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Challenges in the 21st century in pig and poultry nutrition and the future of animal nutrition

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Summary points

- 21st century animal nutrition faces a number of challenges including animal welfare, environmental pollution minimisation, use of novel ingredients, use of ingredients not suitable for human consumption and more.
- New area of science are paramount for animal nutrition to meet these challenges such as molecular biology, nutrigenomics, molecular genetics, information technology.
- Precision animal nutrition will gain in importance as well as the validation of alternative feed ingredients and the increased use of food waste and co-products.
- There is an increasing need for better cooperation between medical and agricultural sciences on the basis of professional logic, as well as cooperation in R&DI programs and education.

Keywords: pig and poultry nutrition, 21st century challenges, future animal nutrition

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1.1 Introduction

The predicted increase in the human population and standards of living in developing countries by 2050are expected to create a high demand for animal-derived protein (Boland *et al.*, 2013). In many OECD countries, overconsumption of food has been increasing over the past 40 years. Currently, one in every 2 persons in these countries is overweight or obese with America having the highest obesity rate (38.2%) and Japan the lowest (3.7%) (OECD, 2017). Nearly 50% of deaths in the Europe Union are due to cardiovascular diseases, while 30% are caused by tumour diseases (Eurostat, 2018). It is without a doubt that nutrition is one of the key risk factors of these illnesses. By changing adverse nutritional habits and by consuming foods and food products which better conform to nutritional requirements, life expectancy of a larger number of people can be increased. In addition to the problems arising from lifestyle, eating habits and eating culture, food related allergies, the overreaction of the organism to certain foods or their ingredients, are increasing (Branum and Lukacs, 2009). Food intolerance – which also belongs to this range of problems – occurs when the abnormal symptoms caused by a food do not have an immunological origin. As a result of this oversensitivity, those affected often require special foods besides nutrition alternatives. As such, the challenge of 21st century animal agriculture is to sustainably produce foods and food products of animal origin in the proper quantity and quality which is safe to eat and can be traced within the production chain.

In order for the agricultural sector to be able to provide proper quantities of safe food materials to the food industry, there is an increasing need for better cooperation between medical and agricultural sciences on the basis of professional logic, as well as cooperation in R&DI programs and education. In addition to agricultural and medical science, nutrition biologists, genetic experts and other professionals dealing with nourishment will have important roles in the future. The food production chain approach and collaboration between various scientific disciplines should be instilled in current education programmes to develop young professionals, in order to produce high quality foods and improve human health. Efforts to such cooperation can already be observed e.g. in the USA, Canada, some EU-countries and in New-Zealand.

The present chapter focusses on the challenges in pig and poultry nutrition in the 21st century and provides a perspective of animal nutrition in the next decades.

1.2 Challenges in the 21st century

The agricultural and food production sectors of many countries have to face major challenges in the 21st century.

As depicted in Figure 1.1, these challenges include:

- Meeting the food demand of a rapidly growing world population. Currently, the human population is nearly 7.5 billion (Figure 1.2) but by the year 2050 the United Nations (2011) predict that there will be more than 9.0 billion people. In addition, living standards are also increasing.
- The increasing demand for high quality and safe food. FAO (2009) estimates the world will have to produce approximately 60-70% more food in the next 35 years. This organisation also predicts that animal protein production will increase at least three-times and meat production will double by 2050.
- Decreasing potential agricultural land area due to industrialisation, the building of new motorways, new city construction programs, urbanisation and natural soil erosion.
- Climate change, and its effects on animal production and elimination of these effects by genetic, nutritional and/or technical innovations (Pullar, 2011).
- Declining fresh water resources.
- Increasing severity of environmental load-related problems.

In addition, aspects such as animal welfare, food-feed-fuel competition and self-sufficiency level are additional challenges facing countries. It is also a known fact that the quality of food of animal origin is greatly determined by the nutrition of animals. Feeds in pig and poultry production systems can make up 50-80% of the costs of production and unutilised dietary components are a major contributor to pollution. As such, animal nutrition has a key role to play in solving many of the above-mentioned challenges. In 2017, nearly 1032 million tons of compound feed for farm animals was produced world-wide (Figure 1.2).

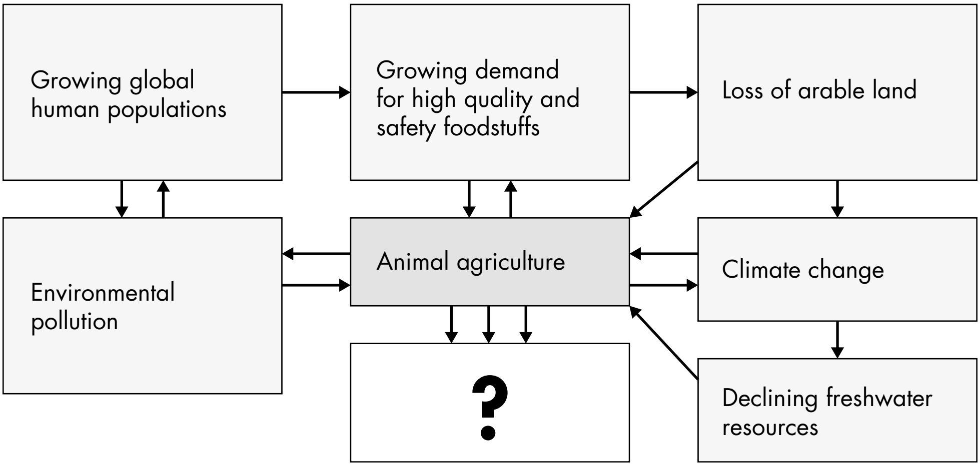

Figure 1.1. Main challenges in 21st century animal agriculture.

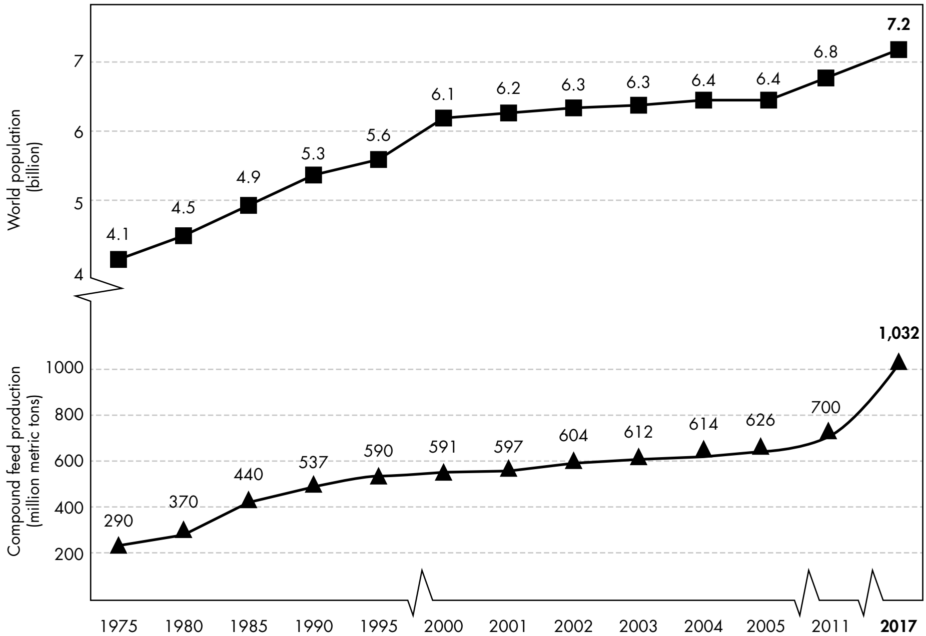

Figure 1.2. World population and compound feed production from 1975 to 2017 (based on Alltech, 2018; Gilbert, 2004; Gill, 2006; United Nations, 2011).

Today it is clear that the quality of the mixed feed can have a determinant effect on the quality of foods of animal origin. In addition, in many countries production animals are still fed diets containing ingredients with an uncertain origin, undermining feed safety and, therefore, food safety and health. It is obvious that livestock nutrition has a major responsibility for food production, not only in terms of quality and quantity of food but also safety and health. Livestock nutrition, therefore, can be considered to face the following important tasks in the 21st century (Babinszky and Halas, 2009):

- More active participation in animal production to supply safe food in sufficient quantities, in accordance with the requirements of society (Koerkamp *et al.*, 2007).
- Further improve the efficiency of animal nutrition (biological efficiency, technological efficiency and economic efficiency).
- Wider use of various co-products as well as further reduction of human edible ingredients in animal nutrition.
- Rethink the interrelation between animal nutrition, animal husbandry and environmental protection. The latter entails that good quality and safe food of animal origin should be produced using technologies which contribute to the increased sustainability of the system, i.e. environmental-friendly nutrition systems which lead to a reduction in nitrogen and phosphorus output.

Based on the above it can be stated, that the key issue will be to produce sustainable food via sustainable feed (and feeding) with year by year decreasing resources and with the need to reduce environmental pollution (Cortly, 2014). Already in 1996, Vavra wrote that if the rate of resource exploitation continues in the future, it will lead to a depleted earth. Most scientists agree that current production systems in animal agriculture are generally non-sustainable.

Sustainability of agriculture has been defined by many researchers but a uniform definition for it is still lacking (White, 2013). The most common definition used is: 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987), but there are many more definitions and interpretations. Rather than seeking or proposing another definition, White (2013) depicted sustainability as a Wordle derived from common elements in over 100 previously-published definitions. Sustainability is also often viewed to encompasses three pillars (Elkington, 1997). First, the planet (environment): in order for something to be sustainable, it must be environmentally viable. Second, people (social): sustainability must be socially viable, in relation to food affordability and changes that would directly impact the human population. Third, profit (economy): if something is not economically profitable, it is non-viable in the long run and will have detrimental effects on future generations. With the other words, this so called 'triple-bottom-line approach' includes three factors: environmental stewardship, social responsibility and economic viability (Capper, 2013). It should be noted that sustainability does not necessarily imply organic agriculture, although some components of this system might be needed to establish sustainable farming system (Tedeschi *et al.*, 2017).

In order to increase the efficiency of animal products, it is especially important to introduce the latest scientific findings into practice as quickly as possible. This means that the so-called innovation time (the time span between product idea and the actual production) has to be reduced as much as possible. However, the question is whether we can respond to the challenges of the 21st century with our classic animal nutrition knowledge. Probably not, and this is why it is important to involve new areas of nutrition (e.g. -omics, big data) but also new technologies (e.g. artificial intelligence, genetic fortune telling) into the innovation activities. Inter- and transdisciplinary research is needed into the mechanisms for achieving improved welfare standards within very different social and economic contexts (Buller *et al.*, 2018). In other words, to provide the right answers to new challenges, a more holistic approach is required involving state of the art technologies.

Babinszky and Halas (2009) presented other areas of natural science and/or technical science that are required besides classic animal nutrition knowledge in order to be able to adequately respond to the current challenges. Figure 1.3 summarises the envisaged relationship between natural, nutritional science and other related disciplines.

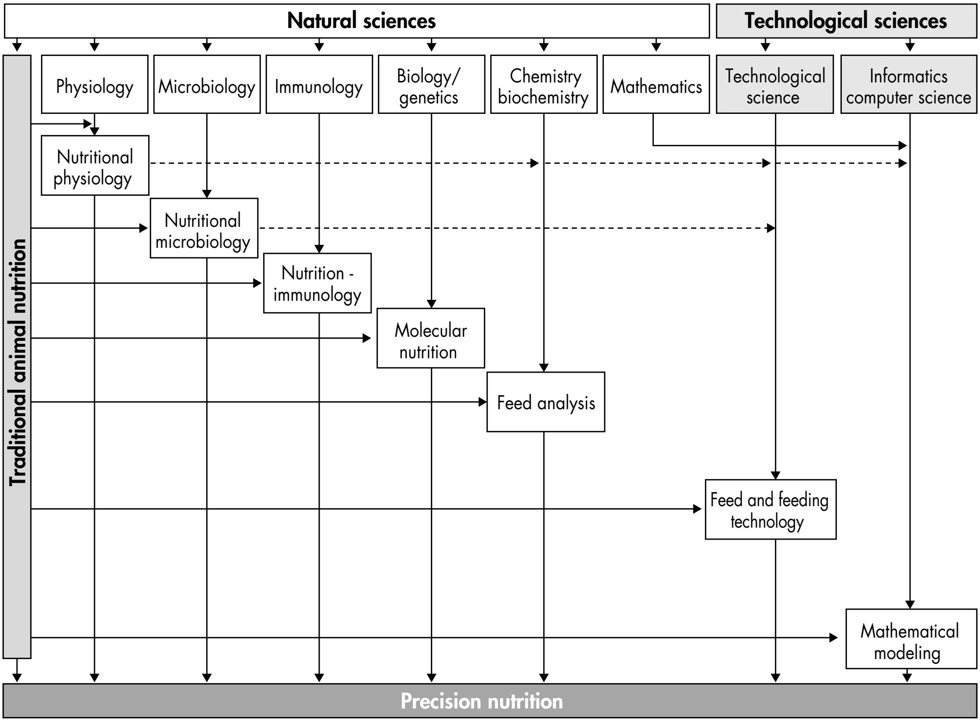

Figure 1.3. Relationship among traditional animal nutrition, natural and technological sciences (Babinszky and Halas, 2009). With permission of Taylor & Francis.

Precision animal nutrition applies the research findings of 'classical' nutrition as well as related areas to animal nutrition in order to meet the unique nutritional requirements of a specific group of animals kept under specific conditions with maximum accuracy. According to Nääs (2001), precision nutrition consists of meeting the nutrient requirements of animals as accurately as possible in the interest of safe, high-quality and efficient production, in addition to ensuring the lowest possible load on the environment. This concept is also in agreement with the principle of sustainability. Important areas of science which are currently being developed and are likely to make a direct impact on the nutrition of production animals in the near future are:

Molecular nutrition. This relatively new interdisciplinary research area has emerged from advances in molecular biology and requirements for explaining the organism's responses to nutrients at a molecular level including gene expression, signal transduction, and covalent modifications of proteins (Yan, 2015). The molecular biological methods developed in the last 20 years and new technologies made it possible to gain a better understanding of these biological processes. This knowledge will have great importance in the near future not only in the field of human nutrition, but also in animal nutrition science. Among others, molecular nutrition examines how nutrients (glucose, fatty acids, amino-acids, vitamins, etc.) affect the signal transmission between cells and gene expression. Due to biochemical processes, micronutrients affect the information flow in cells and, thereby, they influence gene activity or suppression.

Nutritional immunology. Since the early ninety eighties, this has been a very intensively studied area of nutrition. Nutritional immunology investigates the role (mostly to improve) of dietary components (e.g. amino-acids, fatty acids, macro-, micro- and trace minerals, vitamins, etc.) and their interactions with other environmental factors and genes in the cellular and humoral immune responses of farm animals. The development of the so-called 'new type' growth promoters also belongs to this research/development field, as the use of these products results in enhanced performance through the improvement of the immune status of animals.

Nutritional microbiology (e.g. microbiological processes in the intestinal tract and the effect of these processes on animal production). This research area deals not only with the microbiological status of the feed ingredients or compound feeds but also with the impact of the diet on composition of the microbiome and moreover, with the relationships between various physiological processes and diseases in the animal body and the changing of the composition of microbiome. Based on the recent scientific findings it is evident that an optimally functioning gastrointestinal tract is of import to the overall metabolism, physiology, disease status and performance of pigs of all stages of growth and development (Pluske *et al.*, 2018). With the banning of the in-feed use of antibiotics in more and more countries, new methods for maintaining intestinal health and a commensal bacterial community is of the utmost importance. The recent finding that the microbiota affect the immune system of the gut as well as the systemic immune responses including lungs (Keely *et al.,* 2012; Molley *et al.,* 2012) opens new possibilities to improve the immune response to respiratory diseases.

Mathematical modelling of growth and production. One of the most important preconditions for economical production of high quality animal products (meat) is the prediction of the growth of animals, the determination of the nutrient requirements of the expected growth and – based on these – the provision of the necessary amount and quality of feed/nutrients. Mathematical modelling of the growth and nutrient requirements of animals has long been studied since the 1970s. In recent years, however, this area of science has develop in a spectacular way only as a result of the rapid development of information technology, the extended knowledge of physiology and the improvement of the accuracy of various animal testing methods. In a model, the biological processes of animals are described by mathematical equation systems that are built on the knowledge of genetics, biochemistry, physiological processes and environmental effects. The majority of the models used today are mechanistic, able to predict the nutrient requirements of animals and estimate the production level which can be reached under given husbandry, feeding and management conditions.

Development of new in vitro *techniques* (e.g. in order to determine the digestibility of proteins, carbohydrates and other nutrients). Generally, *in vitro* methods are not a complete substitute for *in vivo* examinations. However, they can be of great help for feed analysis laboratories, where it is not possible to perform animal experiments, or for crop breeding institutions in scientific research projects if the large number of samples makes it necessary to perform a so-called preliminary selection before *in vivo* examinations. The significance of *in vitro* techniques will greatly increase in the future, because of new animal ethics laws that will provide less opportunity for *in vivo* examinations. It is usually referred to as the advantage of *in vitro* examinations that they are relatively cheap and quick, they do not call for the infrastructure needed for animal tests, the necessary number of replications can usually be increased more easily than in the case of *in vivo* experiments and it is possible to gain relatively large amounts of data even from a small quantity of investigated sample. However, the main disadvantage is that they are not always as accurate as animal tests and merely provide a ranking rather than an absolute value.

Development of environment preserving feeding technologies (e.g. feeding technologies to reduce N, P, Cu, Zn and methane emissions). Nutrients and other components in feeds not retained by the animal will be lost to the environment. In terms of environmental burden, two of the most critical polluting elements are nitrogen and phosphorus. Also copper and zinc as well as methane emissions are causing concerns. As such, in developing environment-friendly breeding and feeding technologies, the emission of primarily these elements needs to be reduced. In addition, more attention has to be paid to the reduction of unnecessarily high microelement emissions. Among our industrial farm animals, the highest nitrogen and phosphorus pollution is generated by the pig and poultry sectors. This can be traced back to the digestive characteristics of these two species, an inappropriate crude protein and amino acid supply, and the housing (keeping) technology as well as deficiencies in manure management. For copper and zinc, dietary oversupply and low bioavailability are important reasons for high concentrations in manure.

The large emission of P can be significantly reduced by means of expressing requirements in digestible P-content, further specifying the values of nutrient requirement, rational selection of feed ingredients and improving the digestibility of native P-content through phytase-enzyme addition. For example, in the case of pigs of different ages, the level of N emission can be significantly reduced by a more accurate specification of amino acid requirements, introduction and dissemination of modern protein evaluation systems (ileal digestible protein content of the diets) and the so-called ideal protein concept. There are further possibilities for reduction of N emission by improvement of amino acid digestibility of diet components, the further use of first limiting, industrially produced amino acids and characterisation of bioavailability of dietary amino acids. These potentially available feeding tools can enable a 20-25% reduction in both N and P emission without decline in animal performance.

Precision animal (pig and poultry) nutrition, which is an integral part of precision livestock farming, contains several biological elements. Some of these are:

- Diet formulation should be based on available nutrients.
- Application of disposal cost for nutrients in diet formulation to find economical optimum for their inclusion, rather than nutritional optimum only (Van Kempen and Van Heugten, 2001). The consideration of nutrient disposal cost in diet formulation are especially actual nowadays, because large amounts of by-products are produced in the bio- fuels industry (Hadrich *et al.*, 2008). The term cost of disposal is used to describe the incremental expense that can be directly attributed to the disposal of an asset, contract, or cash-generating entity which can be regarded as a future liability.
- Application of phase feeding and split-sex feeding.
- Using mathematical modelling to predict animal performance.
- Reducing the harmful effect of heat-stress with different nutritional tools.
- Base nutrient and energy supply on genetic potential of livestock.
- Improve immune and health status of animals by macro- and micronutrient supply.
- Use industry and agriculture origin co-products based on actual nutrients and energy contents.
- Reduction of N, P, Cu, Zn and methane excretion by different nutritional tools.

Besides up-to-date nutritional knowledge, precision animal nutrition also requires the application of individual feeding based on computers and transponders. Observing the trends of today, it can be concluded that in future of animal feeding, the concept of sustainable precision livestock farming will become more and more important (Den Hartog and Sijtsma, 2011).

1.3 Future perspectives in animal nutrition

Many of the natural and technical sciences as well as interdisciplinary sciences such as animal nutrition, are developing rapidly. Nowadays it is not an easy task to predict the future of a given area of science. The demand by society on animal products and the way they are produced is likely to further increase in importance in the future, effectuated through increasing constraints on production systems by more stringent regulations. Public health issues will become increasingly important, such as concerns associated with the use of antibiotics, residues in food and diseases. New diseases have emerged, such as avian influenza H5N1, which have caused considerable global concern regarding the potential for a change in host species and emerging global pandemics (Thornton, 2010). Environmental issues related to animal production such as methane mitigation, mineral pollution and ammonia emissions are also likely to increase. Stricter animal welfare concerns in many developed countries are likely to decrease production efficiency while the wide-scale use of human-edible ingredients in animal diets will re-ignite the food-feed-fuel competition debate in light of the future global protein shortage.

Animal nutrition science and its co-disciplines are based on biology, chemistry, biochemistry, microbiology, molecular biology, physiology, toxicology, immunology, molecular genetics, information technology, mathematics, physics, various areas of technical sciences, etc., as well as the development of the different examination methods (e.g. surgical techniques) applied during animal experiments. The past two decades has seen an unprecedented advancement in many of these areas of science. The advancement in genomics, transcriptomics, proteomics and metabolomics will continue and provide hitherto unknown opportunities to further fine tune the supply of nutrients through the diet and the demand of the animal for nutrients to grow or produce.

Today, it is self-evident that there is an increasing demand on behalf of societies for high quality, safe and transparently produced food products. However, in the case of foods of animal origin, this demand can only be fulfilled if modern animal nutrition knowledge is applied together with the latest findings of its co-disciplines. As a matter of course, this holistic approach to the problem requires strong teamwork, as even a highly skilled and constantly learning professional could face difficulties when exploring and expertly applying all new findings of a certain area of science.

Besides the demand for increasingly welfare friendly production systems, it is also an important and rightful expectation of society for animal experiments to fully comply with the actual ethical codes, legal stipulations and animal protection laws. Also these societal demands are expected to grow in the future and animal experiments and various examination methods can only be performed and applied in compliance with the increasingly strict prescriptions. The latter will have serious financial implications, which also need to be covered by society.

Based on the relevant literature data, information presented on various conferences and our own international observations, we present the main directions of changes using this non-exhaustive list of examples. We classified tendencies into two main groups: the next 5-10 years and subsequent decades.

1.3.1 Prognosis of the near future (the next 5-10 years)

This group includes the research areas and examination methods whose importance is most likely going to significantly increase in the near future, although they are important even today. Such research areas and examination methods include:

Research on alternative feed ingredients

Using new feed energy and protein sources is mainly aimed at the partial or total replacement of maize and soy. There can be several reasons for this shift, with the main goal being the fact that both feed ingredients are important in human nutrition or as food ingredients for humans. In many cases, feed ingredients are sold as a commodity to both the food and feed industry. The main priority is to supply the human population with high quality and safe foods. Several ingredients are not intended, less suitable or very unsuitable for human consumption. For example, genetically modified energy and protein sources of vegetable origin are banned in many countries. It could be a further argument for replacement that the actual stock exchange rate of these feed ingredients are not determined or not entirely determined solely by the demand in agriculture (livestock management), but also the industry (e.g. food industry, medicine industry, etc.) that generates more profit. On the contrary, this fact results in an increasing feed ingredient price (e.g. in the case of soy and maize), which may significantly increase the specific costs of producing food of animal origin, thereby deteriorating the market position of meat, egg and milk producers, among others.

In the case of protein sources of vegetable origin, further intensive research is expected in order to reduce or eliminate the harmful impact of anti-nutritive factors by means of crop breeding and/or various feed technology or management procedures, thereby improving the biological efficiency of animal nutrition and the production of high quality feed ingredients (Huisman and Tolman, 2010).

The novel protein sources (e.g. insects, algae, microalgae, seaweed, duckweed) are expected to enter the European feed and food market as partial replacement for conventional protein source or due to their potential beneficial effects above the nutrient content they contain (see Chapter 13, Van Krimpen and Hendriks, 2019). However, it should be emphasised that food safety aspects of these new protein sources are not well-known (Van der Spiegel *et al.*, 2013; Chapter 13, Van Krimpen and Hendriks, 2019). More systematic and thorough studies are needed to determine not only the digestible/available amino acid profile of these novel protein sources but also any adverse effects on animal and human health (e.g. possible viral infections), or any other detrimental effect on the consumer.

Determining nutrient requirement values more accurately

Meeting the nutrient requirements of production animals as accurately as possible based on examining the interactions between macro- and micronutrients remains a key issue for the coming years for the purpose of further improving efficiency of production. This topic also involves the effort to make the nutrient requirements of animals with high genetic capacity (e.g. so called 'improved pigs'), more accurate, i.e. to examine the correlations between genetics and animal nutrition (Close, 1994).

Currently the genetic potential of many pig breeds used in production systems are approximately 3-5 years ahead of the nutrient requirement estimates used for feed formulation as a result of continuous genetic improvement efforts and the difficult and time-consuming nature of determining nutrient requirements (Knap, personal communication).

Developing new alternatives for antibiotic growth promoters

The development of the alternatives for the effects commonly observed with the use of in-feed antibiotic growth promoters (Den Hartog *et al.*, 2015; Vallat *et al.*, 2005) is an ongoing effort. It is also a topical question whether antibiotics can be phased out totally (Leeson, 2012). According to some, it is possible to effectively use other alternative products instead of antibiotics in the production of pork and poultry meat (Den Hartog *et al.*, 2015). It is a just expectation on behalf of both the profession and society to obtain accurate knowledge of the exact mode(s) of action of such alternatives, as well as to reveal any possible risks. It is probable that further pro- and prebiotic-based products will be developed, but it is also possible that the key to the solution will be the use of the so-called combined or multifunctional feed additives (a mixture of symbiotic, antioxidants, immunomodulators, various vegetable extracts and new type toxin binders). However, it must be noted that one of the indispensable requirements of the safe use of supplement/additive is the accurate chemical identification of the active substance(s) (Christaki *et al.*, 2012), otherwise it is not possible to expertly use these additives or even to properly adjust the desired concentration of the active substance.

Reduction or total elimination of mycotoxins

Although mycotoxins and the protection against them is already an intensively researched area, it can be stated that it is not going to change in the coming years and decades. New findings in this important field will be greatly dependent on the development of new analytical methods, as well as their implementation in practical analytics and on how soon the obtained biological, biochemical, physiological and immunology research findings will be applied in animal nutrition. Technological advances and breeding for resistant varieties (Lehoczki-Krsjak *et al.*, 2010) are likely to contribute to reduced mycotoxin content of future feeds.

Increased use of co-products in animal nutrition

According to the relevant prognoses, the amount of agricultural, industrial and other co-products used in animal nutrition is going to increase in the coming years, mostly for economic and environmental reasons as well as the food-feed-fuel discussion. The proper and safe use of co-products is possible only if their chemical composition, digestible and/or usable nutrient content and energy content are known and if the co-products used in animal nutrition are free from materials that are harmful to animal health. From an economic perspective, it is an important requirement that these products have a consistent quality and are cost-effective for inclusion in feeds. For this reason, the so-called shadow-price should also be known. In addition to co-products, food waste also has the potential to be used as an animal feed ingredient as is already actively promoted in Japan, South Korea, Taiwan, and Thailand (Chapter 13, Van Krimpen and Hendriks, 2019).

Examining the relationship among climate change, fodder crop production and animal nutrition

Climate change and the actions taken to mitigate its impacts are becoming increasingly topical in science. The findings of international research indicate that the impact of climate change will be more powerful worldwide in the future. In addition to comprehensive research, there is an increasing ##demanded for climate change and its impacts be included in education and in extension service (Babinszky *et al.*, 2011a). Since the climate continues to change and its future course is unknown, it is necessary both for meteorologists and users to constantly keep track of the process, as well as to monitor changes and their impacts.

The most frequently asked question regarding climate change is what impact it will have on agriculture (crop production, livestock management, production of food ingredients of vegetable and animal origin) and, in a broader sense, on food supply. This question has to be formulated at a regional, continental and global level and for this reason, it is more appropriate to provide the answers also at these levels. This means that the climate scenarios prepared by climatologists are necessary to be adapted to local circumstances and evaluated, as well as to connect them to regional production. Action programmes and the elements of the responses, prevention, adaptation, compensation and restoration can be built up mainly on the climatic change prognoses for a given region (Babinszky *et al.*, 2011a). However, it must also be noted that the food supply prognoses based on climate scenarios have certain margins of error, as agricultural production is significantly affected by not only climate, but also other factors as well (genetics, agrotechnics, adaptation ability, etc.). However, it needs to be emphasised that these research areas are still in their infancy. For this reason, it is highly probable that the analysis of climatic effects and, more specifically, the harmful effect of heat stress, its reduction and/or elimination will become a core research topic in the next decade (Babinszky and Halas, 2009; Babinszky *et al.*, 2011b). Currently it is one of the main topics of research to examine the harmful effect of heat stress on the anti- and pro-oxidant balance of animals and the possibility of mitigating this negative impact with various animal nutrition tools. In the near future, this topic is likely to be even more important (Chapter 8, Babinszky *et al.*, 2019).

Animal nutrition and immunology

Starting from the early 1980s, how nutrients (e.g. amino-acids, fatty acids, minerals, vitamins, etc.) and additives mixed into animal feed are capable of affecting the resistance, as well as cellular and humoral immune response of farm animals, has been a rather intensively researched area of animal nutrition. The findings of related research show that a slight decrease in protein supply compared to the recommended value does not compromise the immune system, but the partial shortage of certain amino acids results in a significant reduction of the defensive ability of the organism in case of an enhanced immunity. Knowing the role of nutrients in the immunity of the organism can contribute to maintaining health and reduce the amount of medication used in the course of producing foods of animal origin. Providing certain amino acids (e.g. methionine, threonine, arginine, glutamine or glutamic acid) above the amount necessary for maintenance and growth can potentially result in enhanced immunity of pigs and poultry. However, it must be noted that giving supraphysiological levels of certain nutrients (e.g. fatty acids) may result in immune suppression even before there is a deterioration in performance (Calder, 1998). Even though animal nutrition immunology is an intensively researched field, there are still many gaps in our knowledge on how to determine the amount of nutrients needed for an effective immunity of the organism when working out animal feed recipes (NRC, 2012). In addition to gaining knowledge of the role of nutrients, the development of so-called 'new type' growth promoters also belongs to this research/development field, as these products result in improved performance primarily through enhancing the immunity of the organism. Again, it is expected that the precise mode(s) of action of these products are provided, since this knowledge can provide explanations to the cause(s) of each potential interaction when using a given product.

Animal nutrition immunology will have a key role to play in practical animal nutrition in the near future and nutrient guidelines will need to be based in many cases on the results of animal nutrition immunology tests.

Animal nutrition and microbiology

This area involves the microbiological processes in the intestinal tract and the impact of nutrition on these processes as well as on the productivity of animals. Today, gut health is a well circumscribed field of animal nutrition research. This area is becoming more and more important in the nutrition of especially monogastric animals. With the ban in many countries of the use of in-feed antibiotics, maintaining intestinal health through the use of various additives has already received (Den Hartog *et al.*, 2015) and will receive more attention in the future. Also in ruminant nutrition, the modulation of rumen fermentation and digestion in order to reduce methane production is of paramount importance to develop more sustainable production systems. The latter is important for the drive of society to reduce green-house gas emissions from ruminant production systems and can be to a large extent be solved by animal nutrition research (Cole, 2005; Forano and Flint, 2000; Verstegen and Tamminga, 2005).

Nutrigenomics

Nutrigenomics is a field of science focusing on the interaction between nutrition and genomics, combining the methods of nutrition science (animal nutrition science) and the so-called functional genomics. The aim of this area of science is to examine how bioactive ingredients or regular nutrients in foods or feeds affect gene expression and functioning. In essence, it encompasses the application of gene technologies in the field of nutrition and animal nutrition science. The investigation into the interaction between genes, nutrition (animal nutrition) and health is rapidly developing although it is complicated due to the fact often more than one gene is involved in the regulation of traits. Findings in this field are being used in practice at an increasing rate (Chapter 7, Vailati-Riboni *et al.*, 2019). In our opinions, nutrient supply will soon be based on genetic profiles (e.g. in pig nutrition).

Further research directions influencing the near future of animal nutrition

In addition to the above mentioned fields, there are currently many existing areas which are going to determine the short- and medium-term development of animal nutrition. However, due to the lack of space, these areas cannot be elaborated here. Examples are:

- *Mathematical modelling* of animal production, which is partially connected to bioinformatics (see below in this section),
- *Elaboration of new and more accurate* in vitro *and quick analysis methods*. The urgency for the development of *in vitro* protein, amino acid carbohydrate etc. digestion analyses methods is increasing, since the conduct of *in vivo* analyses is under increasing scrutiny. However, there are also other arguments for *in vitro* analyses to be developed, such as the relatively short duration of analysis and the lower costs than *in vivo* testing. Developing rapid analyses to estimate the chemical composition of animal feed and feed ingredients is also a key issue in the practice of precision animal nutrition.
- Even today, *nanotechnology* plays an important role in producing animal feed additives. An increasing number of micronutrients (e.g. vitamins, minerals, such as Se, etc.) is mixed into the animal feed in the form of nano-sized particles in order to improve absorption and, as a result, to increase nutrient dynamics, i.e. the efficiency of absorption. Based on the analysis of current trends, it can be concluded that nanotechnology will become more important in animal nutrition science.
- *Biotechnology*. The significance of this area of the green (agricultural) biotechnological industry in animal nutrition and the feed industry is already

apparent. Developments in the red (medical science and health industry), yellow (food industry and nutrition science), grey (classic fermentation industry) and white (industry and environmental protection) biotechnological industries contribute to various extents but are likely increase their contribution to the development of animal nutrition science and a more effective practical animal nutrition in the future.

- *Using the findings of the above described research directions and those of classic animal nutrition*, we put together the so-called *precision food traceability chain* ('from farm to fork animal origin food production traceability chain'), which can be an important guarantee of the transparent and safe food production product path (Figure 1.4).
- As it can be seen in Figure 1.4, 'From farm to fork traceability food production chain' includes precision plant (crop) production, precision livestock farming and precision meat and/or milk industry. It also can be seen that the precision animal nutrition is an integrate part of precision livestock farming.
- The significance of these product paths will further increase in the future, mainly because of society's demand for healthy, high quality, safe and traceable foods. For this reason it can be safely stated that launching and implementing integrated research and innovation programs involving the whole product path will have much greater significance in the future.
- In connection with the previous point, it is highly likely that the legal and ethical issues associated with animal nutrition will be of greater importance to producers.

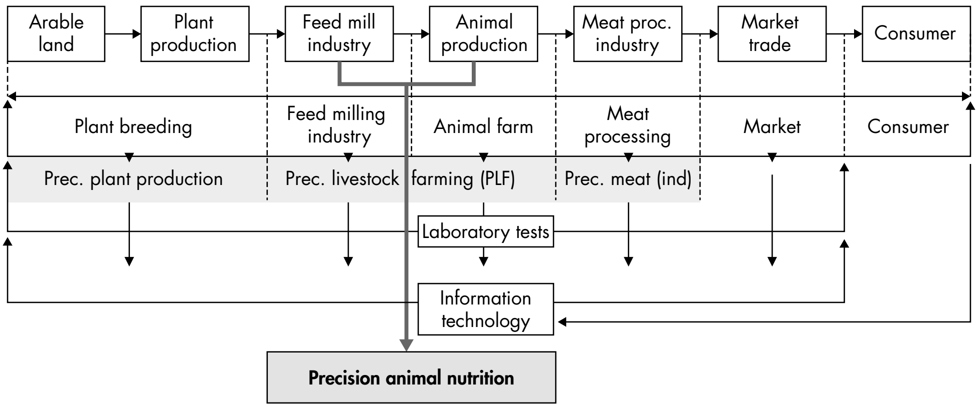

Figure 1.4. 'From farm to fork' precision food production and traceability chain.

1.3.2. Prognosis for the more distant future (the next 10-20 years)

Bioinformatics

Bioinformatics is a branch of science which uses information technology tools and methods in order to explore, model and affect biological processes. According to an early description, bioinformatics is interdisciplinary science which uses computer science in molecular biology (Luscombe *et al.*, 2001). Based on the definition used today, bioinformatics is the *in silico*, i.e. computerised application of all mathematical algorithms and methods which assist in providing solutions to biological problems based on experimental data. For example, from the aspect of animal nutrition, the mathematical modelling of various biological processes (e.g. animal growth, protein and fat incorporation or rumen fermentation). However, within bioinformatics there are entirely specialised areas. For example, structural bioinformatics focuses on the spatial structure of macromolecules. In addition to sequencing, there are several other data which are produced with the so-called 'high-throughput' method and can only be managed using bioinformatics. For example, gene expression, electrophoretic and mass spectrometry data and the genetic, metabolic, signal transmission and protein-protein interaction pathways and networks. Based on these data and the use of bioinformatics models, we will be able to explore the cause of several animal nutrition problems which are still unclear today (e.g. nutrient interactions and their targeted utilisation).

The relevant technical literature data so far led us to conclude that the findings of bioinformatics will not only be used in mathematical modelling, but also in the interpretation of processes connected to digestion physiology at an increasing frequency.

Molecular nutrition

Despite the fact that this area of science is already two decades old, it is obvious that this is only the beginning of the journey. In the coming decades, this field is going to develop, hitherto, unknown opportunities in both animal and human nutrition science. Among others, molecular nutrition focuses on how nutrients (glucose, fatty acids, amino acids, vitamins) affect signal transmission between cells and gene expression. Micronutrients affect the information flow within cells by means of biochemical processes, thereby, eliciting gene activation or suppression. The knowledge of all these processes is the basis for examining the transport mechanism of nutrients, as well as the correlation between micronutrients, cellular homeostasis, cell proliferation and apoptosis (Zhang, 2003). Since the functioning of all cells of the organism is basically under the control of genes, revealing these regulatory mechanisms greatly contribute to understanding vital processes (Babinszky and Halas, 2009).

Quantum biology and nutrition (animal nutrition) science

Using quantum biology, physicists and biologists attempt to interpret and explain complex physiological and biochemical processes at the subatomic level together. The question whether quantum mechanics can play a role in the interpretation of biological processes was raised only a few decades ago. According to numerous research findings, the answer is yes (Arndt *et al.*, 2009; Lambert *et al.*, 2013), as it seems that nearly all chemical processes are based on quantum mechanics. In their outstanding technical literature review, Arndt *et al.* (2009) came to the conclusion that the studying of quantum physics and biology in a coherent system (in quantum biology) in order to understand many biological processes is a very timely and important task. Scientific visions, theories and interdisciplinary research with a wide scientific background will be needed to develop in this rather new area of science. The question arises whether quantum biology can be used in the future in nutrition and animal nutrition science to provide subatomic interpretation of intermediary metabolism and the physiological processes of digestion, as well as the processes which are still unknown or only partially known today. The answer is rather hopeful than firm, since this scientific field is still in its infancy. However, as various physiological processes can be interpreted and understood at the level of electrons, protons and neutrons in 15-20 years, let us just consider molecular nutrition as similarly, 25 years ago, not many would have thought that biochemical processes could be examined and interpreted at the intracellular and molecular level (Sanders and Emery, 2003).

1.4 Conclusions

For the 21st century challenges in pig and poultry nutrition, it is necessary to involve into the innovation activity besides classical animal nutrition knowledge, newer areas of natural and technical sciences (e.g. nutrition physiology, nutrition immunology. molecular biology, molecular nutrition, molecular genetics, nutrigenomics, information technology, etc.). The importance of these disciplines will continue to grow in the near future, in the following 5-10 years. The use of precision animal nutrition in practice will greatly contribute to the implementation of the above written aims, as well as the improvement of the successfulness of innovation activity. It is highly probable that new areas of science will revolutionise animal nutrition sciences such as bioinformatics, molecular biology, molecular nutrition and nutrition immunology, as well as quantum biology. These areas of science will greatly contribute to the development of animal nutrition science and, as a result, to a more efficient animal nutrition, as well as to a better quality and safe foods based on products derived from animals.

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