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Achieving sustainable production of pig meat

Volume 2: Animal breeding and nutrition

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Introduction

Pig meat is the most widely-consumed meat in the world, accounting for 40% of the world's overall meat consumption. The leading producers are China, the EU, USA, Brazil, Russia, Vietnam, Canada, Japan, the Philippines and Mexico. Consumption is growing, both in developed markets such as the United States and particularly in developing countries in Asia. Previous growth in pig production has been driven primarily by developments in breeding and the shift to larger, more intensive systems. These systems face a range of challenges in increasing production sustainably to meet rising demand. Pig production remains vulnerable to zoonotic and other diseases affecting pigs as well as the problem of antibiotic resistance. There is growing pressure to improve feed efficiency in the face of competition for raw materials and rising feed costs. At the same time, there is an increasing focus on reducing the environmental impact of animal production. Finally, consumers are increasingly concerned about animal welfare in intensive systems.

These challenges are addressed by *Achieving sustainable production of pig meat*. The three volumes are:

- Volume 1 Safety, quality and sustainability
- Volume 2 Animal breeding and nutrition
- Volume 3 Animal health and welfare

This volume, Volume 2, reviews the ways that developments in breeding and nutrition can contribute to more efficient and sustainable pig production. Part 1 looks at the continuing potential of and constraints in conventional breeding as well as new genetic breeding techniques to improve areas such as reproductive performance and feeding efficiency. Part 2 discusses nutritional strategies, from a better understanding of pig nutritional requirements to more targeted 'precision' nutrition linked to particular stages in the life cycle. The chapters show how improvements in nutrition can enhance reproductive performance and overall health (particularly gut health), promote more efficient feed conversion and more consistency in weight and meat quality at the point of slaughter.

Part 1 Genetics and breeding

Chapter 1 reviews advances and constraints in conventional breeding of pigs. Traditional methods of genetic improvement, both through selection programs and proper use of breed differences and heterosis, have been effective in improving production efficiency. This improvement has been realized primarily in reproductive performance, growth rate and carcass composition. Conventional approaches have resulted in significant increases in areas such as feed efficiency, daily weight gain, average carcass weight, number and sizes of litters. There remains, however, a need for improvement in traits associated with traits such as disease resistance, behavior and longevity. Whilst further improvement may depend upon development of molecular genetic tools, there are still opportunities to use conventional animal breeding technologies, albeit with the addition of some novel traits or measurements, to create genetic change.

As an example, as more is understood about the biology of growth and intake, alternative methods of measuring feed efficiency have been developed. Residual feed intake (RFI) (the difference between the observed feed intake and that predicted from the average requirements for growth and maintenance) has been recommended as a measure of efficiency. Selection for reduced RFI has decreased the amount of feed required for growth and also reduced backfat. Research at the University of Illinois, for example, has also suggested that inclusion of semen traits (volume, concentration, motility and presence of abnormal spermatozoa) in selection criteria will help further improve reproductive performance.

In contrast, efforts to select for genetic improvement of disease resistance have been limited. Conventional quantitative breeding methods have not been very successful because of low heritability for disease development, the time for symptoms to appear in infected animals and the fact that selection of animals that do not display the disease might result in higher tolerance but not reduced infectivity. In one study, scientists at the University of Nebraska used the selection lines (developed for reproductive performance or feed efficiency) to study genetic differences in resistance to Porcine Reproductive and Respiratory Syndrome (PRRS) and Porcine Circovirus Associated Disease (PCVAD) which can then be translated into breeding targets. This suggests that there are opportunities for genetic improvement in disease resistance through traditional genetic improvement techniques. The existence of breed differences, moderate heritabilities and evidence that selection may be effective are all encouraging. However, the substantial cost associated with such techniques remains. Much of this research also suggests that molecular techniques (discussed in the following chapter) will bear fruit and that improvement in disease resistance will, ultimately, result from a combination of quantitative and molecular techniques.

Chapter 2 builds on Chapter 1 by reviewing the use of molecular genetic information in genetic improvement programs for pigs. As discussed in Chapter 1, conventional genetic improvement of pigs has been achieved by selection of individuals (young males and females) for breeding based on estimates of breeding values (EBV) derived using phenotypes for important traits that have been recorded on the selection candidates themselves and/or their close relatives. For that purpose, sophisticated statistical methods based on mixed linear models and best linear unbiased prediction (BLUP) have been pioneered in animal breeding. These methods optimally utilize all available phenotypes on the individual itself and its relatives in order to obtain the most accurate estimate of the breeding value of the individual, which can then be used to rank individuals to identify animals that should be used to breed the next generation.

However, there are multiple challenges and limitations associated with these phenotype-based programs. Many of these can be overcome by using molecular information to help predict breeding values and inform selection decisions. Chapter 2 describes how molecular genetic information can be used to enhance selection programs in pigs, what is required to develop such information, and what strategies are available for the use of molecular information in breeding programs. Example cases, challenges and future developments are also reviewed.

In contrast to the 'black box' approach of phenotype-based prediction, DNA-based molecular genetic tests can provide information on the genetic basis of traits of interest and the genotype that individuals have at specific locations of the genome that may be related to the trait. If a genetic marker can be found that is in linkage disequilibrium (LD) with a quantitative trait locus (QTL) for a trait, individuals that have the marker genotype that is associated with the favorable genotype at the QTL are expected to have a higher breeding value. The procedure for determining whether a genetic marker can be used to identify animals that have better genetics for that trait is based on a statistical analysis of the association between the genotype of individuals at the genetic marker and their phenotype for the trait. Chapter 2 reviews how this works by discussing the principles of genome-wide association studies (GWAS) and their potential pitfalls. Nevertheless, despite the pitfalls, many QTL have been identified using genetic markers for many traits in livestock using different population designs.

Methods for detection of QTL or association analysis result in estimates of the effects of marker genotypes on a phenotype, often in the form of allele substitution effects. Based on the genotype of selection candidates at the identified markers, these estimates can be used to compute a molecular breeding value (MBV) of each individual. In addition to an MBV, each selection candidate will also have an EBV based on regular phenotype-based BLUP evaluation. As discussed in Chapter 1, the combination of MBV and EBV can then be used for selection.

Despite a large number of reports of significant QTL and genetic markers associated with important traits, the application of the resulting QTL or markers in marker-assisted selection (MAS) livestock breeding programs has been limited until recently. The main reasons for the limited use of MAS include the limited amount of genetic variation that the significant markers explain, the limited number of genetic markers available, the relatively high costs of genotyping, poor reproducibility of marker or QTL effects in populations of interest, in particular when discovery populations were experimental or of limited size, and estimation of marker or QTL effects on a within-family basis, which has made it more difficult to incorporate them into breeding programs. Research has shown, for example, that substantial (training) data sets of genotyped and phenotyped animals are required to obtain substantial accuracies of MBV.

Many of these limitations are, however, being overcome by recent advances in molecular technology such as genome sequencing, the identification of large numbers of SNPs across the genome, and cost-effective high-throughput genotyping of tens of thousands of such SNPs. The ability to effectively use this large number of SNPs for breeding value estimation, however, also required a paradigm shift in statistical models for estimation of SNP effects, which has taken us from MAS to new techniques such as genomic selection (GS). Since 2009, GS has been successfully implemented in dairy cattle breeding programs across the world. The use of GS has allowed a substantial decrease in the generation interval in dairy cattle because bulls can now be selected based on genomics before they reach reproductive age, rather than having to wait until they have received an EBV based on milk production performance of their daughters.

The implementation of GS in pigs has progressed more slowly because opportunities to reduce generation intervals are less prominent in swine breeding programs. However, research has shown that genomic selection is cost-effective in at least the larger swine breeding programs, especially with the use of low-density SNP genotyping and imputation, and, as the chapter shows, GS has now also been implemented in several swine breeding programs. As an example, trials have been implemented to investigate the genetic basis of resistance or susceptibility of pigs to infection with porcine reproductive and respiratory syndrome (PRRS) virus.

As Chapter 3 points out, the reproductive performance of sow herds has improved considerably over the last few decades. Farrowing rates and litter sizes are reaching levels that previously were unattainable. The chapter reviews the challenges in maintaining and further improving the reproductive efficiency of pigs. After first discussing measures of reproductive efficiency, the chapter highlights some of the factors affecting reproductive efficiency, including gilt development, litter size, control of the weaning to estrus interval, and factors affecting seasonal infertility such as heat stress.

As the chapter points out, gilt development is a key component for reproductive success and longevity in sow herds. The chapter discuses use of gilt development units (GDUs) to improve the identification of select gilts with superior reproductive potential and lifetime productivity, the importance of birth weights, the role of nutrition, as well as management of boar contact and timing of mating. The chapter goes on to discuss research on best practice in mating management and insemination techniques and the key overall role of stockmanship in influencing reproductive performance. It also assesses management strategies to sustain reproductive performance of sows in dry sow and other housing systems. Diminished conception rates and high pregnancy losses are also attributable to infections, and the chapter discusses ways of dealing with diseases such as porcine reproductive and respiratory syndrome virus (PRRSv), porcine circovirus (PCV-2), swine influenza and porcine epidemic diarrhea virus (PEDv) outbreaks.

Complementing Chapter 3, Chapter 4 reviews factors affecting the reproductive efficiency of boars. The main goal of breeding is efficient dissemination of genes of high-indexed boars. Efficient artificial insemination (AI) is essential in achieving this by diluting semen from high fertile breeding boars to allow insemination of many sows. The chapter provides an overview of factors affecting the reproductive efficiency of boars. It then reviews research and best practice in such areas as boar selection, semen management and quality assessment, implementation of AI and monitoring of its effectiveness. As an example, the chapter assesses ways of predicting porcine male fertility, including sub-fertile boars, by matching ejaculate records with field fertility data, to optimise boar selection.

Chapter 5 complements Chapter 2 by discussing genetic factors affecting feed efficiency, feeding behaviour and related traits in pigs. Feed resource efficiency contributes to sustainable production of pig meat, both economically and environmentally. This chapter begins by describing the relative merits of different measures of feed efficiency such as feed conversion (also called as food conversion) ratio (FCR) and residual feed intake (RFI).

The chapter also discusses the underlying genetics of feeding in pigs. It reviews research on the heritability of good RFI values in pigs. As the chapter points out (echoing Chapter 2), a key requirement for breeding is to establish genetic correlations between phenotypic, genetic and nutritional RFI measures. The chapter then reviews research on quantitative trait loci (QTL) mapping of traits associated with feed efficiency, the identification of candidate genes as well as other research describing biological pathways that might regulate RFI. The chapter also looks at genetic correlations between RFI and observed feeding behaviour. The chapter draws on studies of genetic correlations of RFI with pig production traits and Genome Wide Association Studies (GWAS). Understanding these relationships and the genetics underlying component traits of RFI helps in prioritizing of candidate genes for further investigation. It also helps assure that marker assisted selection based on candidate genes for RFI does not adversely affect daily weight gain. The chapter goes on to review the use of genomic selection (GS) in improved selection for feed efficiency, with GS estimated to increase the rate of genetic gain by up to 25% compared with traditional breeding. Finally, the chapter looks ahead to the future and the adoption of an integrative systems genomic approach which combines genomics, epigenomics, transcrtiptomics and metabolomics. This integrated approach will provide a more complete picture of the biological mechanisms underlying feed efficiency as well as more accurate genomic prediction for breeding.

Part 2 Animal nutrition

Part 2 begins with an overview of some of the key issues in improving pig nutrition. As Chapter 6 points out, our understanding of the nutritional requirements and metabolism of the pig has advanced significantly over the last 10-20 years. The magnitude of progress is evident when we compare the performance of pigs today compared to the late 1980s with whole of life average daily gain increasing by 60%. The chapter provides a wide-ranging and authoritative overview of some of the key ways this has been achieved and some of the key areas of research to ensure both continued improvement as well as more consistent feed efficiency and meat output across the herd. The need for continued research is all the more important because significant technologies like porcine somatotropin (pST) and ractopamine, that have been key contributors to this improved performance, are no longer viable technologies for use by the industry.

One key theme is nutrition at particular stages in the life cycle. Echoing Chapter 3, Chapter 6 first emphasises the importance of minimising sow replacement and maintaining sow health through optimal gilt development. As the chapter points out, the key to a long reproductive is to optimise the entry of the gilt into the breeding herd through meeting key weight targets, and then maintain an adequate level of nutrition throughout gestation. Nutritional programs need to support maintenance of body tissues and the growth of maternal and foetal tissues, as well as ensure a high level of feed intake during lactation to reduce losses of body reserves and maintain good ovarian function. The addition of spray-dried plasma products (SDPP) to diets has also revolutionized the feeding of newly-weaned pigs, enhancing performance through increased feed intake and feed efficiency in the immediate post-weaning period. Later in the life cycle, one method of inhibiting sexual development and aggressive behaviours in the late finisher phase is immunization against gonadotropin-releasing factor, referred to as immunocastration, which increases feed intake and average daily gain and decreases feed conversion rate.

A second key theme is ways to reduce variation at the point of sale to improve the profitability and efficiency of a pig enterprise. The chapter therefore looks at nutritional factors that can influence birthweight and variability in birthweight. While the greatest effects of lactation feeding will be on post-natal piglet performance and variation, research also shows, for example, that nutrition of the sow during lactation can also influence variation in litter birthweights. The chapter also looks at the role of supplementary milk on the performance of lightweight piglets before or after weaning, as well as studies on improving the performance of light-weight weaners through nutritional intervention.

A third key theme is the role on nutrition in 'gut health'. Gut health can be viewed as an outcome of the complex interactions occurring in the gastrointestinal tract (GIT) between nutrition, the mucosa and the microbiota of the GIT. The chapter reviews the wealth of research on the range of ingredients promoting gut heath such as: zinc oxide, probiotics (such as soluble non-starch polysaccharides (NSP) and resistant starch (RS)) as well as organic and inorganic acids in pig diets (including the encapsulation of acids for targeted delivery to different gut segments), phosphorylated mannans, amino acids (such as glutamine), yeast extract and peptides. The chapter also looks at research on ingredients such as dietary chromium in increasing feed efficiency and daily gain whilst improving aspects of meat quality such as decreased back fat thickness, as well as renewed research into safe and effective ways of using food waste as a potential source of feed.

A final key theme is the capacity to measure and control variation in the nutritional quality of feed ingredients prior to diet formulation. The chapter assesses the debate over the suitability of digestible energy (DE) and metabolisable energy (ME) versus net energy (NE) systems as the most appropriate measures of available energy in feed ingredients, particularly cereal grains. The chapter also describes advances in analysis of ingredients using either chemical or rapid techniques such as near infrared spectrophotometry (NIRS) as well as the progress in countries such as Australia in developing rapid, online assessment of digestible energy content in cereals and oilseed used in pig diets. Results have shown significant differences in energy intake which represent a major source of variation in pig growth which increases as the pigs grow. Technologies like NIR and other 'precision farming' technologies must be better utilised to ensure that the diets we are feeding our pigs actually meet their requirements.

The level of energy in a pig's diet influences the rate and efficiency of gain, the quality of the resulting carcass and even the quality of the pork produced from the carcass. The concentration of energy in the diet represents a critical balance among factors such as cost, the energy level of available ingredients and the level of growth performance desired. However, given the complexity of the subject, energy requirements and energy use in pigs remain poorly understood. Chapter 7 discusses the basics of energy metabolism, energy systems, energy sources, energy requirements and methods to improve the utilization of energy by the pig.

As the chapter notes, energy can be supplied in the diet by starch and other simple carbohydrates such as lactose, by more complex carbohydrates known as fibre, by individual amino acids within protein and by lipids. Each of these is utilized by the pig as an energy source in different ways. A key variable is the efficiency with which dietary components can be used by the pig to generate adenosine triphosphate (ATP) for the purpose of maintenance and protein accretion or to deposit lipid in the body. The digestibility of dietary components is also an important variable. Areas of research include the most effective way to incorporate highly fibrous – but often less expensive – ingredients in the diet of the pig as well as the use of dietary fats to enhance pig performance. The chapter also discusses ways of processing ingredients including pelleting to increase availability of energy or the addition of digestive enzymes to improve swine diets to improve the digestibility of energy. The chapter also reviews the relative merits of different ways of measuring energy such as net energy (NE), digestible energy (DE) and metabolizable energy (ME) as well as the potential role of modelling in measuring and optimising the delivery of energy through diet.

Chapter 8 discusses ways of meeting amino acid requirements in pig nutrition. Protein is the one of major components of the pig body, and dietary protein is the sole source of the essential amino acids required for protein synthesis for body maintenance, growth, and reproduction. Protein synthesis is limited when there is a deficiency of any amino acid, and it is therefore important to ensure that feed meets the amino acid requirements of pigs at their various growth stages. Chapter 8 reviews the principles and practical aspects of meeting the amino acid requirements of pigs, with information organised according to growth stage and physiological status. These growth stages include: gestating sows, lactating sows, nursing pigs, nursery pigs, growing and finishing pigs

The chapter shows how amino acid needs and their ratios for fetal and mammary gland growth affect dietary amino acid requirements which mainly occur during late gestation in sows. The chapter discusses amino acid needs and their ratios for milk production and mammary gland growth as well as the way amino acid contribution from maternal tissue mobilization during lactation affects dietary amino acid requirements for lactating sows. In feeding growing pigs, research shows that dietary amino acids should meet the requirements but also minimize excess provision to reduce amino acid catabolism. Use of supplemental amino acids allows the nutritionist formulating feed to reduce nitrogen excretion to the environment. With an increased number of supplemental amino acids available in swine feed, nutritionists can formulate feeds with ideal amino acid patterns based on their growth stages and physiological status which also significantly reduces the use of protein supplements.

Requirements for vitamins in modern intensive swine production are still based on genetically outdated lines of pigs and production conditions which have changed dramatically during the last 30 years. There is lack of scientific information on the vitamin requirement for the fast-growing lean meat type of pigs according to their physiological responses. There is evidence of lower levels of micronutrients in pork which may not only affect meat quality parameters such as oxidative stability, colour and water-binding but also affect consumer perception of the nutritional value of pork. At the same time, the criteria used to estimate vitamin requirements for pigs have moved from prevention of deficiencies to optimisation of performance for growth and reproduction. The estimation of requirements needs to include criteria related to other aspects potentially limiting for full expression of performances such as metabolic stress and disease resistance.

Chapter 9 reviews recent advances in understanding the role of vitamins and their importance for oxidative mechanisms, especially in relation to the development and competence of the immune system which are key contributors to optimal health status of pigs and to their ability to face pathogenic pressure during their life. The chapter outlines what current research shows about the potential contribution of both fat-soluble vitamins (e.g. A, D and E) and water-soluble vitamins (such as folates, vitamin B12 and the intermediary amino acid homocysteine) and offers new perspectives on the relationship between vitamins and antioxidation capacity. The chapter shows ways of balancing requirements for prevention of vitamin deficiencies and optimization of performance as well as disease protection.

As Chapter 10 points out, improvement of feed efficiency is crucial if pig production is meet the challenge of sustainability in terms of production costs and environmental impact. Chapter 10 describes advances in modelling approaches developed to predict the nutrient requirement of a single individual animal (growing pig or sow) in terms of protein/amino acids, energy, and minerals. The chapter reviews modelling approaches for growing pigs and reproducing sows such as the InraPorc sow model based on integrating on-farm data on reproductive performance, feeding practices, and housing conditions. The chapter explains recent advances in integration of individual variability among animals into models for pig feeding, including the use of stochastic modelling techniques and illustrates via a case study the potential for improving feed efficiency through the application of these models in precision feeding. Precision feeding is based on the dynamic adjustment (if possible day by day) of dietary nutrient supplies to requirements, at a group or at an individual level. In this approach, individual pigs are treated as such and each pig/group is to be modelled individually. The purpose is to improve feed efficiency whilst reducing feed cost and environmental impact. These themes are also picked up in Chapter 14

Echoing Chapter 6, Chapter 10 reviews ways of reducing variability at slaughter, including a herd modelling approach to evaluate different feeding strategies to control or reduce variability among pigs at slaughter. It also reviews the use of the InraPorc model to characterise the effect of different feeding strategies (e.g. amino acid content or feed allowance), on the mean and variation in growth rate and slaughter weight. As the chapter points out, new developments in sensors and data collection will allow access to more precise, detailed, real-time data on characteristics such as feed intake and body weight. When combined with historical data, it will be possible to predict the outcome of different feeding strategies with even greater accuracy to improve economic returns and environmental impact.

As Chapter 11 makes clear, exogenous feed enzymes have been in commercial use in swine diets for almost 30 years. This chapter focuses on the use of three classes of enzyme: NSP'ases, phytases and proteases. Lipolytic enzymes are also considered. The chapter reviews the evidence on their benefits and mechanisms of action as well as assays for measurement. As the chapter points out, it was the emergence of cost effective phytases that resulted in the now almost universal deployment of exogenous enzymes in swine diets. The commercialisation of microbial phytases has resulted in substantial reductions in rock phosphate utilisation and phosphorus (P) excretion into the environment. Phytase use to replace inorganic phosphate has significantly improved the sustainability of pork production through the reduction of raw material use coupled with reduced P excretion in manure. As the chapter discusses, novel uses for these evolved phytases have started to emerge with 'extra-phosphoric' effects of superdoses of phytase gaining considerable attention in the past few years. These extra-phosphoric effects of phytase are associated with the improvements in utilisation of nutrients other than P (such as zinc and nitrogen) and reduced maintenance costs to the animal, which may be attributed to the mitigation of the anti-nutritive effects of dietary phytate. Research shows that the value of feed enzymes is not only that performance on average is improved, or nutrient density reduced and performance maintained, but also the potential of exogenous enzymes to reduce the variation between the best and worst animals and herds. As more is learned of the factors which influence the response to exogenous enzymes, the greater the likelihood that their value and thus payback will increase.

Chapter 12 describes the use of growth promoters in pigs, specifically growth hormone (GH) and beta-adrenergic agonist (BA). Although banned in some parts of the world, such as the European Union, growth promoters have now been used in some countries for over 20 years with no adverse human safety issues, suggesting that they are relatively safe when used according to recommended guidelines. Despite the term 'growth promoter', these substances do not necessarily always result in increased growth rates, but they do tend to alter body composition and improve feed efficiency, as determined by the gain-to-feed ratio. After introducing each growth promoter, the chapter discusses current research on their individual effects on growth and feed efficiency, followed by sections on their mechanisms of action and effects on muscle fibre type and meat quality. The chapter also summarises recent studies on the use of growth promoters such as Ractopamine and Reporcin in combination and assesses their future use commercially.

Prebiotics and probiotics have attracted considerable interest as alternatives or replacements for growth promoting antibiotics and (or) some heavy metals in diets for pigs, particularly in the post-weaning period where the newly-weaned pig is subject to considerable challenges in its new environment. As Chapter 13 points out, the microbiota, i.e. the ecological community of commensal, symbiotic and pathogenic microorganisms, is of huge importance to the host, particularly in the gastrointestinal tract (GIT). The microbiota, particularly bacteria, plays a part in prevention of establishment of pathogenic bacteria, modulation of the immune system, detoxification, production of vitamins and short-chain fatty acids, and facilitation of digestion and absorption processes.

This chapter briefly reviews the microbiota of the gastrointestinal tract (GIT) of the young pig and the important roles it plays in the early stages of life, before introducing probiotics, prebiotics and synbiotics. Probiotics are live beneficial microorganisms (bacteria) that may exert a beneficial effect on the host and can aid in the establishment or composition of the GIT microbiota. Prebiotics are non-digestible food ingredients and are thought to benefit the host by providing substrates for beneficial microbiota, giving them a competitive advantage. The term synbiotics is used when probiotics and prebiotics are combined.

The most commonly used probiotic organisms are bacillus, yeast and lactic-acid producing bacteria (LAB such as *Lactobacillus* spp.). As research shows, the mode of action varies between different probiotics, but typically involves competitive exclusion through mucosal adhesion, competition of nutrients in the GIT, decrease in luminal pH, production of bacteriocins/defensin, and (or) modulation of the mucosal and systematic immune responses and strengthening of the intestinal barrier. The chapter reviews research on the benefits from supplementation of probiotics in pigs. These include improved absorption and digestion, stimulation of GIT immunity and increased resistance to infectious diseases of the GIT, which all together may improve production performance. To illustrate the benefits of probiotics, the chapter includes a case study of a probiotic product (Peribios™**)** (which contains a strain of *Enterococcus*) used commercially for sows and suckling piglets to modulate production around parturition. The probiotic was found to be beneficial in increasing the number of liveborn piglets, the number of weaned piglets per litter, and an increase in piglets weaned per sow per year.

Prebiotics that have been identified for use in pigs are generally carbohydrates containing a different molecular structure, namely dietary carbohydrates such as fibres and resistant starch, and non-digestible oligosaccharides (NDOs). They also include fructooligosaccharide (FOS), oligofructose (OF) and inulin, galactooligosaccharides (GOS), transgalacto-oligosaccharides (TOS), and lactulose. Prebiotics exert their effect in two ways: they may be fermented by beneficial bacteria such as *Lactobacilli* and *Bifidobacteria,* which would give the beneficial bacteria a competitive advantage by giving them the opportunity to work more efficiently; and, secondly, they appear to interfere with the attachment of pathogenic bacteria to the GIT wall, which would alter the microbiota. As the chapter shows, it has been suggested that the use of synbiotics would be a more beneficial strategy for preventing and controlling diseases during early life and weaning, compared with supplementing with either by itself. The prebiotics would provide a readily available substrate for the probiotics, allowing enhanced growth and enhancing their survival rate, colonisation and effects.

As the chapter concludes, given the complexity of the GIT, the range of probiotics and prebiotics and many other variables, it has been hard to compare studies or achieve consistent results. Fundamentally, there remains a lack of detailed knowledge on the influence of the complex interactions inside the GIT ecosystem as well as the definite mode(s) of action of each probiotic strain or prebiotic material. Advances in this fundamental understanding will make it easier to predict and control performance of individual probiotics and prebiotics.

The final chapter in the book builds on Chapter 10 by looking at developments in precision feeding which involves feeding techniques that provide individual animals with diets tailored daily to production objectives (e.g. maximum growth). A method of estimating energy and nutrient requirements by integrating current relevant knowledge on pig metabolism has been developed and incorporated into a mathematical model. This chapter reviews recent research projects which indicate that feeding pigs a diet tailored daily to their individual requirements is essential to maximize nutrient efficiency and ensure the sustainability of the pig industry by reducing the excretion of nutrients and nutrient constituents and lowering feeding costs. This new nutritional approach represents a paradigm shift in pig feeding, because the optimal dietary nutrient level is no longer considered a static population attribute, but rather a dynamic process that evolves independently for each animal. Precision feeding is a highly promising avenue for improving resource-use efficiency in comparison with conventional group phase-feeding programs. The chapter includes a case study on the use of precision feeding in practice.

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