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Innovative swine nutrition: some present and potential applications of latest scientific findings for safe pork production

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ABSTRACT

One of the biggest challenges facing animal agriculture in the 21st century is to produce safe and traceable foodstuffs of animal origin in sufficient volumes and quality besides the lowest possible load on the environment. A point to consider is how animal feeding and nutrition can contribute to the solution of this challenge. Another question is, that the results of which new scientific fields should be used in the area of innovation to achieve the desired product quality. The article answers these questions based on the latest data in the scientific literature and on the authors’ own research results. Having reviewed and processed the data, the authors drew the following conclusions:

1. The impact of climate changes on crop production and consequently on animal nutrition needs to be studied in comprehensive, systematic research programs, and based on their results animal feeding systems should be modified if necessary.
2. The role of molecular nutrition and the immunological role of nutrition for enhancing the efficiency of production will gain in importance.
3. The cooperation between nutritionists and geneticists needs to be strengthened in order to satisfy the nutrient requirements more accurately, and thus to improve the profitability of production.
4. New mathematical growth models, also incorporating the quality of animal products, need to be developed for better production estimates.
5. The integrated “from farm to fork” programs will be essential in the production of safe and high quality animal food products. Animal nutrition will play a key role in these product development and monitoring programs.
6. The production of environmentally friendly animal products will become a social imperative. Animal nutrition still has huge unexploited reserves in this field, for instance in the development of novel animal feeding systems and technologies.
7. The practical implementation of precision nutrition can be of great help in achieving these goals and in improving the efficiency innovation activities.

Key words: Swine nutrition, Innovation, Feed quality, Food quality, Food safety.

RIASSUNTO

INNOVAZIONE NELLA NUTRIZIONE DEI SUINI: ATTUALI E POTENZIALI APPLICAZIONI DELLE PIÙ RECENTI ACQUISIZIONI SCIENTIFICHE PER LA PRODUZIONE DI ALIMENTI SUINI SICURI

La produzione di alimenti sani, sicuri e tracciabili in quantità sufficiente e con il minimo impatto ambientale rappresenta la principale sfida per la zootecnia del 21mo secolo. Un primo interrogativo di grande
interesse a questo proposito riguarda il possibile contributo della nutrizione e alimentazione degli animali. Un altro importante quesito è quale tra i nuovi settori della ricerca scientifica dovrebbe essere utilizzato in modo innovativo per permettere la produzione di alimenti della qualità desiderata. Il presente lavoro cerca di dare una risposta a queste domande sulla base delle più recenti acquisizioni scientifiche nel campo della nutrizione dei suini considerando anche alcuni risultati di ricerche condotte dagli stessi Autori. I dati emerse dalla presente revisione delle esistenti letterature scientifiche suggeriscono le seguenti conclusioni:
1. L'impatto delle modificazioni climatiche sulle produzioni agronomiche e conseguentemente sull'alimentazione degli animali da reddito deve essere studiato in modo completo e sistematico. I riflessi più importanti di queste sperimentazioni dovrebbero essere inseriti negli attuali sistemi di razionamento.
2. Il ruolo della nutrizione molecolare e la ricaduta dell'alimentazione sulla sfera immunitaria sono destinatari ad aumentare la loro importanza quali strumenti per elevare l'efficienza produttiva.
3. La collaborazione tra nutrizionisti e genetisti deve essere rafforzata per permettere una più accurata determinazione dei fabbisogni alimentari degli animali aumentando in questo modo la convenienza economica dell'attività di allevamento.
4. Nuovi approcci matematici che modellizzano il processo di crescita degli animali da reddito devono essere sviluppati con l'inclusione anche di aspetti legati alla qualità delle produzioni. Tutto questo per ottimizzare l'accuratezza delle previsioni di produzione.
5. Un approccio di tipo integrato “dall'azienda alla forchetta” lungo l’intera filiera di produzione degli alimenti sarà essenziale per garantire derrate di origine animale sicure e di elevata qualità. La nutrizione animale giocherà un ruolo chiave nello sviluppo e nel monitoraggio di queste filiere.
6. La produzione di alimenti sostenibili dal punto di vista dell'impatto ambientale è destinata a diventare un imperativo sociale. La nutrizione animale, soprattutto attraverso lo sviluppo di sistemi e tecnologie di alimentazione innovativi, ha ancora ampi margini di azione in questo senso.
7. L'implementazione a livello pratico della nutrizione di precisione può fornire un grande supporto nel raggiungimento degli obiettivi sopra citati così come nel migliorare l'efficienza della produzione.

Parole chiave: Alimentazione dei suini, Innovazione, Qualità degli alimenti zootecnici, Qualità degli alimenti di origine animale, Sicurezza alimentare.

Introduction

Animal nutrition in the 21st century aims to provide safe and good quality foodstuffs of animal origin besides a high efficiency of production and a low level of environmental pollution. These criteria, however, contribute to the complexity and rapid expansion of nutrition science. The increasing demand of the human population for foodstuffs needs to be supplied from a diminishing agricultural area, maintaining at the same time sustainability of production. According to the global trends, the challenges facing animal nutrition in the 21st century can be summarized as follows: more awareness and activity of participation is needed in animal production to supply quality and safe food in sufficient quantities, in accordance with the requirements of the society (Koerkamp et al., 2007).

Considering the limited nature of available agricultural area, the efficiency of animal production needs to be improved. This can be achieved by enhancing i) biological efficiency, ii) technological efficiency and iii) economic efficiency. The science of animal nutrition deals with the first two factors by using advanced knowledge. One of the practical solutions for saving grains for human consumption is to increase the amount of feedstuffs available for animal nutrition by using by-products. This concept is also in agreement with the principles of sustainability. However, a more extensive utilization of by-products in animal feeding – particularly of those rich in fiber – forces the nutritionist to reconsider the role of dietary fiber and its consequences in diet formulation. The effect of climatic change on crop production and animal nutrition should be studied in the near future (Miraglia et al.,
Figure 1. Relationship between traditional animal nutrition and other related sciences.

TRADITIONAL ANIMAL NUTRITION

(including plant production, animal husbandry)
2009), together with the investigation and evaluation of different climate scenarios, in the interest of maintaining sustainability of production. Another aspect of sustainable production is the relationship between animal production and environmental protection. Animal nutrition can have a great impact on reducing environmental N, P, CH₄ and microelements pollution caused by animal farming (Verstegen and Tamminga, 2005; Cole, 2005).

Innovation in animal (pig) nutrition aims at high quality of production besides a low level of environmental pollution. For that purpose new scientific areas are being developed, as discussed in the following sections.

**Main research areas foreseen in animal nutrition**

A key factor in enhancing the efficiency of pork production is the implementation of the latest scientific results in practical production. This means that the so-called innovation lag (the time passing from the inception of the idea to the implementation of the product) should be shortened as much as possible. The question, however, is whether the challenges of the 21st century can be faced using the knowledge of traditional animal nutrition science. Given that this is not very likely, it is necessary to make the new areas of animal nutrition a part of the innovation activity. This is not a new process, since nutrition physiology, or nutrition immunology have already become a highly important component of today's modern animal nutrition. Figure 1 shows those areas of natural sciences and/or technical sciences that should be integrated into the traditional animal nutrition science in order to come up with an adequate answer to the challenges of today. Such relatively novel fields are for instance molecular nutrition or the mathematical modeling of growth. Precision nutrition, which is an innovative area of animal nutrition, is a unique combination of traditional animal nutrition science, new animal nutrition knowledge incorporating natural science areas and informatics.

In our view the following research areas shall be of vital importance in the near future, and the issues presented by these areas can only be solved by linking the scientific areas shown in Figure 1 with nutritional science:

1. **Studies pertaining to the properties of animal feeds** (e.g. new energy and protein feeds, interactions between the various nutrients, alternatives to growth promoting antibiotics, mycotoxin contamination and the means to reduce it, issues of GMO feeds, study of the relationship between climatic change, feed crop production and animal nutrition, etc.).

2. **Research related to molecular nutrition**.

3. **Nutritional immunology studies** (effect of nutrients on the cellular and humoral immune status of the animals).

4. **Research in nutritional microbiology** (e.g. microbiological processes in the intestinal tract and their impact on animal production).

5. **Study of the nutrient requirements of high genetic potential animals** (the relationship between genetics and nutrition).

6. **Modeling of animal production** (predicting animal production with mathematical models).

7. **Develop new in vitro techniques** (develop novel, rapid, high-precision in vitro techniques for determining the digestibility of proteins, carbohydrates and other nutrients).

8. **Develop environmentally friendly feeding technologies** (primarily the development of feeding technologies aimed at reducing N and P excretion).
9. Work out integrated research and innovation programs for the “from farm to fork” food chain in the interest of producing safe and traceable food products of animal origin.

10. Apply precision nutrition in the production of animal products.

Due to the limitations of size, this publication focuses on and discusses in detail only some of the aforementioned research areas.

The relationship between climatic change and animal nutrition

Climatic change and its impact on crop production, livestock production and nutrition will be a major challenge for the forthcoming decades (Bernstein et al., 2007; Solomon et al., 2007).

It is well known from the field of plant physiology that based on the type of photosynthesis we can speak of type C3 and C4 plants. From the aspect of feed crop production it is important, that while the draught resistance of type C3 plants (e.g. wheat, barley, rice, oat, sunflower, alfalfa, soya bean, sugarbeet, etc.) is weaker, plants of type C4 (such as corn, sorghum, millet, etc.) are considerably more resistant to arid weather (Nayyar and Gupta, 2006). These plant physiological data will be of key importance in the future when deciding on which crops it would be feasible to grow in a given region under the changed climatic conditions (Chavas et al., 2009). Such changes of crop production will have a definite impact on the animal nutrition of the given region as well. Therefore, the study and analysis of the various climate scenarios, and on that basis the significantly closer cooperation of crop producers and animal nutritionists will be the task of the near future.

Molecular nutrition research

Molecular nutrition is a 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).

Nutritional immunology studies

In recent years nutritional research has focused on the impact of different nutrients on animal health and on how the supplemental and the feed’s own nutrient can manipulate the immune functions in livestock (Yaqoob and Calder, 2003). Some new generation growth promoters, such as mannan-oligosaccharides, β-glucan, some herb extracts, egg yolk antibodies operate by manipulating the immunity of the animal. It has also been clearly shown that individual nutrients, such as amino acids, fatty acids, starch, fermentable carbohydrates and their ratio in the diet has a significant impact on the immune response of the animals. The nutrient recommendations for pigs as regards the requirements of maintenance and growth are not always sufficient for an adequate immune function (Defa et al., 1999; Kidd et al., 2001, O’Quinn et al., 2002). The results of different studies show that a moder-
ate protein deficiency does not reduce immune response. However, 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 (Tsiagbe et al., 1987; Defa et al., 1999; Borbolla et al., 2000; Kidd et al., 2001, Lawrence and Hahn, 2001; Pierzynowksi et al., 2001; O’Quinn et al., 2002;). Therefore, among essential amino acids the recommended methionine, threonine, arginine supply will certainly be revised in the near future. There is a maximum curve of dose-response in case of methionine and unsaturated fatty acids. Increasing these nutrients in the diet results in an increase of growth performance and immune responsiveness, however, an overdose may have an immune suppressive effect before the performance is reduced (Cook, 1990). Thus, the nutrient requirement should be supplied besides considering both the requirements of production (growth) and that of immune responses. Consequently, less medication is used in animal production and as a result better quality and safe food can be achieved.

Table 1 shows the results of studies conducted by Defa et al. (1999). The trial used pigs of 17 kg weight, and the dietary treatments differed in their threonine levels only (5.9 to 8.9g/kg). The trial results suggest, that diets with a threonine level exceeding 6.8g/kg do not improve the production parameters of growing pigs anymore. On the other hand, the blood IgG concentration and antibody production in response to immunization with bovine serum albumin increased considerably in animals that were fed with a diet containing 8.9g/kg threonine. According to other authors, although the development of immune organs does not necessarily change with an inadequate threonine supply, the deterioration of certain immune parameters, such as the reduction of blood leukocyte proliferation ability should be expected in consequence (MacDougal and Klasing, 1998; Kidd et al., 2001).

The results discussed in the above suggest that nutritional immunology will play a central role in practical swine nutrition in the near future, and also that the nutrient recommendations will have to be revised in several instances based on the results of the nutritional immunology studies.

### Relationship between genetics and nutrition

The growth performance and the chemical composition of the carcass (the meat quality) are affected by many factors. One

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**Table 1. Effect of dietary threonine on serum IgG and bovine serum antibody production in pigs (Defa et al., 1999).**

| Threonine content (g/kg diet) | 5.9 | 6.8 | 7.7 | 8.9 | SEM | P-value |
|------------------------------|-----|-----|-----|-----|-----|---------|
| IgG content of the blood [mg/100ml]* |     |     |     |     |     |         |
| d7                           | 570.8 | 556.9 | 534.8 | 589.5 | 6.9 | NS      |
| d14                          | 648.1 | 667.7 | 660.0 | 695.4 | 5.5 | 0.01    |
| d28                          | 703.9 | 730.4 | 730.9 | 777.1 | 6.8 | 0.01    |
| Bovine serum albumin antibody content* |     |     |     |     |     |         |
| d14                          | 0.10 | 0.15 | 0.25 | 0.43 | 0.02 | 0.01    |
| d28                          | 0.61 | 0.62 | 0.69 | 0.78 | 0.10 | 0.01    |

*animals were immunized with 1mg/kg BW bovine serum albumin at 7th d of the experiment; SEM- standard error of mean; NS – non significant.
of the most important factors is the amino acid/energy ratio of the diet. It is well known, that for pigs the primary limiting amino acid is usually lysine. Table 2 illustrates the strong correlation between ileal digestible lysine intake and average daily weight gain, daily protein deposition and feed conversion rate (Halas and Babinszky, 2000). In consequence, it is indispensable that we aim for creating the best possible lysine/digestible energy (DE) ratio during diet formulation, in order to enhance protein deposition (Babinszky, 2006).

The trial results of Batterham et al. (1990) show, that in the case of growing pigs (between 25 and 45kg of live weight) the lowest fat deposition level can be expected with an 0.63g ileal digestible lysine/MJ DE ratio. The data from this study suggest, that any deviation from this lysine/energy ratio will lead to a higher fat content of the carcass and consequently to the deterioration of the meat quality. The optimal ratio of ileal digestible lysine/MJ DE for protein deposition is 0.55-0.60g for pigs between 25 and 60kg live weight, and according to the relevant data this decreases to 0.46-0.47 during the second phase of fattening (between 60 and 105kg live weight; Degussa, 1997; NRC, 1998; Szabó et al., 2001). It should be noted however, that the foregoing lysine/energy ratios pertain to hybrids with a so-called average genetic potential (normal pig).

Three categories were set up for pig breeds in the literature (Close, 1994):
1. Superior, genetically improved pigs;
2. Normal pigs;
3. Traditional, unimproved pigs.

The average daily weight gains and protein content of the empty body, characteristic of each category, are shown in Table 3.

Due to their higher potential for protein deposition and the fact that improved pigs reach their maximum genetic capacity for

Table 2. The relationship between daily ileal digestible lysine intake, daily weight gain, daily protein deposition and feed conversion ratio (Halas and Babinszky, 2000).

| Body weight | Daily weight gain | Daily protein deposition | Feed conversion ratio |
|-------------|------------------|--------------------------|-----------------------|
| 30-60kg     | r=0.94           | r=0.78                   | r=-0.94               |
|             | p=0.0001         | p=0.0001                 | p=0.0001              |
| 60-105kg    | r=0.89           | r=0.77                   | r=-0.87               |
|             | p=0.0001         | p=0.0013                 | p=0.0001              |

Table 3. Three categories of pigs have been identified depending upon their rate and composition of body gain (Close, 1994).

| Categories                                  | Growth rate (kg/d) | Protein content of empty body (g/kg) |
|---------------------------------------------|--------------------|-------------------------------------|
| Superior, genetically improved pigs         | up to 1.2          | 180                                 |
| Normal pig                                  | up to 1.0          | 170                                 |
| Traditional, unimproved pigs                | up to 0.8          | 160                                 |

Note: the assumption is, that maximum growth rate is achieved at a body weight of 60kg and is then maintained at a constant level up to 100kg body weight, that is in a linear-plateau fashion.
protein gain at approximately 90-100kg, the nutrient requirements of improved pigs are higher than those of a normal hybrid (Figure 2). Results of the studies conducted so far show, that when the lysine/energy ratio in the diet of hybrids belonging to the first category (improved pigs) is the same as in the feed of normal pigs, the former will deposit access fat by the end of the fattening period, i.e. the quality of the pork will deteriorate substantially. For this reason Varley (2001) suggests to feed these pigs with a diet containing 0.7g ileal digestible lysine per MJ DE during the first phase of fattening (between 20 and 55kg of live weight), and 0.6g during the second phase (between 55 and 100kg live weight).

These data stress the importance of knowing the genetic potential of our growing/finishing herd, because this knowledge is indispensable during diet formulation for establishing a proper lysine/energy ratio, so that the quality of pork can satisfy the criteria of human nutrition even in the case of the improved, high-producing pigs.

Modelling (prediction) of animal production

Nutritional simulation models transform the knowledge and concepts of the growth process or (milk) production into mathematical equations by developing algorithms. Integrating these equations, the model predicts the production from the nutrient intake. Unlike empirical ones, the mechanistic model’s equations are based on the knowledge of biological, biochemical, physiological and environmental response. Thus, with animal level models the effects of desirable and undesirable changes can be simulated (Halas et al., 2004a,b).

Nutritional models, therefore, are an effective tool for optimizing production and carcass quality and thus by integrating them into farm management programs they can improve profitability. The main purposes of using models in practice are the following (van Milgen, 1999): define the number of diets fed (phases used) in the whole feeding period; decision making in the use of alternative feed components (such as sugar beet pulp, soya hulls, various by-products, etc.); define the optimal slaughter weight for a certain livestock and in case of a certain feed; help to formulate diets that reduce environmental pollution (N and P excretion) without impairing the quality of production. Mecha-
Innovative growth models can be integrated into the feed evaluation systems as well. By its nature - being developed on the basis of biological, physiological or biochemical principles - a mechanistic model can be used in education and research (Black, 1995). The consecutive equations help to understand easily the mechanism underlying the growth process, but a model also highlights areas in which knowledge is inadequate and thus helps to formulate new scientific questions (Gill et al., 1989).

The major steps in a modeling process can be seen in Figure 3. The animal is a physiological system with measurable features (physiological data) and biological processes (physiological pathways). The first step in the modeling process is to carry out an investigation to collect basic data, such as weekly body weight readings, daily protein and fat deposition or daily feed intake, etc. The physiological process and the control of the system are then developed from this information. Traditionally in science, these two steps are repeated many times until the system can be described at some uniform level of detail (Black, 1995).

The concepts and data are transformed into mathematical equations by algorithms that can be solved rapidly by computer to provide a quantitative and dynamic approach of the system.

The next step is to check the validity of the model with regard to pathways and data, by comparing predictions with the trial results. Whenever there is a considerable difference between the model predictions and experimental observations, new approaches of pathway and equation parameters can be devised and tested within the model. The modeling process begins again in that case. When model outcome and the experiences agree over a wide range of different circumstances, some confidence in the understanding of the system is obtained (Black, 1995), that this could be the final model.

In the near future the development of new models can also be expected in addition to the prediction of growth, and these will be suitable to predict the quality of animal products (e.g. meat) as well, improving thereby the economics of production (Halas, 2004).

"From farm to fork chain" - integrated research and innovation programs

In the interest of producing high quality and safe animal food products (e.g. pork), it is necessary to examine the entire chain both in research and in the production of animal products (Babinszky, 2006; Koerkamp et al., 2007). Indeed, the production of high quality and safe animal food products demands that already at the first link of the animal product production chain, i.e. at field crop production high quality and safe production practices be in place. Accurate information are required about soil management, plant protection, and...
Figure 4. “From farm to fork” precision food production chain at Kaposvár University.
as to whether GMO grain is produced on the farm in question. The next link in the production chain is the animal feed industry. At this step in addition to the feed ingredients of plant origin also the industrially manufactured feed ingredients and feed supplements need to be controlled. Furthermore, each step of the compound feed manufacturing process and eventual manipulations in the feed mill (such as hydrothermic treatment, extruding, expanding, micronizing or other) should be controlled. The resulting compound feed is transferred to the pig operation, where all important data of each phase in the feeding and fattening process must be recorded together with the herd data. Having reached the slaughter weight the herd is transported to the slaughterhouse or the processing plant. Here again each processing stage is controlled and the data are entered in the central terminal (data file) of the product chain where, upon the evaluation of the data it can be discovered immediately if the activities at a certain point of the production chain deviate from the regulations, or if the data measured do not meet the regulations and the quality criteria. At the end of the product chain the output is a “food product of planned quality and safety derived from a planned feed” controlled at every stage of production, which when delivered to the supermarket shelves and cold counters can also be verified by the consumers themselves with the help of a bar-code.

Figure 4 presents the entire food production chain outlined in the above under the title “from farm to fork” developed by Kaposvár University. The purpose of this research and development and innovation (R+DI) project is to supply to the consumers animal products (pork) of the highest possible quality and safety. To this end however, crop production, feed industry, livestock production and the food processing industry and trade need to work in very close cooperation. Above all this it is also necessary that the researchers involved in the fields of animal nutrition, human nutrition, nutrition biology, nutritional immunology, molecular nutrition and the information technology specialists work together.

It is natural, that such a highly qualified research team committed by the foregoing philosophy will only be able to perform any high standard work in case it possesses a high standard research basis, laboratories and a sufficiently comprehensive and accurate technical data base, quality criteria pertaining to each member of the production chain, and a high standard informatics background (software, hardware). This type of high-level cooperation enables the controlling of every single point of the product chain in the interest of producing safe animal products (e.g. pork).

In recent years the number of programs called “from farm to fork chain”, “from field to consumer chain” or “from feed to food chain” is continuously increasing in the EU, the US and Canada, equally. It is a task of the near future that Central Europe should participate in these and similar research programs more intensively.

Precision nutrition for pigs

Precision nutrition, as can be seen in Figure 1, applies the research findings of traditional nutrition and of the new areas of animal nutrition, using large databanks with the help of computer technology. Precision 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 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 (Sifri, 1997). This is facilitated by electronic feeding; an important but by far not the only tool of precision nutrition. American and Australian examples prove that in the near future precision nutrition will be of key importance equally in producing pork economically and in high quality, and in the innovation activities.

Conclusions

The following most important conclusions can be drawn from the latest global trends concerning innovation in pig nutrition:

The impact of climate changes on crop production and consequently on animal nutrition needs to be studied in comprehensive, systematic research programs, and based on their results animal feeding systems should be modified if necessary.

The role of molecular nutrition and the immunological role of nutrition for enhancing the efficiency of production will gain in importance.

The cooperation between nutritionists and geneticists needs to be strengthened in order to satisfy the nutrient requirements more accurately, and thus to improve the profitability of production.

New mathematical growth models need to be developed for better production estimates, which also incorporate the quality of animal products.

The integrated “from farm to fork” programs will be essential in the production of safe and high quality animal food products. Animal nutrition will play a key role in these product development and monitoring programs.

The production of environmentally friendly animal products will become a social imperative. Animal nutrition still has huge unexploited reserves in this field, for instance in the development of novel animal feeding systems and technologies.

The practical implementation of precision nutrition can be of great help in achieving these goals and in enhancing the efficiency of innovation activities.

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