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Ensuring safety and quality in the production of beef

Volume 2: Quality

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Introduction

Beef production faces a range of challenges. There is an ongoing need to ensure **safety** in the face of threats from zoonoses and other contaminants. Consumers also have ever-higher expectations of sensory **quality**. There is a sharper focus on the role of meat in nutrition and health, as well as growing interest by consumers in animal welfare and the environmental impact of beef farming as components of quality. These topics and challenges are addressed in two volumes. Volume 1 looks at key research trends in production and processing to ensure **safety** of beef. This volume, *Ensuring safety and quality in the production of beef Volume 2: Quality*, reviews developments related to beef **quality**.

The chapters of this volume suggest a number of common themes. They show the progress and continuing challenges in understanding and exploiting the genetic basis of factors affecting the growth and composition of muscle in cattle, and of meat quality traits in particular. They also show how an understanding of muscle development and fat deposition, and the process of post-slaughter conversion of muscle to meat, is critical to the understanding and improvement of individual quality traits.

Part 1 Breeding and growth

Chapter 1 looks at the relative importance of genetic compared to other factors such as sex, age and husbandry in determining carcass and meat quality. The evolution of each breed represents a particular combination of traits, which can be used to tailor the combination of carcass size, conformation and finish demanded in any specific market. From a carcass quality point of view, the important breed traits are muscularity and propensity to fatten. Indicators of carcass quality can include dressing percentage (the weight of the carcass expressed as a percentage of the live weight), cutability or meat yield (the proportion of the carcass that is saleable as meat), and finish (subcutaneous and intermuscular fatness). It has also been shown that meat quality characteristics such as appearance, texture, fat colour, marbling, flavour and, in particular, tenderness are heritable.

While these traits are genetically influenced, until recently it has only been possible to select for them on the basis of their phenotypic expression. The mapping of the bovine genome in 2009 has led to an ongoing effort to find quantitative trait loci (QTL), markers, genes and single-nucleotide polymorphisms (SNPs) associated with aspects of carcass and meat quality. A number of QTL for traits of importance to carcass and meat quality have been identified and are now being incorporated into commercial breeding programmes. As the science and practice of genomics advances, so too will opportunities to select for these traits genotypically, allowing for earlier selection and a more precise tailoring of carcass size and composition to match market preferences. Chapter 1 concludes by suggesting that the role of the traditional breeds as repositories of traits of interest to beef breeders will continue, but increasingly, commercial breeders will be searching for individual animals carrying the genotype for desirable carcass and meat quality traits, regardless of the breed type itself. This topic is discussed in more detail in Chapter 17.

Chapter 1 provides a foundation for Chapter 2, which explores traditional animal breeding of cattle to improve carcass composition and meat quality. It focuses, in

particular, on both marbling and tenderness that are moderately to highly heritable traits. Genetic selection for carcass attributes such as marbling and tenderness is relatively new compared to selection for growth traits. They have traditionally been difficult and expensive to measure phenotypically. However, structured progeny testing schemes have aided in the development of estimated breeding values (EBV) and expected progeny differences (EPDs), which allow for the comparison of animals within a breed for their genetic potential for a given trait. These progeny tests have now given way to the use of techniques such as ultrasound that have allowed EBV for marbling to become pervasive in breeding programmes. The chapter includes case studies of successful breeding for such traits. It concludes by suggesting the advantages of augmenting genomic information with traditional EPDs in the future, a topic which is further reviewed in Chapter 17.

Chapters 2 and 3 discuss factors affecting muscle development and fat deposition in cattle and how they impact on carcass and meat quality. An understanding of these biological processes is critical to understanding the effects of cattle nutrition, for example. As Chapter 3 shows, bovine skeletal muscle is mainly composed of three types of oxidative and glycolytic muscle fibres that are found in varying proportions in different muscles. The proportion of these different fibre types varies with biological and environmental factors (breed, age, sex, rearing conditions), resulting in variability of carcass and meat qualities. The chapter reviews the various factors that determine muscle composition and the relationships between muscle fibre type composition, carcass composition and meat quality. It shows ways in which the proportion of different fibre types can be altered by genetic selection, rearing conditions and slaughter age.

Beef cattle are quite efficient at depositing fat: first abdominal, then seam (intermuscular), then subcutaneous and finally marbling (intramuscular and interfascicular) fat. The development and composition of these fat deposits are influenced primarily by the diet of the cattle, although marbling is under significant genetic control. Chapter 4 addresses the origin of adipocytes, the ontogeny of fat development, factors influencing fat development (such as the relative effects of grain and pasture-based diets) and finally factors influencing fatty acid composition of fat deposits. As it shows, research has helped to establish the appropriate balance between forage feeding and finishing on a high-concentrate diet in optimising the quantity and quality of fat deposition in beef cattle.

Part 2 Management of cattle

Chapter 5 builds on Chapter 4 by looking in more detail at cattle nutrition. This chapter focuses on nutrition of growing cattle post-weaning through the intervening backgrounding or stocker phase and, finally, the finishing phase. It looks at what research suggests about the relative merits of pasture-based and feed-based diets (including the effects of different forage types, grain-based diets and feed supplements), as well as combinations of pasture and feed, together with issues such as composition and timing of high-concentrate feeding on quality traits. The chapter focuses primarily on how the nutrition in each phase impacts marbling or quality grade of the final products, but also discusses other quality traits such as tenderness, flavour, and lipid or nutrient profiles, and shelf life. As the chapter shows, there is evidence that nutrition at all stages of growth, rather than just the finishing phase, has the potential to impact final beef quality. It is clear, for example, that marbling can be developed before the finishing phase by providing sufficient energy intake for

muscle growth and marbling development. This suggests that a better understanding of lifetime management on quality could lead to both greater efficiency and better and more consistent quality.

Metabolic modifiers are compounds that are either fed to animals or implanted to improve rate of gain, feed efficiency, dressing per cent, carcass meat yield, visual meat quality and shelf life, with varying effects on meat palatability. Chapter 6 presents a general review of current research on the effects of metabolic modifiers on carcass composition, fresh meat quality and cooked meat palatability. It focuses on the effects of single use and re-implant of anabolic steroids; beta-adrenergic agonists (ractopamine hydrochloride and zilpaterol hydrochloride (ZH)); vitamins D₃, E and A; and somatotropin on both carcass composition and meat quality. None of the implants or neither of the beta agonists improve marbling or tenderness, but when used properly, have minimal negative effects. They are used because they are very cost effective.

Handling, transport, lairage and slaughter are stressful for cattle, and can have consequences on the quality of the beef produced. Chapter 7 considers what we know about potential stresses and cattle responses directly before and during transport as well in the lead-up to slaughter. The chapter addresses the complexity of each pre-harvest management stage, arising from the interactions between different types of cattle, different physical environments, the manner in which cattle are handled and the methods used for slaughter. The chapter reviews the effects of pre-slaughter management on beef quality, including the risk of dark, firm, dry meat and bruising. It then discusses the main factors during transportation which have been identified as affecting welfare and meat quality, such as loaded density and thermal environment. Finally, the chapter provides an overview of the extensive research on handling and movement of cattle through lairage, to the stunning pen and onto slaughter and how these stages can be optimised for both animal welfare and meat quality.

The final chapter in Part 2, Chapter 8, looks at post-slaughter processes. The conversion of muscle to meat during the rigor mortis process and the conditions under which this process occurs are important for quality attributes of beef including colour, water-holding capacity and tenderness. Electrical stimulation (ES) is used to prevent cold-induced toughening of beef, especially hot-boned meat, but is also applied to enhance the ageing process and, therefore, improve tenderness of aged beef. ES can also impact on other quality parameters such as colour and moisture characteristics as a result of its effect on glycolysis and the rigor mortis process. However, poor use of ES combined with improper chilling may have detrimental effects on the tenderness, colour and water-holding capacity of meat. This chapter discusses current research on the factors influencing the effectivity of ES in optimising meat quality. It also reviews current research on the effects of chilling, including very fast chilling and blast chilling on meat quality, including ways to adjust chilling parameters and other inputs during and after slaughter to improve the economics of carcass chilling while maintaining or improving the quality of the final product.

Part 3 Quality traits

The chapters in Part 3 consider both individual quality traits and ways they can be measured. One group of chapters discusses individual traits such as colour, tenderness and flavour (Chapters 9, 12 and 13). They are accompanied by Chapter 14, which looks

at the role of packaging in optimising visual appearance and palatability, and Chapter 16, which reviews the role of beef in human nutrition.

Meat colour is a critical visual sensory attribute influencing purchasing decisions. Post-mortem muscle is biochemically active and any deviation in ultimate post-mortem muscle pH can influence processes affecting meat colour, such as metmyoglobin reducing activity (MRA), oxygen consumption and lipid oxidation. Recently, much research focus has been given to the role of mitochondria in meat colour. As the chapter shows, mitochondria remain active in post-mortem muscle and can influence myoglobin redox state via oxygen consumption and MRA. Hence, characterising factors that influence mitochondrial function is helping to develop pre- and post-harvest technologies that minimise the economic losses due to discolouration. Research has shown the ways in which minimising ante-mortem stress of cattle, utilising optimum chilling and proper packaging can optimise beef colour development and stability.

In addition to protecting the product, packaging is largely responsible for maintaining myoglobin in the bright red, oxygenated state consumers expect to see. Chapter 14 reviews the strengths and weaknesses in achieving these objectives of traditional aerobic packaging, vacuum packaging, modified atmosphere packages and active packaging (incorporating oxygen scavenging or carbon dioxide emitting technology, films with antioxidant or antimicrobial properties, or colour-enhancing nitrite embedded in the film). In addition, 'intelligent packaging' (e.g. with sensors or labelling to monitor or measure product freshness) is discussed. It also discusses the role of centralised packaging systems and reducing packaging waste using biodegradable materials.

Tenderisation through ageing of meat results from proteolysis, the degradation of proteins (myofibrillar, cytoskeletal and costameric) into smaller subunits. Chapter 12 reviews factors affecting this process, such as the development of rigor mortis, chilling and muscle variation. The biochemical understanding of tenderisation has helped in the design of more targeted approaches to improve beef tenderness. The chapter reviews current research on carcass methods such as ES, the 'tenderstretch' and 'tendercut' techniques as well as foreshank manipulation. It also surveys the effectiveness of other methods such as SmartStretch™ and the Pi-Vac Elasto-Pack System®, as well as pulsed electric fields and newer techniques such as ultrasound and high hydrostatic pressure. Finally, it discusses chemical methods such as the use of ionic solutions, acids and enzymes. Picking up on Chapter 10, it suggests that grading systems able to grade individual cuts or even individual muscles are required so that the inherent variation within and between carcasses can be accounted for and value maximised. Several countries have 'carcass classification' systems that have little relationship to visual appearance of beef and cooked palatability. In other words, they do not provide information consumers desire when purchasing and cooking beef. 'Grading' systems attempt to identify quality traits and to assign value that are important to consumers.

As Chapter 13 indicates, the complex structure and chemistry of raw meat provides the foundation for the distinctive flavour of cooked beef, down to individual amino acid side chains and fatty acids. The generation of the aromas associated with beef flavour during cooking is complex and involves hundreds of chemical reactions taking place simultaneously to form the aroma we recognise. The chapter reviews what we know about the chemistry of beef flavour; the thermal degradation of components such as lipids, which have a particularly important effect on flavour; and the role of Maillard reactions. The chapter also discusses the way we perceive flavour and ways of measuring it, whether through sensory testing or instrumental measurement of flavour compounds. It also

surveys the range of factors that help to determine flavour, from genetic variations in fatty acid composition, through the role of cattle nutrition, particularly finishing on grass and forage, as well as the role of marbling and ageing.

As discussed in Chapter 16, beef is an important source of both macronutrients and micronutrients. Macronutrients include protein, and both saturated and unsaturated fatty acids. Micronutrients in beef include haeme iron; zinc; selenium; and vitamins D, B1 (thiamin), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxin) and B12 (cobalamin). In each case, the chapter discusses factors affecting amounts and bioavailability. The chapter also reviews the evidence linking beef with reported increased risk of cancer, from intrinsic factors that include fat and iron, to extrinsic factors such as heterocyclic amines, polycyclic aromatic hydrocarbons and *N*-nitroso compounds (nitrosamines). The role of beef in nutrition and health is also discussed in Chapter 19.

Building on the discussion of individual quality traits, a second group of chapters in Part 3 looks at ways quality is measured and communicated through grading systems and branded programmes. Chapter 10 reviews the three main beef carcass grading or classification systems used across three continents. These are used for a large proportion of beef production and processing in the world. One is the 'EUROP' system for EU countries, another is the USDA Beef Carcass Grading system in the United States and the third is the Meat Standards Australia system in Australia. The chapter also discusses grading in Japan. The EUROP 'classification' system does little to relate to the visual appearance or palatability of beef. Instrument grading using video image analysis is predominant in the United States for assessment of marbling. The Meat Standards Australia system is the only one in the world that 'grades' individual cuts or muscles and is based on extensive consumer evaluations. The chapter reviews the way the different schemes work and how effective they are in ensuring beef meets consumer expectations of quality.

The emergence of branded beef programmes has had a tremendous impact on the beef industry as a tool for differentiation. Chapter 11 discusses what we know about the factors that define successful brands and the effects of brands on consumer perceptions of meat quality. It reviews different kinds of brands, from those based on breed, and those focused on particular producers, retailers or countries, to those focused on methods of production such as organic brands. Picking up on Chapter 2, it discusses the use of EPDs and instrumental techniques to validate quality aspects involved in branding.

As discussed in Chapter 15, verifying qualities prior to consumption that contribute to a pleasurable eating experience remains a challenge for the beef industry. There are several ways to assess eating quality, such as trained sensory evaluation, consumer taste tests, shear force measurement and relying on quality grading schemes. Most recently, research has focused on flavour evaluation and muscle profiling. As well as sensory evaluation and quality grading, the chapter reviews instrumental assessment of marbling, shear force measurements for tenderness, and assessment of juiciness and flavour (e.g. using measurement of moisture content). The chapter highlights the continuing challenges in successful, non-destructive assessment of beef sensory properties. It also discusses what consumer research suggests about attitudes related to meat quality. As an example, research has indicated that the beef industry has done a good job of increasing the proportion of carcasses that are considered tender. Better husbandry to reduce stress, components of finishing diets and judicious use of finishing implants have resulted in a more consistent product. Research also shows that marbling plays a significant role in flavour.

Part 4 Emerging trends

Genetic improvement of carcass and meat quality traits by conventional selection has been limited by the difficulties and cost of measuring and recording these traits, as well as the complexity of implementing progeny tests that require individual traceability from birth to harvest. As discussed in Chapter 17, significant benefits in the genetic improvement of meat quality are expected through the use of genomic selection (GS), due to the possibility of providing more accurate estimations of genetic values at early ages, as well as including quality-related traits in breeding programmes that have received less attention due to the difficulties of collecting the phenotypic information needed for the estimation of genetic merit.

Significant developments in DNA technology and genome sequencing have led to the detection of millions of SNPs, making it possible to obtain a very dense coverage of the genome. Genome sequencing and genotyping have also become faster and cheaper. Dense, high-throughput genotyping assays have been developed for many livestock species, allowing the screening of tens to hundreds of thousands of SNPs simultaneously. The availability of genomic information for large numbers of animals allows the implementation of genome-wide association studies (GWAS), which provides a deeper and more comprehensive understanding of the genetic basis for traits of interest.

The implementation of GS depends on building training or reference populations that comprise a large number of genotyped and phenotyped animals, providing the information to estimate SNP effects accurately. However, the improvement of accuracy for many traits included in beef cattle breeding programmes by GS has so far been slow compared, for example, to dairy cattle. This chapter reviews results from current investigations of GS and GWAS for marbling, fatty acid profiles and tenderness. Current results indicate that accuracies of EBVs for these traits are moderate with the current sizes of training populations, but that these could be increased further by increasing the size of such populations. There is also a need to develop faster, non-invasive methods to map and predict meat quality traits in training populations. Genome sequencing data will also greatly improve the understanding of the genetic basis of these traits, and, together with transcriptomic and other 'omics' sciences, identify genes and gene networks. Future research could focus on traits such as flavour, palatability or micronutrient content.

In the face of growing concern about climate change, as well as government and consumer pressure for more sustainable methods of production, the beef industry faces a significant challenge in both producing sufficient food to feed a growing population and reducing environmental impacts per unit of beef produced. Chapter 18 addresses these issues by first discussing definitions of sustainability. It then looks at ways of assessing environmental impact, such as measuring the carbon footprint of beef production or tracking greenhouse gas emissions. A final section reviews practical steps in achieving 'sustainable intensification' to increase production whilst reducing environmental impact, ranging from improving growth rates and finishing weights (e.g. through the use of metabolic modifiers) to improving feed efficiency, reproductive efficiency and animal health.

The debate continues about whether 'red' or 'processed meat' intake is related to adverse health outcomes in the US population and other developed countries. 'Processed meat' can be minimally processed with no added ingredients, or further processed in which chemical additives and heat processing can be involved. Beef is often a focus of

such discussions, because of its contribution to saturated fat intake in the diet, although beef has almost as much monounsaturated fat as it does saturated fat. Chapter 19 provides a detailed examination of the evidence for a possible connection between beef intake and cardiovascular disease, and beef intake and the development of diabetes. It also reviews the fatty acid composition of beef, and outlines the dietary recommendations considered to be best supported by the evidence.

It is important to note that epidemiologic studies of nutrition and chronic disease do not establish whether the relationships are real or simply random associations. Concerns about whether red or processed meat causes adverse outcomes cannot simply be justified because epidemiologic studies might not adequately account for fat content, meat processing treatments, other dietary components and/or cooking methods. These factors can modify the health effects of lean beef in the diet. For example, it is important to distinguish the health outcomes that result from further processed meats versus unprocessed red meat, and for the purposes of this chapter, lean beef. As the chapter indicates, an important message to convey is that lean beef in recommended amounts can be included in a healthy dietary pattern.

Summary

These chapters suggest a number of common themes. They show how an understanding of muscle development and fat deposition is critical to the understanding and improvement of individual quality traits. They also highlight the role of different aspects of production in improving quality traits, for example, the effect of animal management practices to minimise stress on colour, or the role of post-slaughter processes in tenderisation. Grading systems and/or branded programmes enhance consumer confidence and demand for beef. Many of the chapters emphasise the central role of diets of cattle, including the relative merits of pasture-based and feed-based diets in enhancing flavour as well as the significance of the 'finishing' phase compared to earlier phases of nutrition. A major theme is the continuing challenges in measuring and grading quality, which impacts, for example, on further improvements in breeding as well as the enhancement of individual aspects of quality. Finally, beef production can be environmentally friendly and sustainable. Looking at the book as a whole, it is clear that achieving significant and sustainable improvements in beef quality requires an understanding of the importance of each step in the value chain in beef production, and appropriate interventions at each of these stages. This requires understanding and collaboration between different specialists and disciplines. It is hoped that this volume will help to support this kind of interdisciplinary work.

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