques can be categorised into subjective and objective categories based on how the data is obtained. The chapter also describes the current techniques used for determining fertility, before concluding with an overview of how on-farm semen evaluation remains crucial in poultry breeding management.

Chapter 5 draws attention to the key stages of embryo development in poultry. The chapter first uses nomenclature to describe the different phases of embryonic development, which is then followed by an overview of fertilisation. The chapter also covers intra-uterine development, focusing on zygotic gene activation and the formation of primordial germ cells and the role of these primordial germ cells in reproduction. A section on embryo development during the incubation period is also provided, followed by a discussion of endocrine control systems and maternal thyroids. The chapter also describes growth and development of the embryo E10-E15, the E16-E19 plateau phase and how extra embryonic fluids can influence compartment development. The chapter also provides an overview of the hatching process, drawing specific attention to synchronous hatching and physiology including the endocrinology of hatching.

The next chapter focuses on chicken egg storage and transport. Chapter 6 first describes how both egg quality and embryo development can influence the effect of egg storage. The chapter also considers practical aspects of using storage temperature, humidity and egg turning to keep eggs in good condition, with some reference to particular aspects of egg hygiene and egg transport. A case study describes the work at Aviagen developing a robust method to deliver short periods of incubation during egg storage to improve the hatchability of stored eggs.

The subject of Chapter 7 is in ovo sexing in poultry chicks. The chapter begins by first highlighting the key issues and challenges of in ovo sexing, then moves on to provide three methods for in ovo sexing through the inclusion of case studies. The case studies section highlights the use of hyperspectral analysis, how endocrinology is crucial for analysing certain components in the allantoic fluid of a chicken embryo, the use of DNA analysis and also mass spectrometry. The chapter also provides an overview of research projects whilst also indicating methods that need to be developed further, such as vibrational spectroscopic methods, magnetic resonance imaging, gene editing, avian egg odour detection and protein quantification.

The final chapter of Part 1 expands on topics previously discussed in Chapter 7 by addressing in ovo vaccination of chicken eggs. Chapter 8 first discusses the history and evolution of in ovo vaccination, then goes on to highlight the various interacting factors of in ovo vaccination success. A section on additional interactions and considerations are also provided, focusing specifically on egg candling for viability, chick handling and welfare, labour efficiencies and quality assurance. The chapter concludes by providing an overview of the challenges that need to be overcome in order to develop more efficient vaccines for in ovo use.

Part 2 Incubation

Part 2 opens with a chapter that focuses on the principles and techniques of incubator design for poultry eggs. Chapter 9 begins by first reviewing the key factors that need to be controlled during the incubation process, individual sections are provided for factors such as temperature, heat production and transfer, positioning and turning of eggs as well as the importance of maintaining moisture, carbon dioxide, oxygen and heat levels through ventilation. The chapter also includes an overview of cooling techniques, then moves on to discuss incubator machine design issues. A section on potential hatcher design issues is also provided, followed by an overview of how the hatching process can be managed and what hatchers should look like for a successful incubation process.

Chapter 10 draws attention to the effects of incubator temperature on embryo and post-hatch chick development. The chapter first compares single

stage incubation to multiple stage incubation, then moves on to highlight embryonic heat requirements. It moves on to review the effect of temperature on hatchling quality and growth, then discusses how thermal manipulation can be used to improve embryo development. The influence of embryonic temperature on organ development is also addressed, drawing specific attention to bone and heart development, endocrine development and the use of thermoregulation. The chapter also discusses how embryonic temperature can affect muscle and adipose tissue development, intestine development and its effect on the immune system. A section on incubation temperature effects on incidence of ascites is also provided, followed by an overview of temperature effects on the integument system.

Chapter 11 focuses on understanding the effects of light on embryo and post-hatch chick development. It begins by assessing the role of monochromatic light on the growth of meat-type birds, focusing specifically on the effect of post-hatch and in ovo monochromatic photostimulation on broilers. The chapter moves on to review the effect of in ovo green light photostimulation on somatotrophic axis activity in embryos and the post-hatch period. The chapter also suggests that embryos are highly sensitive to green light photostimulation, a phenomenon that can be a tool for acceleration of muscle growth in meat type birds. It concludes by highlighting the importance of improving poultry meat production through different external manipulations.

The next chapter examines the effects of humidity/air composition on embryo and post-hatch chick development. Chapter 12 describes the physical function of the eggshell as a respiratory organ for the developing avian embryo, focusing on eggshell porosity, water vapour conductance and incubational egg weight loss and the influence of incubational temperature and airflow. The chapter moves on to review humidity, discussing aspects such as relative humidity and its effects on hatchability, hatchling quality, embryo metabolism and embryonic and post-hatch chick development. It also addresses the influences of breeder age on the effects of relative humidity on embryonic development. A section on vital gases is also provided, specifically focusing on oxygen and carbon dioxide.

Chapter 13 examines the role of egg turning in embryo development. The chapter identifies the four main aspects of turning deemed crucial to successful integration. It first focuses on turning during the egg storage period, then moves on to highlight critical periods during the incubation period. A section on turning frequency during incubation is also included, followed by a discussion on the influence of the turning angle during incubation. A section on signs of turning failure is also provided.

The final chapter of Part 2 reviews poultry embryo development and skeletal growth. Chapter 14 first provides an overview of embryo bone development, drawing specific attention to early development, the growth of long bones,

hormonal regulation and developmental fluctuating asymmetry. The chapter moves on to assess incubation factors that can effect skeletal development, such as temperature, oxygen, carbon dioxide and ventilation, light, egg storage and SPIDES effects on bone and how incubation can effect vertebral development and chondronecrosis with osteomyelitis. Stressful conditions during transportation to the farm is also touched upon.

Part 3 Managing the hatching stage

The final part of the book begins with a chapter that examines alternative hatching systems for broilers. Chapter 15 introduces the current alternative hatching systems in use, then uses this introduction to compare alternative hatching systems to conventional ones. The chapter highlights the environmental factors that can influence both types of hatching systems, such as climate, egg position, light, noise as well as dust and the use of disinfectants. It then moves on to review the management factors that can influence conventional and alternative systems, focusing specifically on chicken handling and transport, the removal of second-grade chickens and time to feed and water access. A section on the effects of alternative hatching systems on health, welfare and poultry production is also provided.

Chapter 16 focuses on managing the poultry hatcher environment. The chapter first looks at the embryonic phase, focusing on development, physiology and metabolism of the chicken embryo and how the hatching position, hatch time and hatch window can effect embryonic mortality. Environmental settings within the hatching phase are also examined, such as temperature settings – both high and low – and relative humidity settings in the hatcher as well. Carbon dioxide concentration settings in the hatcher are also examined. The chapter concludes by providing an overview of why monitoring these settings is crucial in developing and maturing the chicken embryo.

The final chapter of the book discusses the key issues in the transportation of broiler and layer chickens. Chapter 17 focuses first on the transportation of newly hatched chicks, then goes on to look at welfare issues that can affect them during pre-transportation and the transportation process itself. The chapter then reviews how these welfare issues can be assessed which is followed by a discussion on how journey times and periods without feed and water can impact newly hatched chicks. A section on thermal stress in transit is also provided, where the use of thermal comfort zones for chicks is assessed, followed by the use of thermal imaging for surface temperature measurement and the use of thermal micro-environments and ventilation. Stocking density is also examined and exposure of chicks to acceleration and vibration is analysed. The chapter also discusses transport pathologies and provides guidance on good practice for animal transportation as well.

Chapter 1

Genetic selection to improve reproductive traits in chickens

David Cavero and Maurice Raccoursier, H&N International, Germany

1 Introduction

Global egg production increased from 51.13 million metric tons (Mt) in 2000 to 86.67 Mt in 2020 – an average annual growth of almost 3.5% (FAO, 2022). The number of hens worldwide also increased, albeit at a lower rate, from 4.97 to 7.90 billion hens (2.9% yearly) in the same time frame, which reflects higher productivity on the part of hens.

Disease control, modern housing systems and the use of balanced compound feed have contributed to highly improved performance in the layer industry. However, probably the most significant contribution has come from genetic improvement of birds, which has had a positive and cumulative effect over time. Genetic progress has been documented in experiments designed

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especially for broilers and turkeys (Havenstein, 2006), in layers (Jones et al., 2001; Pelletier et al., 2014) and across different farm animal species (Hill, 2008).

The layer breeding industry has substantially contributed to the success of the poultry industry with the development of genetically improved birds. Consistent and continuous improvements in multiple traits such as increased egg production, improved feed efficiency, adaptation of egg quality to consumer preferences and improved robustness and liveability have led to high-performance birds with extended single productive cycles over 100 weeks.

Whilst the focus remains on maximising genetic potential for producing high-quality protein at a competitive cost, additional requirements of the egg industry, changing consumer habits and public opinion related to animal welfare and environmental load are being taken into consideration in order to guarantee the sustainability of egg production. The concept of sustainable development was described by the United Nations Brundtland Commission Report (Brundtland, 1987) as 'meeting the needs of current generations without compromising the ability of future generations to meet their own needs'. As Neeteson et al. (2020) explained, breeding contributes to sustainability by delivering genetic potential to match environmental (through lower resource utilisation and carbon footprint), economic (through increased profitability of the wider industry) and welfare requirements (through meeting societal requirements).

Breeding companies must look beyond current requirements and anticipate future needs and opportunities in the medium and long term. Breeding goals are broad and holistic, oriented towards optimising the use of resources, reducing the production of waste and carbon footprint, increasing food security and food quality, and enhancing the economic and social well-being of producers, consumers and society, as well as the welfare and well-being of the birds.

This chapter reviews these developments in the layer breeding industry, focusing on the current performance of commercial strains as well as selection criteria that might be significant in the future. Special attention is given to reproduction traits and the impact of other important traits on hatchability results. Additionally, the incorporation of new traits, the application of new evaluation methods and future improvements in breeding programmes are discussed.

2 Layer breeding programme structure

Since World War II, poultry production has developed from small scale, local enterprises to an economically important branch of agriculture (Fröhlich et al., 2012). Prior to the introduction of modern breeding, laying hens seldom

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