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INNOVATION IN SWINE NUTRITION RESEARCH: PAST, PRESENT AND FUTURE

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ABSTRACT

The development of a scientific area is greatly influenced by the level and efficiency of the related innovation activity. The purpose of this paper is to present some important innovative activities in swine nutrition from the past and present that contributed to the production of better quality pork. A further aim is to summarize briefly the innovation activities which can be expected in pig nutrition in the future. In the present paper, the following main topics are discussed: challenges of 21st century animal nutrition; evolution of the innovation in pig nutrition; innovation activities in energy- and protein (amino acid) metabolism studies, in the fight against heat stress and in the determination of the molecular structure. Further discussed topics are animal nutrition and immunology, application of molecular nutrition findings in pig feeding, animal nutrition and gut microbiology, and pig nutrition based on genetic profile. The paper also predicts the possible innovation activities in the future. It was concluded that future innovation activity in pig nutrition research is carrying out in three directions: a) Research related to feed (new feed ingredients and feedstuffs); b) Development of new animal experimental and laboratory methods together with associated sciences; c) Development of new (biological, technical) concepts and principles.

1. Introduction

The Oslo Manual (2018) defines the term “innovation” as follows: “An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).” In case of firm and research site the strength and quality of the innovation activity is influenced by several factors. These factors can be divided in two main groups:

Macro environmental factors (e.g. political and legislative environment, financing system, education system, innovation policy, national innovation system)

Micro environmental factors:

a) Outside the company (research site): proximity to a (other) research site,
b) existence of skilled workforce, the infrastructure conditions, and regional innovation systems, local financial resources, competitive environment.
c) Within the company (research site): existence of the innovation management, organizational knowledge, furthermore, existence of the willingness to take risks, and organizational culture.

From the above, it can be seen that innovation is a multifactorial activity, i.e. many conditions must coexist at the same time in order for a company and/or a research site to be able to carry out real innovation.

Since the production of animal origin foodstuffs in the proper amount and quality is a key issue worldwide, innovation, i.e. the introduction of new measuring and analytical methods and procedures as well as principles and concepts, plays an increasingly important role in animal nutrition research as well.

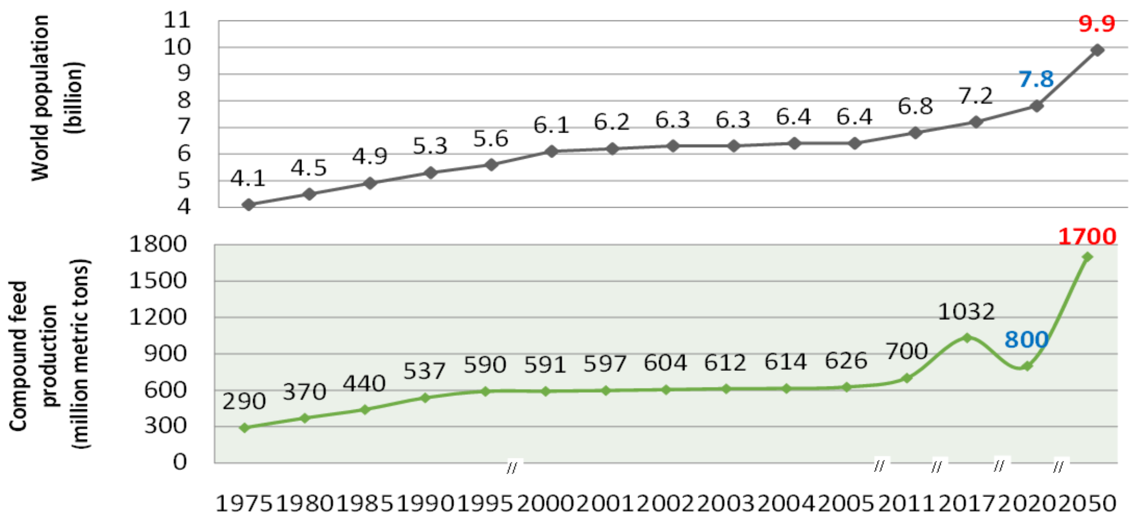
The purpose of this paper is to present some innovative activities in the field of swine nutrition from the past and present that have contributed to the production of better quality pork. A further aim is to summarize briefly the innovation activities which can be expected in pig nutrition in the future.

2. Challenges of 21st century animal nutrition

It is well known that the quality of food of animal origin is greatly determined by the nutrition of animals. However, it should also be noted that the quality of the animal product (e.g. meat) can be not only improved but also worsened by feeding. Therefore, providing the animals with the appropriate nutrient supply and the quality of the compound feeds is a key issue in terms of the quality of the product.

Feeds in pig production systems can make up 60-80% of the costs of production and unutilised dietary components are a major contributor to environmental pollution. This means that feeding has a great impact not only on the economy of pig production, but also on our environment. In Figure 1 the changing of human population and world’s industrial feed output is summarized.

Figure 1
Changing of human population and world’s industrial feed output
(Based on Gilbert, 2004; Gill, 2006; United Nations, 2011, AllAboutFeed, 2017 and FIF, 2022)



The figure shows that the amount of compound feed produced by the feed industry increases almost parallel to the growth of the human population.

In 2021, nearly 800 million tons of compound feed for farm animals was produced world-wide. This data warns that this huge amount of feed can have a major impact on the quality of animal origin foodstuffs globally.

It is also clear from Figure 1 that, by 2050, the human population of the Earth will reach 9.9 billion and, at that time, about 1700 million tons of compound feed will be produced.

Therefore, animal nutrition faces the following important tasks in the 21st century (Babinszky and Halas, 2009; Babinszky et al., 2019a):

More active participation in animal production to supply safe food in sufficient quantities, in accordance with the requirements of society.

Further improvement of the efficiency of animal nutrition (biological efficiency, technological efficiency and economic efficiency),

Wider use of various by-products, as well as further reduction of human edible ingredients in animal nutrition,

Rethinking of 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. environmentally-friendly nutrition systems which lead to a reduction in nitrogen and phosphorus output.

In order for the animal 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 animal nutrition and associate sciences (including medical science) on the basis of professional logic, as well as cooperation in R&DI programs and education. In addition to 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.

In fact, these and similar collaborations create the foundations for high-quality innovation activity in animal nutrition.

3. The evolution of the innovation in pig nutrition (from simple measurement methods to precision animal nutrition concept)

The direction of innovation in the animal nutrition research in the past, present and future can be seen in Figure 2.

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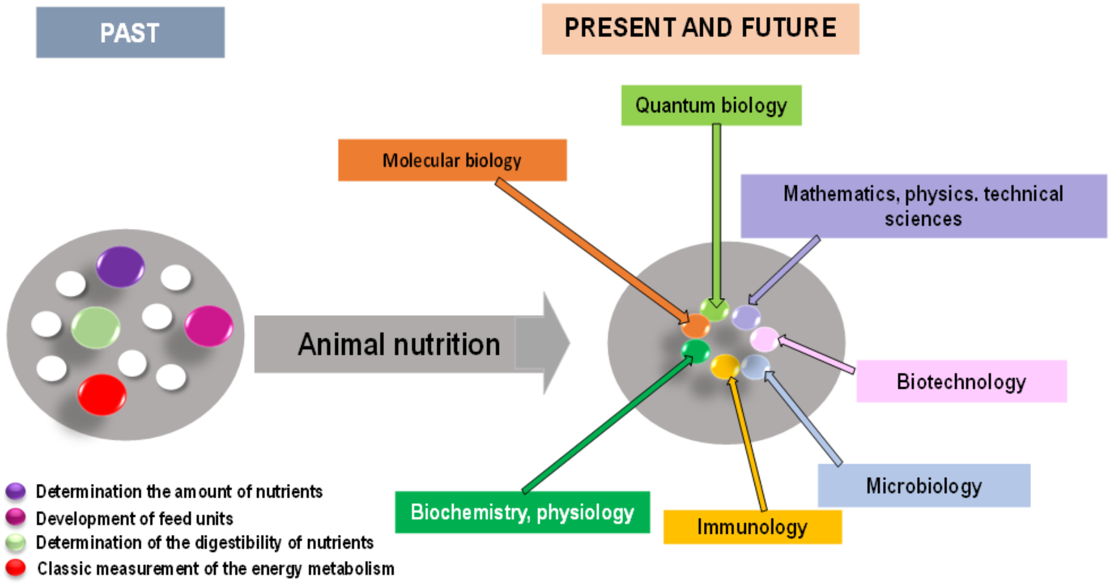

Figure 2
The direction of innovative activity in animal nutrition

The beginning of the 18th century can be dated as the time when animal feeding based on scientifIc knowledge began. The characteristic of this time was that the development of various measurement and laboratory tests was carried out still within the scope of animal nutrition (see left side of the Figure 2).

However, the direction of innovation activity later changed. Animal nutrition research has adopted new results and test methods from "outside" of the associated sciences (see right side of the Figure 2). In the mid-1970s, joint methodological, chemical analytical and product developments began with various fields of natural science, computer science, and veterinary science or medicine. These joint works meant much more than a simple cooperation. At that point, real innovation activity was taking place already. During this time, the first-generation growth promoters for practical pig feeding were developed and the application of the computer for diet formulation, based on linear programming, began. Diets formulated by linear programming are based on an assumption of linearity between animal production and the nutrient ingredients included in the diet. The diet formulation model seeks the optimum combination of available feed ingredients that will satisfy the nutritional requirements of the animal at the least cost possible.

Later, joint developments and innovation activities with related sciences reached a very high level. This high level of cooperation resulted in the development of the precision animal nutrition concept at the end of the 1990s.

Precision animal nutrition, as can be seen in Figure 3, applies the research findings of traditional ("classical") animal nutrition and of the new areas of natural and technical science, using large databanks with the help of computer technology.

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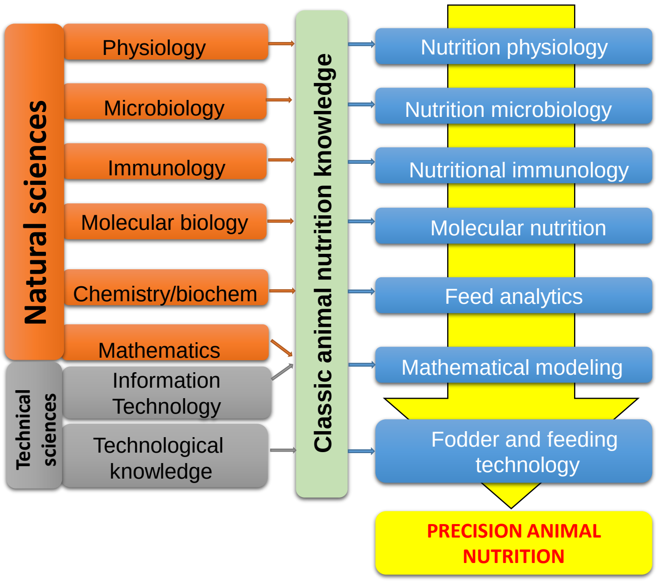
Figure 3
Scientific background of precision animal nutrition (Babinszky et al., 2019a)



Precision animal nutrition consists of meeting the nutrient requirements of animals as accurately as possible in the interest of a safe, high-quality and efficient production, besides ensuring the lowest possible load on the environment (Nääs, 2001). For optimum efficiency of nutrient use, it is important to feed pigs the right quantity of nutrients in an ideal ratio.

Precision animal nutrition is also called "information intensive nutrition". In other words, it uses the latest scientific findings in feed formulation in order to meet with the maximum accuracy the unique nutrient requirements of a given herd kept under given conditions. This is facilitated by electronic feeding; an important but by far not the only tool of precision animal nutrition.

American and Australian examples prove that, in the near future, precision animal nutrition will be of key importance equally in producing pork economically and in high quality, and in innovation activities.

Precision animal nutrition is an integral part of precision livestock farming (PLF), and therefore also of the precision food production chain. A schematic representation of the precision food production chain can be seen in Figure 4.

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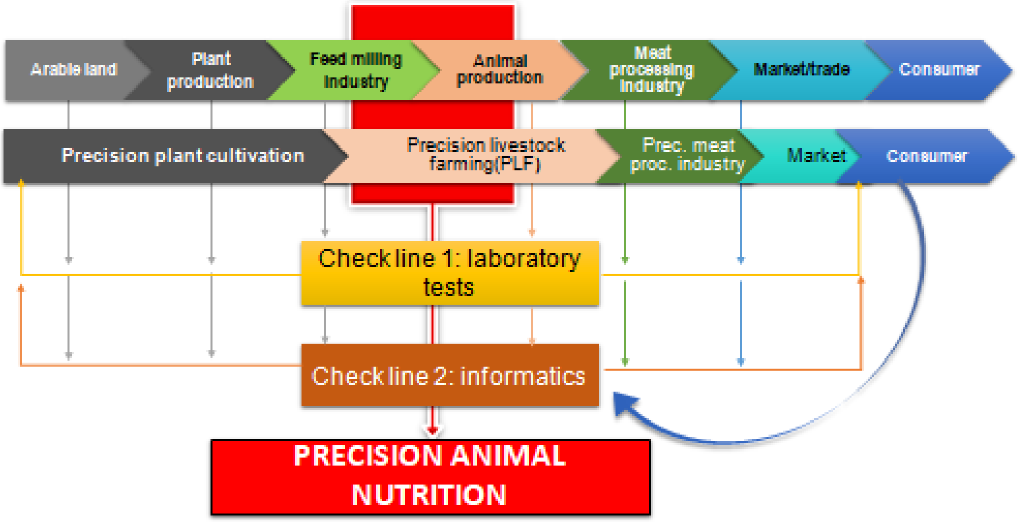
Figure 4
The relationship between the precision food production chain and precision animal nutrition (Babinszky et al., 2019a)



As can be seen in Figure 4, the food production chain includes precision plant (crop) production, precision livestock farming (PLF) and precision meat industry. This means that the entire traceable production chain starts on arable land and ends at the consumer. It should also be emphasized that every step of the production chain must be controlled by laboratory tests and an informatics network.

It is already clear today that 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.

4. Some examples of innovations in pig nutritions (past and present)

4.1. Energy metabolism studies

Innovation has always played an important role in the development of energy metabolism studies. It is no different today, either.

One of the most important goals of energy metabolism studies is to determine the energy balance, as well as the net energy requirements of farm animals and the net energy content of feed components and compound diet.

The animal body uses the dietary gross energy content for maintenance and production, after loss of energy via feces, urine, gas and heat production. These studies are performed in respiration chambers (Es and Boekholt, 1987; Verstegen et al., 1987).

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The first respiration apparatus was built by M. H. Kühn in Möckern, (Germany), in 1879. Although this and subsequent respiration chambers were very rudimentary from a technical point of view, they still provided very important data on the energy metabolism of livestock. Naturally, today's devices already have very advanced technology. Their operation is computer-controlled and fully automated. In these so-called indirect calorimeters, the heat production of the animals can be indirectly measured based on the animals' oxygen consumption and carbon dioxide production during the same time (Verstegen et al., 1987, McDonald et al., 2011).The measuring of heat production is often supplemented with nitrogen and energy and carbon balance studies (Pond et al., 2005). Based on these measurements, in addition to heat production, the amount of daily protein and fat deposition and degradation can be calculated. Having this data, it is possible to decide which of the different compound feeds can be used with the highest efficiency.

The feeding efficiency of a given compound diet can also be determined using another method. This method is called the comparative slaughter technique or total body analysis. In this case, at the start and at the end of a trial, representative animals of each treatment are slaughtered and analyzed for protein and fat, and sometimes for energy. From protein and fat data, energy content of the body can also be derived by calculation. Accurate results are only obtained when the time interval between start and finish is long and thus the weight change is large enough (Verstegen et al., 1987). The advantage of this method is that it is not as expensive as the respiration study, and the disadvantage is that it provides less information on energy metabolism and, due to slaughter, one animal can only be tested once. This means that the protein and fat deposition process cannot be continuously studied in the same animal during its life. Thus, the data of the comparative slaughter technique provides data for livestock (for treatment group) and not for individuals.

The use of a non-invasive technique (computer tomography: CT) in pig feeding research was a major breakthrough (Szabó et al., 1999, Szabó et al., 2001). A software has been developed that can be used to determine the protein and fat content of a live animal's body from cross-sectional images taken by CT (Figure 5).

Thanks to this innovation, CT is now used in many nutrition trials and feeding tests. The application of this technique is greatly facilitated by the increasing number of mobile CT devices.

In the late 1990s and early 2000s, the development of the physiologically available energy concept was also another important innovation activity. In short, physiologically available energy corresponds to the production of the universal energy source at cellular level (adenosine triphosphate: ATP). ATP captures chemical energy obtained from the breakdown of feed molecules and releases it to fuel other cellular processes. Thus, this concept already determines the energy content of each feed at the cellular level. This new feed energy evaluation system will be able to more accurately approximate the true energy requirements of farm animals, as this system is based on the ATP requirement of animal cells and the ATP production capacity of nutrients.

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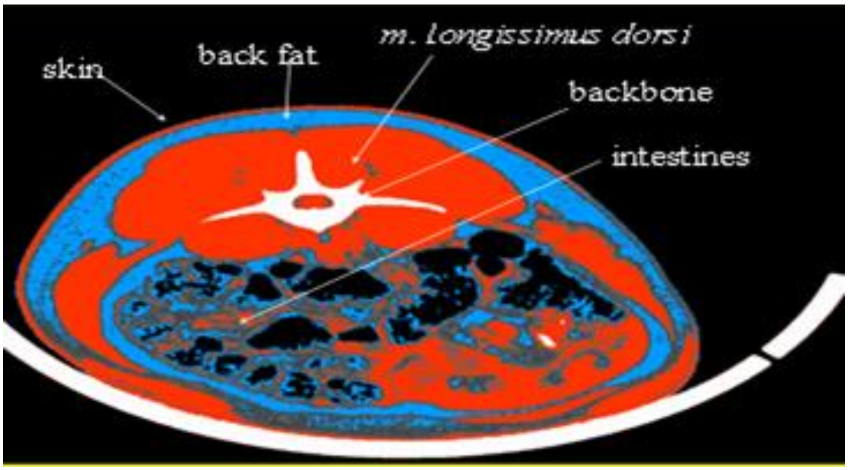
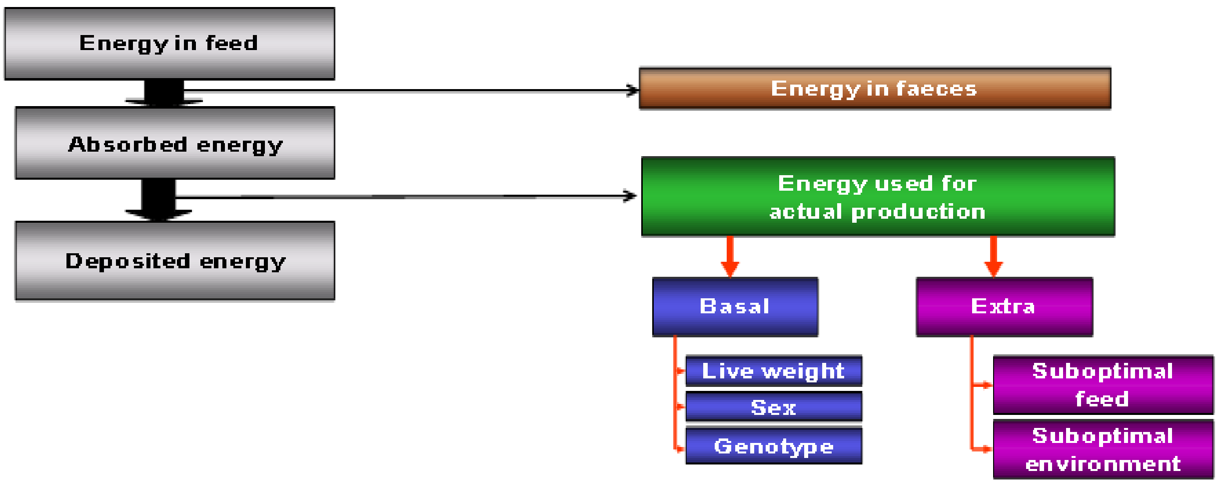
Figure 5
Cross-sectional computer tomography image of a pig (Szabó, 2001)



The principle of this new energy system is shown in Figure 6 (Boisen, and Verstegen 2000).

The figure shows that, unlike the scheme of the classic energy transformation process (from gross energy to net energy) this new system further specifies the energy used for actual production. The energy for actual production is separated into two components. The basal component is determined by live weight, sex and genotype. To the other component (extra energy requirement) belongs the suboptimal feed composition (e.g. low protein quality or too high protein level which increases heat production), or suboptimal environment (e.g., too high or too low air temperature, high stocking density). This figure also indicates whether the feed or the environment is not optimal. As the animal must compensate for these negative factors, consequently, the animal's energy requirements increase. However, it should be noted that this new feed evaluation system is not yet fully developed (Boisen and Verstegen, 2000). Nonetheless, it is very likely that, in the near future, the energy requirements of animals will be specified in physiologically available energy.

Figure 6
Physiologically available energy (Boisen, and Verstegen 2000)



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4.2. Protein (amino acid) metabolism studies

In the past fifty years, the evaluation of dietary protein has also changed a lot, thanks to the innovation activity carried out in this area. Already in the early 1900s, feed specialists attempted to compare different protein sources. At that time, it was already agreed that the digestible protein content of the feed is a better basis for comparison than the total or so called crude protein (N content x 6.25) content.

First of all, the term digestibility had to be defined. It was generally agreed that digestibility of a nutrient (e.g. protein) is the proportion of the total ingested that has been absorbed. This means that these so-called traditional digestibility trials were based on fecal collection.

However, at that time, there was no agreement yet on many questions of the measurement method (e.g. the length of adaptation and collection period in the trial, the sex and age of the test animals, etc.). Finally, the Dutch researcher Dammers (1964) clarified all these questions in a scientific report. This report was published first in The Netherlands, and later worldwide, and this became the internationally accepted protocol for digestibility study with growing and fattening pigs. For many decades, digestibility studies with pigs were carried out based on Dammers' protocol.

However, since the 1980s, there has been increased criticism of the method based on fecal collection. The findings of digestion-physiology research works proved that the intestinal flora in the colon simultaneously synthesizes and metabolizes protein. This is the reason why the fecal digestibility of dietary protein will in some cases underestimate, and in others overestimates the actual value. As a result of this and other criticisms, in the early 1980s, the methodology for measuring the so-called ileal protein (amino) digestibility began to be developed. The name of the method implies that amino acid absorption is measured in the last section of the small intestine, in ileum, where the main site of amino acid absorption is located. This means that the measurement method requires surgical intervention, as a cannula must be implanted in the last section of the ileum (Photo 1).

Photo 1
Cannulated growing pig just after surgery

Digesta can be collected through the cannula. Over the years, several types of cannula and cannulation techniques were developed. The collection of digesta (intestinal contents) depends on the type of cannula used (Babinszky 2008). Currently, worldwide, both the amino acid requirement of pigs and the amino acid content of feed ingredients are expressed in term of ileal digestible amino acid.

However, as in the case of determination of the energy requirements, more precise data would be needed for amino acid requirements as well. In addition, several criticisms have been made against the ileal digestible amino acid concept. Some of these are: for use of this method, surgical preparation of animals is needed; the method is relatively expensive; staff with special knowledge is required; and the collection of digesta is very labor-intensive. Finally, in case of the use of the ileal amino acid concept, it is still not clear how much of the amino acid absorbed from the small intestine is actually available for protein synthesis. Therefore, increasingly, attention is being paid to the concept of the so-called available amino acid. Amino acid availability is the portion of the total amount of amino acids in the feed that is potentially available for protein synthesis in the animal body. Currently, the following three methods can be used to determine the available amino acid requirements of pigs: method based on the free amino acid content of the blood plasma, method based on free amino acid content of muscle, and method of so called growth test. Currently, the accuracy and repeatability of these methods are not yet adequate. This is the reason why some people try to estimate the available amino acid content of the feed ingredients by calculation based on the digestible amino acid content of the diet. However, this is also neither a real and accurate solution to this problem. Therefore, a high-accuracy in vivo method is still required to be developed. This need provides a nice challenge for innovation.

4.3. Determination of the molecular structure (synchrotron technique)

The laboratory methods currently used in animal nutrition, including proximate analysis (Weende method), are suitable for the quantitative determination of nutrients only and not for the determination of their molecule structure. Unlike these traditional "wet" analytical methods which during processing for analysis often result in destruction or alteration of the intrinsic protein structures, advanced synchrotron radiation-based Fourier transform infrared micro spectroscopy has been developed as a rapid and nondestructive and bioanalytical technique (Yu et al., 2019). The synchrotron is an extremely powerful source of X-rays. The X-rays are produced by high energy electrons as they circulate around the synchrotron. The structure of synchrotron equipment operating in Japan is shown in Photo 2.

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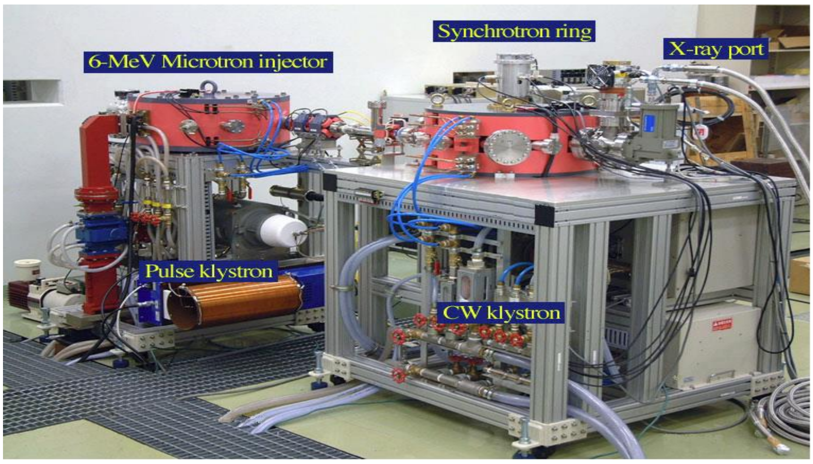
Photo 2
Synchrotron (Photon Production Laboratory Ltd, Japan)



This cutting-edge synchrotron-based bioanalytical technology, taking advantages of synchrotron light brightness (million times brighter than sun), is capable of exploring the molecular chemistry or structure of a biological tissue without destruction inherent structures at ultra-special resolutions (Yu et al., 2019).

In the near future, it will become clear that this innovative product of the 21st century what extent will be used in animal and human nutrition research.

4.4. Innovation in the fight against heat stress

Climate change affects all economic sectors, but perhaps one of the most endangered sectors is agriculture, including animal husbandry. One of the most obvious manifestations of climate change is global warming.

It is well known that high ambient temperatures negatively affect the production of all domestic animals, but perhaps the pig and poultry industries are affected the most (Babinszky et al., 2019b). In the case of high ambient temperatures, very often the animals cannot release the produced heat to their environment, resulting in heat shock.

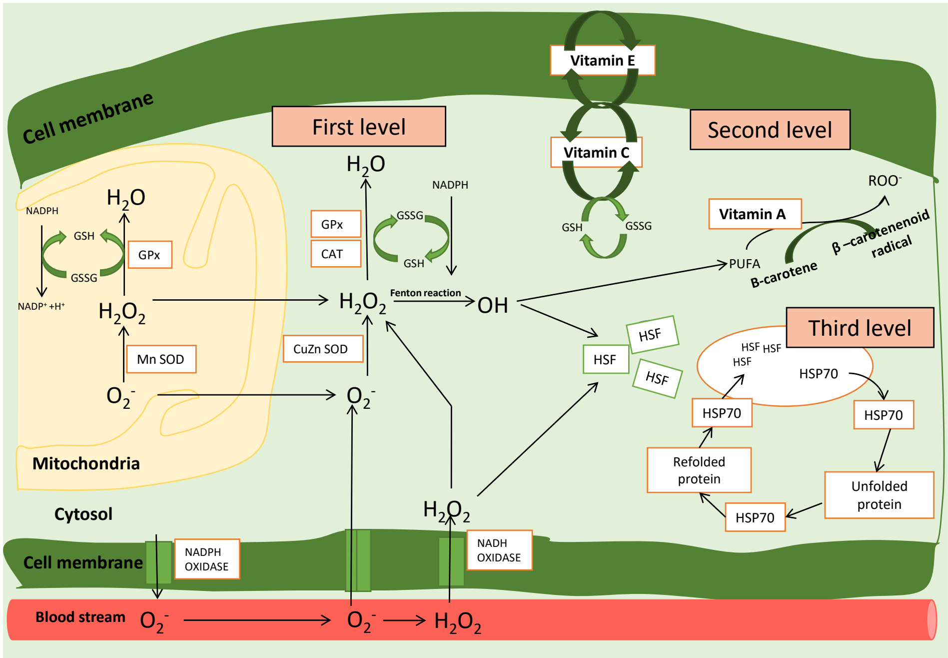
There are several ways to protect against heat shock in animal agriculture.A solution for prevention of heat stress in animals includes biological (e.g. genetics, thermal conditioning, and nutrition) or keeping technology devices (e.g. air conditioning, intensive ventilation, and humidification).

However, housing methods are expensive and the service costs are high and, in many cases, not always adequate. Therefore, reducing the biochemical and physiological negative effects of heat stress with different nutritional tools is one of the primary interests for the economical production of food produced from animals (Daghir, 2009; Horváth 2021).

Increased environmental temperature and heat shock caused increased lipid peroxidation (as well as induced formation of malondialdehyde (MDA), which is an indicator for lipid peroxidation). Therefore, the antioxidant defence system is altered. According to the latest research, the elimination of the free radicals activates three level antioxidant systems. The application of this scientific finding started a very important innovation activity in pig nutrition. In fact, learning about this three-level antioxidant system gave a huge impetus to those research (and innovation) aimed at reducing the harmful effects of heat stress via nutrition tools.

A schematic representation of the three-level antioxidant system is shown in Figure 7.

Figure7
The three level antioxidant system (Babinszky et al., 2022)



CAT = catalase; Cu SOD = copper superoxide dismutase; GPx = glutathione peroxidase; GR =glutathione reductase; GSH = glutathione; GSSG = glutathione disulphide; H_2O = water; H_2O_2 = hydrogen peroxide; HSF = heat shock factors; HSP70 = heat shock protein 70; Mn SOD = manganese superoxide dismutase; NADH = nicotinamide-adenine-dinucleotide; $NADP^+$ = oxidized nicotinamide-adenine-dinucleotide-phosphate, NADPH = nicotinamide-adenine-dinucleotide-phosphate, O_2^- = superoxide anion radical; OH = hydroxyl radical; PUFA = polyunsaturated fatty acids; ROO^- = peroxyl radical.

Elimination of free radicals is done by the first level of the antioxidant system which functions at the same time as the detoxification and regeneration pathways of the second level. The third level starts working after damage has been done, to repair and eliminate damaged cells.

This first level (direct enzymatic pathway) includes the neutralization of the oxygen and nitrogen centred free radicals by enzymes. The second level includes the detoxification and regeneration reactions of the small molecule antioxidants. The third level is activated when damaged systems (proteins, DNA) have to be repaired and/or removed from the cells by chaperones and DNA-repair enzymes (Baker et al., 1988; Noctor and Foyer, 1998, Babinszky et al., 2019b).

Without going into detail, it can be stated that with nutrition tools, the second antioxidant defence level can be influenced in the easiest way. This means that in cases of high ambient temperature, vitamin C, E and A, and selenium and zinc content must be increased in diets (Renaudeau et al., 2012; Liu et al., 2016).

Summarizing the relevant scientific findings on pigs, it can be stated that in the case of high ambient temperatures, the following nutrition methods can be used to avoid the deterioration of animal production (Noblet et al., 2001; Schrama et al., 2003; Babinszky et al., 2011, 2019b, 2022):

- using more antioxidant vitamins (vitamin A, C, E, etc.) and micro minerals (e.g., zinc, selenium) in the diets to support the antioxidant system of the animals,
- supplementing diets with monovalent ions (Na- and K-bicarbonate, K-hydrocarbonate, K-sulfate) to alleviate the reduction of water retention in the animal's body,
- feed a more concentrated diet to (partly) counteract low feed intake,
- feeding higher fat content diets to reduce heat production of animals,
- feeding low protein diets with crystalline amino acids according to the ideal protein concept,
- adding dietary betaine.
  Betaine (trimethylglycine) is an intermediate metabolite in the catabolism of choline, which can modify osmolarity, acts as a methyl donor, and has potential lipotropic effects (Metzler-Zebeli et al., 2008). Schrama et al. (2003) showed that under thermoneutral conditions, dietary betaine supplementation (1.23 g/kg) reduced the total heat production of pigs.

5. Possible innovation activity in the future

For the sake of better overview, the possible innovation activities in animal nutrition are divided into two groups: the next 5-10 years and subsequent decades.

5.1. Innovation activity in the near future (the next 5-10 years)

It is typical for these research areas that innovation activity will increase very rapidly in the near future. These areas are as follows (Babinszky and Halas, 2009; Babinszky et al., 2019a):

Studies pertaining to the properties of animal feeds
This research area includes e.g. new energy and protein feeds, interactions between the various nutrients, alternatives to growth promoting antibiotics, reducing mycotoxin contamination, issues of GMO feeds.

It is very likely that 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. By employing these technological processes, the biological efficiency of animal nutrition and the production of high quality feed ingredients could be improved (Huisman and Tolman, 2010).

Since quite a few feed ingredients (e.g. corn, wheat, barley, oats and soy) also play an important role in human nutrition, it is in our fundamental interest to substitute them in compound feed by alternative components.

Novel protein sources (e.g. insects, algae, microalgae, seaweed, and duckweed) are expected to enter the European feed and food market as partial replacement for conventional protein sources or due to their potential beneficial effects above and beyond the nutrient content they contain. However, it should be emphasized that food safety aspects of these new protein sources are not well-known. 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 (Babinszky et al., 2019a).

Application of molecular nutrition findings in pig feeding

Molecular nutrition is a relatively new area of animal and human nutrition, developed on the basis of genomics, linking it to nutrition science. In the past 20 years, the introduction of powerful new molecular techniques has made it possible to advance knowledge in animal and human biology. In most disciplines, a reductionist approach is used, but in nutrition, an integrationist approach is needed to deal with the complexity of the subject.

Molecular nutrition investigates the roles of nutrients at the molecular level, such as signal transduction, gene expression and covalent modifications of proteins. The micronutrients at the cellular level modulate the milieu in which biochemical and genetic metabolisms operate, and thus they can influence gene expression. Nutrient transport mechanisms and intracellular trafficking, apoptosis, intracellular signaling mechanisms and the role of nutrients, nutrient interactions with gene expression, and epigenetic regulation of gene expression by nutrient dependent reactions are all included in molecular nutrition (Zhang, 2003).

Many professional forecasts predict that the results of molecular nutrition will revolutionize not only human, but also animal (such as pig) nutrition. (Babinszky and Halas, 2009; Babinszky et al., 2019a).

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.

Various research results also show that increased intake of some amino acids (methionine, threonine, arginine, glutamine or glutamic acid) compared to the nutrient requirement of maintenance and growth may result in better immunity (Defa et al., 1999; Kidd et al., 2001, O'Quinn et al., 2002; Pierzynowsky et al., 2001; Lawrence and Hahn, 2001). Therefore, among essential amino acids the recommended methionine, threonine, arginine supply will certainly be revised in the near future.

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However, it must be noted that giving supra-physiological levels of certain nutrients (e.g. fatty acids) may result in immune suppression even before there is deterioration in performance.

It should also be emphasized that 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 animals when diet formulation is made (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. Some new generation growth promoters, such as mannan-oligosaccharides, β-glucan, some herb extracts, and egg yolk antibodies operate by manipulating the immunity of the animal.

It can be summarized that nutritional immunology will play a much more decisive role in the innovation of animal nutrition in the near future.

Animal nutrition and gut microbiology and gut heath

This area involves the microbiological processes in the gastro intestinal tract (GIT) and the impact of nutrition on these processes as well as on the productivity of animals.

Based on the latest scientific findings, it is increasingly clear that alterations in pig and poultry GIT microbiota composition have a pivotal role in the development of metabolic disorder (Stanley et al., 2014; Turnbaugh et al., 2006; Tolnai et al., 2021). The diversity of the microbiota is one of the key determinants in resistance to invading pathogens. Higher microbial community diversity is related to a healthier host status, whereas a significant loss in complexity is associated with various diseases and susceptibility to pathogen colonization. Shifts of the GIT microbiota toward beneficial bacteria could improve the health conditions of the host.

These scientific results also draw attention to the fact that, in order to achieve effective nutrient supply, much more attention should be paid to the change in the composition of the microbiome.

The main question is that the altering in the composition of GIT microbiome what kind of changes does induce in the animal's metabolic processes and health status. Further question is how we can favorably influence the composition of the microbiome by nutrition tools, e.g. with feed additives.

The research findings so far are rather promising, but many questions still need to be clarified with the help of innovation activity.

Nutrigenomics and swine nutrition based on genetic profile

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 function. 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

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(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.

Cano (2020) reports on a gene editing technology (CRISPR-Cas9) which could be a promising method in animal nutrition in the future. Due to its efficacy, precision, simplicity, and low cost of this technique could be the beginning of a new era in genetics.

According to Cano (2020), this technique could be used in the following areas:

- Development of new fodder plants in which it is possible to over express or silence part of the genome.
- Incorporating exogenous genes in plants, so that they can synthesize proteins, such as antibodies, enzymes, prebiotics, and functional components.
- This technique is also applicable to farm animals. It can be used to develop an accelerated, totally directed gene selection. Furthermore, this gene technology can be used e.g. to reduce the occurrence of different diseases, and to increase resistance to disease, and to increase productivity.

A very good example of the cooperation between animal nutrition and molecular genetics is the so-called concept of animal nutrition based on genetic profile. In short, this research (innovation) program is based on three different series of experiment:

- Genotyping of the hybrid swine (gene polymorphism studies). In this study, the frequency of genes responsible for different production parameters (weight gain, feed intake, protein and fat deposition, etc.) should be determined.
- Gene expression tests for mRNA (using RT-PCR technology: polymerase chain reaction) and specific proteins. In the gene expression profiling measures, which genes are being expressed in a cell at any moment? This method can measure thousands of genes at a time; some experiments can measure the entire genome at once.
- Based on the results of genotyping and gene expression, nutrition trials with diets with different ileal digestible lysine/digestible energy ratio mast are carried out. At the end of the fattening period (app. 110 kg body weight) performance (daily gain, daily feed intake feed conversion ratio), moreover meat quality and daily protein, fat deposition should be determined. On the basis of the production data and the data above, it is possible to decide which compound feed can be used most economically on the given pig operation.

However, it should be noted that swine nutrition based on genetic profile is still in its infancy. The development of this technique depends primarily on the development of molecular biology and molecular genetics.

But there is no doubt that in the near future this method will be used in practical pig feeding.

The spread of this method naturally strongly depends on the simplicity of the test and its price as well.

Further expected innovation activities in pig nutrition (Babinszky et al., 2019a)

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:

- Elaboration of new and more accurate in vitro and quick analysis methods. The urgency for the development of in vitro protein, amino acids, and carbohydrate digestion analyses methods, inter alia, is increasing, since it is increasingly difficult to acquire obtain the official permits for animal experiments. 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) 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. It can be expected that the new biotechnological products will appear much faster than before in everyday pig feeding. Such products are already used in feeding industry, but the possibilities are nowhere near being exploited.

5.2. Expected innovation activity in the distant future in pig nutrition (the next 10-20 years)

It is very difficult to predict the innovation activity in animal nutrition research for such a long period of time, because such a prediction strongly depends on the development speed of this research area and related sciences, as well as on their future technical backgrounds. However, certain trends can already be fathomed. They are briefly summarized below (Babinszky et al., 2019a).

According to Cano (2020) the future of animal nutrition will be deeply determined by the following scientific disciplines: block-chain technology, big data analysis, artificial intelligence.

Block chain technology: This technology allows digital records, such as databases, documents, and computer files, to be publicly accessible and in a safe, inviolable way. Blockchain users themselves guarantee the integrity of those records through the formation of a chain of blocks, distribution networks, and a complex encryption and verification technology. It must also be highlighted that this technology enables safe, reliable management of the large amount of data generated in the production chain in which animal nutrition participates.

Big data analysis: Currently, billions of mobile devices are sending a large amount of data to the network. This info is stored in large capacity servers and managed with powerful relational database systems. In addition to this the machines are generating their own data in the so-called internet of things (IOT). To process this huge data set, big data provides help.

Artificial intelligence: The artificial intelligence (Deep Learning or Machine Learning) is an automated learning model based on artificial neural networks. It works like the "human brain". According to Cano (2020), artificial intelligence can be used for e.g. estimating the nutritional requirements of the animals, or establishing feeding plans based not only on productive objectives, but also addressing the product quality, health, sustainability and many other aspects too.

Bioinformatics: This area is partially related to what was described in the previous subsection.

Bioinformatics is a branch of science which uses information technology (IT) 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. computerized 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 deposition in the body) (Halas, 2004).

However, within bioinformatics, there are entirely specialized 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 (HTP) 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 utilization).

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.

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. 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).

It is already clear that the quantum biology can be of great help in animal nutrition in areas such as understanding of cell communication or the clarification of the mechanism of action of hormones and their effect on the nutrient supply.

6. Conclusions

The following main conclusions can be drawn from the latest global trends concerning innovation activity in swine nutrition:

- The demand of the Earth's population for healthy, safe and traceable food of animal origin will continue to increase in the future.
- Therefore, in order to satisfy this demand, the innovation activity in the field of animal nutrition science must be further strengthened.
- While in the past, innovation in animal nutrition research was based on developments within this field of science, currently - and even more so in the future - these activities will be carried out in closer cooperation with associate sciences than before.
- The cooperation between different sciences provides the basis of the concept of precision animal nutrition (PAN).
- It is very likely that future innovation activity in animal nutrition research is carrying out in three directions:
    1. Research related to feed (new feed ingredients and feedstuffs);
    2. Development of new animal experimental and laboratory methods together with associated sciences;
    3. Development of new (biological, technical) concepts and principles.
- These three main directions of the innovation activity will be necessary for the economical and environmentally friendly production of health, safety and traceable animal origin food foodstuffs.

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