Chapter 1
A short history of the development of pig production and pig nutrition

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This chapter deals with:

- The historic development of pig production
- The national and global importance of pig production
- The development and adaptation of the Danish pig production industry
- Statistical data on pig population, pig production and the consumption of pork
- The development in nutrient research
- Implementation of research results in practice

1. From wild animal to domesticated animal

Today's domesticated pig descends from the wild boar. As far as we know, pigs were first seen in Denmark around the time of the Palaeolithic age (old stone age). Bones of wild boars were found at the Mullerup find and at other similar sites. Pigs were not kept as domesticated animals then, but were hunted for their meat. Archaeologists have excavated remains of bones and teeth from domesticated pigs in kitchen middens from the Neolithic age (the later stone age) and these remains probably belonged to the livestock.

The earliest Danish domesticated pigs were considerably smaller than the wild boars and were probably imported by trades men, seafarers, soldiers etc. as supplies. However, this was not actual pig keeping; the pigs were not fed, but had to find their food in forests, in nearby fields and in the kitchen middens. Pigs were also kept in towns where they fed on garbage and in middens. The pig caused extensive damage to forests, fields and towns. They were small and weighed approx. 40 kg by the time they were 3-4 years old. In the 15th and 16th century, manor owners rarely kept more than 100 pigs at a time and peasants only a few. At the Registration in 1688, forests were estimated according to the number of pigs they fed. In years with plenty of beechnuts, a large forest fed 4,000-18,000 pigs a year [1].

By the beginning of the 19th century, Denmark had two types of pig: a big one in Jutland and a smaller one on the islands [1]. The pigs in Jutland had a long body, long legs, bent back and long pendulous ears. The pigs on the islands had a shorter body, level back, were bristly and prick-eared. When well cared for, the Jutland pigs were as big at nine months as the island pigs at 3-4 years. Generally, Jutland pigs were slaughtered by the time they were two years old and produced 96-160 kg pork, while the island pigs at the same age produced 48-72 kg pork (see Figures 1.2 and 1.3 for an illustration of these two pigs). The domesticated pig inherited hardiness and robustness from the wild boar, and was also fertile, but grew slowly as a consequence of poor keeping. It was not until the late 19th century that breeding, nutrition, housing and actual tending to pigs improved drastically.

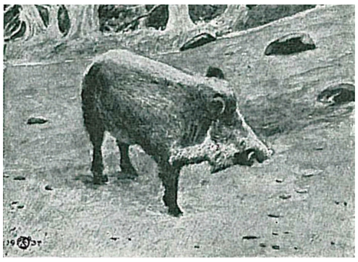

Figure 1.1.The wild boar

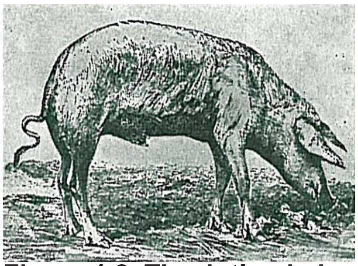

Figure 1.2. The Jutland pig

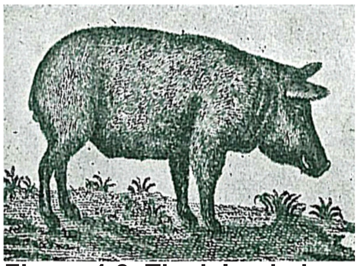

Figure 1.3. The island pig

2. National and global pig production

2.1. Population and production of pigs in Denmark

The first official livestock census in Denmark took place in 1837 [2]. The result was 235,000 pigs. By 1881, this figure had increased to more than half a million pigs, and has increased ever since, with the exception of the periods around World Wars 1 and 2 when populations declined slightly. Before World War 2, the population peaked in 1931 with 5.5 million pigs in Denmark. In 1960, there were 6.2 million pigs and the population has increased steadily since until peaking in 2007 at 13.7 million. In 2008, the population amounted to 12.7 million pigs of which 1.06 million were sows. Since 1970, the sow population has remained at approx. 1 million and is essential to maintaining a production of weaners and finishers [2]. Table 1.1 provides an outline of the trends in population, production scope and structure of pig farms in the period 1960-2008. It should be noted that due to increasing growth rates, production increases more than the population (more pigs are produced per place unit).

Table 1.1. Development in herd sizes and farm structure, 1960-2008 (figures are rounded off)

Year	1960	1970	1980	1990	2000	2008
Pigs, million	6.2	8.4	10.0	9.5	11.9	12.7
Of these sows, millions	0.68	1.0	0.96	0.90	1.07	1.06
Pigs slaughtered, million	8.1	11.3	14.1	15.7	20.1	22.1
Farms, 1,000	171,1	120,4	67,7	29,9	13,2	5,5
Av. herd size	36.1	69.5	147	318	901	2,189

Source: Danmarks Statistik [3]

Table 1.1 clearly shows that the pig population has increased drastically, whereas the number of farms has dropped rapidly. Herd sizes have increased as has the scope of specialised production. In 1960s, a mix of pigs and other livestock, such as cattle and poultry, was often kept on the same farm. By 1975, 50.5% of all farms housed pigs as well as cattle; by 2001, this figure had dropped to 3.1%. In 1975, 19.7% of all farms housed pigs exclusively; by 2008, this figure had dropped to 10.3%. In 2008, 62% of all sows in Denmark were housed on farms with more than 500 sows/year versus only 15% in 1998. In 1970, each farm housed averagely 69.5 pigs and 10.5 sows, which increased to 2189 and 357, respectively, by 2008. The production of sows and weaners has undergone a radical specialisation process where all pigs are sold or transported to another premises at 7 or 30 kg live weight where finishers are produced (multisite).

In 2008, farms approved for organic production housed 7,000 sows and 109,000 finishers corresponding to 0.6% and 0.5% of all sows and finishers, respectively, in Denmark [5].

2.2. Population and production of pigs globally

The development of pig production in other countries is highly important for our own pig production and export. The countries of greatest interest to Danish pig producers are those that compete with the Danish export and the countries that import our products.

In 1960s, the global population of pigs was estimated at 574 million pigs: 150 million in Europe incl. the Soviet Union; 150 million in North and South America; and the rest in Asia and Africa. By 2007, the population had doubled to approx. 1 billion pigs. The majority of these pigs are found in China (approx. 550 million) followed by Europe (EU-27) with 161 million pigs and North America with approx. 93 million. It is difficult to give an estimate of the population in Africa, Oceania and remaining Asia as pig censuses here are not fully adequate [4]. China is the world's largest producer of pork, but due to various disease problems in the production industry, production has declined over the last years. The products are sold largely on the Chinese market. The EU, the US and Canada are the largest exporters of pork and Japan the main importer [5]. Globally, 115 million tonnes pork were produced in 2007. Table 1.2 shows the ten main producers of pork - with a production of 1.75 million tonnes pork, Denmark is eleventh.

Table 1.2. Top ten pork producing countries in proportion to Denmark (1,000 tonnes)

Globally	115,554
China	61,150
USA	9,953
Germany	4,670
Spain	3,222
Brazil	3,130
Vietnam	2,500
Poland	2,100
France	1,982
Canada	1,894
Russia	1,788
Total	92,389
% of total	80.0
Denmark	1,750

Source: Statistisk Årbog [4].

3. Consumption of pork

3.1. Denmark

Pork has always played a prominent role in Danish households. In prehistoric Denmark and in medieval times, the wild boar was a popular quarry, and the meat of the wild boar as well as the domesticated pig was a significant part at feasts of the nobles. Peasants were also fond of bacon. Brawn and pickled pigs feet were among the favourite dishes around 1200, at the time of King Valdemar Sejr, and these were followed by dishes such as varieties of sausage and bacon, pork roast (from around 1860), fried bacon and meat balls (from end 19th century) and on to today's varieties such as sliced bacon, spare ribs, wok meat and pigs' cheeks [6]. In Denmark and in large parts of the world, the consumption of pork per capita has increased; in the period 1970-1977, the consumption of pork increased from 29.0 kg to 41.7 kg per capita. The method for recording the consumption of pork has been revised several times; most recently in 2005 when consumption at restaurants, public institutions etc. was included. All food produced in Denmark is not used for consumption; some is used for industrial purposes and some for production of feed for animals. Furthermore, Denmark also imports a fairly large amount of pork; in 2008, consumption per capita was 35.5 kg. However, the actual consumption is slightly lower than this figure due to trimming and driploss.

3.2. Export of pigs and pork

According to [1], Denmark has exported pigs since the time of Valdemar. Up to the end of the 19th century, this export consisted primarily of live pigs, but also bacon was exported to Germany in particular. Export skyrocketed when pig production started increasing in 1860s. The main export was constituted by live pigs to the market in Hamburg, but in 1890s Germany banned these imports due to fear of swine fever. In the period 1881-1885, the annual export amounted to approx. 300,000 live pigs. The export of live pigs dropped up to 1915 when only 50,000 live pigs were exported annually. However, the export of fat bacon rose to 122.7 million kg a year, the majority of which were exported to the UK. From 1920 to 1940, 95-100% of the export of fat bacon was destined for the UK, while Germany bought the majority of live pigs, pig fat and slaughter waste. The UK was the main importer of Danish bacon and canned goods until approx. 1970 when cuts and sausage products became dominant. Market conditions changed when Denmark joined the EC in 1973 as pork then had to be marketed under EC market terms. Germany is now the largest market for Danish pig meat followed by the UK, Poland and China. The export of pig meat now amounts to approx. DKK 29 billion a year: approximately 2/3 of the products are sold to EU-27 countries and the remaining third to other countries.

For the past years, the export of live weaners to Germany has increased steadily. In the period 1996-2000, 214,000 finishers were exported increasing to approx. 770,000 in 2010. In that same period, the export of weaners increased from 1.0 million to 7.5 million.

3.3. Consumer demands for production conditions

Danish pig producers have successfully managed to adapt product quality to the changes in consumer demands. After World War 2, consumers demanded less fat and more meat in Danish pork. Through improved breeding routines, nutrition, housing and care, fat content was successfully reduced and lean meat percentage dramatically improved. Along with this, however, came problems with so-called PSE meat – pale, soft and exudative. This was caused by a genetic defect that was eliminated through dedicated selection.

The use of antibiotics in pig feed as growth enhancers – antimicrobial growth promoters – introduced a fear of transmission of antibiotic resistance to humans. Up to April 1, 1997, ten different antimicrobial growth promoters were allowed in feed for pigs, but these were subsequently phased out, and as of January 1, 2006, antimicrobial growth promoters were banned in the EU. However, in many parts of the world, for instance the US, growth promoters are still allowed in pig feed. Danish pig meat is internationally renowned for its high quality and for being free of drug residue. Food safety is a special quality of the Danish food industry and a very important competitive parameter.

Feedstuff producers, farmers, slaughterhouses and processing companies are subject to audits during which their products are analysed for pathogens and unwanted substances. As part of the compliance with the EU directive on zoonoses, authorities and industries have since 1995 worked on reducing the prevalence of Salmonella in pig production. Consequently, all finisher farms slaughtering more than 200 finishers a year must be audited. As a result, Salmonella prevalence in finishers dropped from approx. 8% in 1994 to approx. 3% in 2008. In that same period, the slaughterhouses recorded a drop in Salmonella in fresh pig meat from approx. 3% to 1% [5]. This has also reduced the incidences of Salmonella in humans caused by Danish pig meat.

For years, Danish authorities extensively controlled drug residue in foodstuffs, and today common EU rules govern this area. In 2008, the Danish Veterinary and Food Administration analysed 11,038 samples of pig meat for residue of hormones, antibiotics and other drugs for animals. The results revealed seven samples, corresponding to 0.06% of all samples, that contained values that were too high in pigs. All seven findings concerned too much residue of antibiotics in sows [5]. Analyses of products from Danish pigs rarely reveal any drug residue or residue of other unwanted substances. In 1995, Bent Sloth, the chairman of Danish Bacon and Meat Council [7] laid down the following requirements for production and product quality in Danish pig production, which still apply to this day:

- Clean production apparatus, no residue and no risk of resistance for the consumer
- Foodstuffs are produced under conditions that have minimum impact on the environment
- Animal welfare is benefited when pig housing is designed
- Appropriate transport conditions and treatment of animals prior to slaughter.

4. Development in the Danish pig production industry

4.1. Increasing control with production methods and sale

In the last half of the 19th century, focus increased on improving the profitability and efficiency of the pig production process. This happened with dairy farming as dairy co-operatives were established, which meant the rise of by-products such as skimmed milk, butter milk and whey. Together with grain and various types of roughage, these by-products were excellent food for pigs. At the same time, the industry realised that by using boars of foreign breeds from England and Holsten, it was possible to improve "the Danish national pig" and the products from these pigs. A census in 1871 revealed a boar population in Denmark of approx. 2,100 boars of which half were of British origin. The pigs that were imported were primarily of the lard type and were used for mating with the Danish Landrace, resulting in bigger and fatter pigs that were suitable for and asked for in Germany [1], [8].

The export of live pigs to Germany continued to increase until 1880s, when Germany repeatedly banned the import of live pigs from Denmark. The German market became so uncertain that Danish pig producers were forced to find alternative markets such as the British market. However, the endeavours were unsuccessful as the Danish product consisting of live fatteners was almost impossible to sell in Britain. It was subsequently agreed to adapt the Danish pig production industry to match the British market that appeared to be a market with a huge potential for Danish products. The large, fat lard-type pigs were replaced by young, light, meaty, uniform bacon pigs [1], [8].

4.2. Slaughterhouses

The first export slaughterhouse was built in Holstebro in 1879. Magnus Kjær initiated the project and he was also owner and manager of the slaughterhouse. In 1880, he began importing breeding stock of the breed Large White from the UK. Breeding was subsequently organised and a significant number of Large White boars were now found in and around Holstebro. The combination of the new boars and the old Landrace exceeded everybody's expectations. Products from Holstebro Slaughterhouse obtained a prominent place in the UK market and sold at high prices. Thereby, the "Holstebro pigs" paved the way from fatteners to bacon pigs.

The new, emerging export of slaughtered pigs to the UK was quickly followed by a variety of new cooperative slaughterhouses. The first was established in Horsens in 1887 and in 1888 more followed in Esbjerg, Faaborg, Holbæk, Kolding and Slagelse. In the years that followed, many new cooperative slaughterhouses saw the light of day, and this trend increased the interest in and efficiency of the production of pigs. The cooperative slaughterhouses formed the grounds for cooperation and organized sale of products [1], [8].

By 1960, Denmark had 78 pig slaughterhouses of which 62 were cooperative. The total number of slaughter facilities was also 78, but from 1960 onwards the number of companies as well as slaughter facilities dropped drastically. The trend has now moved towards few, large companies with multiple slaughter sites. As a result, by 2008 Denmark had two slaughter companies, both cooperative, operating a total of ten slaughter sites [7], [5].

4.3. Organizing of pig breeding

In 1890s, it was decided to improve the organizing of breeding and to adapt the structure to match the changing market conditions. Government adviser P.A. Mørkeberg drafted a proposal for appropriate structure and management of the work with pig breeding. This involved systematic crossing the Large White (boars) and Danish Landrace (sows) to improve Danish Landrace. The long-term aim was to have this improved Landrace alone (through pure breeding) form the basis of the entire Danish pig production [1], [8].

Mørkeberg proposed that breeding centres be established on agricultural premises owned by skilled breeders. These breeding centres were subject to public inspection and the work was granted public aid. Their main task was to improve the new Landrace, but also, inasmuch as possible, to supply female animals to commercial farms. Material was purchased from the UK to produce Large White boars for the production of finishers. In 1900, there were 88 centres for Landrace and 15 for Large White [7].

At approved pig breeding centres, it was to a certain extent possible to base the selection of breeding stock on fertility, health and conformation. Sows and boars in these centres were therefore evaluated and selected by people from agricultural centres and slaughterhouses. This also ensured that Landrace improved as desired. However, it was quickly realised that this was not sufficient for selection as information was also required on daily gain, feed conversion ratio and carcass quality. Hence, it was decided to set up actual experimental stations where offspring would be tested. In 1907, three stations were set up followed by two more in 1926, and it was now possible to test offspring of sows as well as boars from the breeding centres.

4.4. The National Committee for the Management of Pig Breeding

In 1931, close co-operation procedures on management of pig breeding were implemented between the cooperative slaughterhouses and the agricultural organisations, and “The National Committee for the Management of Pig Breeding” was established. The Committee consisted of representatives of the Federation of Danish Cooperative Slaughterhouses, the Federation of Danish Agricultural Societies, the Federation of Danish Smallholders and the national consultant of pig breeding and the professor of pig breeding at the Royal Veterinary and Agricultural University. The Committee was responsible for prime breeding at the approved breeding centres, for keeping pedigree records and for running the permanent offspring experimental stations. Consequently, the Committee had extensive influence on the future development of pig production [7]. The Committee subsequently changed its name and composition, and in the following it will be named “the National Committee” (see paragraph 5).

4.5. Pure breeding with Danish Landrace

After World War 2, it was hard to procure enough food, but as the production and supply of pork increased both nationally as well as in the UK, consumers started complaining of fat pig products. Consequently, breeding strategies in Denmark concentrated on increasing the lean meat percentage in the pigs. As a result, pigs’ back fat thickness was significantly reduced, and, until1980s, Danish bacon sold at premium prices compared with bacon from the UK and other countries.

However, as lean meat percentage increased in Danish Landrace, problems occurred with light and exudative meat that was tough and had poor keeping qualities. Another drawback of the one-sided selection for good slaughter quality was lower quality in other important production traits such as fertility, gain and feed conversion ratio as well as certain traits for longevity and health [7].

4.6. New hybrid programme

In 1970, Professor Hjalmar Clausen gave his legendary Maribo speech. Based on positive results from crossbreeding trials abroad, he came up with a proposal for a crossbreeding programme with Danish Landrace and Large White. In 1971, a trial investigated crossing English Large White with Swedish and Danish Landrace. The outcome was positive, and in 1973 the National Committee decided to start hybrid production with Landrace and Large White.

According to the programme, breeding centres for Danish Landrace and Large White were to be approved, and, crossing Danish Landrace sows and Large White boars, multiplication farms would produce F1 female pigs (YL) for the commercial farms. Both pure breeds used for multiplication of hybrids were subject to certain quality requirements, and to benefit good slaughter quality all YL sows must be mated with Landrace boars or inseminated with Landrace semen. This ensured that finishers' pedigree was 75% Landrace and 25% Large White.

As expected, this hybrid programme demonstrated significant improvement of several of the important production traits:

- Pigs produced per sow/year
- Daily gain
- Feed conversion ratio
- Lean meat percentage

It therefore quickly became common to use hybrids on commercial farms. Because of the positive experience, interest increased in the two foreign, pigmented breeds Hampshire and Duroc in the last half of the seventies. Duroc turned out to be suitable as "paternal breed" for finishers. The two breeds were also ideal for production of hybrid boars (HD) that could be used for YL sows (four-breed finisher). Subsequently, approved breeding centres for both Hampshire and Duroc were established [7].

In 1993, the Danish pig breeding industry was re-structured under the name DanBred. Here it was decided to continue work with two dam lines (Landrace and Large White) and two sire lines (Duroc and Hampshire) on breeding and multiplication farms [7]. However, interest in Hampshire faded by the turn of the millennium and it ceased being used for breeding. Duroc is now the primary breed for production of finishers.

The hybrid programme adopted in 1973 formed a significant basis for pig production for many years. However, the rigid management and control seen in the first years of the programme has slackened considerably. Today's pig producers are free to vary and adapt hybrid programmes to their own farms. There is no doubt that pig production will be based on hybrid pigs for years to come.

4.7. Today's breeding

Today's breeding system is organised in DanBred and the breeding work is administered by Pig Research Centre – PRC - (previously the National Committee) through DanBred. Breeding and multiplication farms are owned by private breeders who have made a contract with PRC on breeding. The selection methods used today are based on comprehensive recording and testing on breeding and multiplication farms and subsequent statistical treatment of this data. For each of the three breeds (Landrace, Large White and Duroc, see Figures 1.4-1.6), "breed specific" breeding objectives are laid down that are routinely evaluated and revised. An individual index is calculated for all breeding stock, which provides an estimate of the production economy that it is possible genetically to achieve with the individual breeding stock. This index is calculated on a weekly basis for all pigs in the Danish breeding system.

Today, 25 breeding farms and 115 multiplication farms are affiliated to DanBred. Put together, all breeding farms house approx. 16,000 sows, corresponding to an average herd size of 600 sows, and multiplication farms house approx. 53,000 sows corresponding to an average herd size of 460 sows. Minimum limits apply to herd size to take into consideration on-farm performance testing of breeding stock [9].

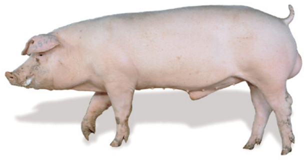

Figure 1.4. Danish Landrace

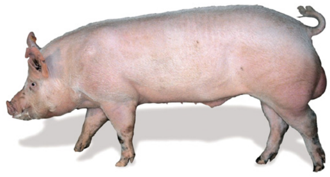

Figure 1.5.Large White

Figure 1.6.Duroc

4.8. Essential aids for breeding and production of pigs

The Danish pig production industry underwent massive, positive development after World War 2, and this is attributed to multiple factors. One was the fact that pig producers and slaughterhouses were capable of setting up various efficient tools for joint use. Some of these were already mentioned in paragraphs 4.1-4.6, but a range of others can be mentioned: test stations for testing of offspring; demonstration farms and the Applied Pig Research Scheme; SPF production; artificial insemination; and early weaning.

4.8.1. Test stations for performance testing of offspring

When the first test stations for offspring were established (1907-1925), it was quickly realised that they were essential to the genetic progress. In 1950s, the old stations could no longer keep up, and they were replaced by four new, completely identical stations ("Sjælland", "Fyn", "Jylland" and "Vestylland") each with 400 pens for individual housing and feeding of pigs. Pigs from the breeding centres were submitted for testing in batches of four litter mates each (two female pigs and two barrows). All pigs on the stations were fed and tended to identically in the period 20-90 kg to be able to record daily gain, feed conversion ratio, and slaughter and meat quality to obtain an impression of differences in the pigs' genetics. Post-slaughter, carcasses were subject to extensive evaluation at the slaughterhouse. Each year, the four stations tested approx. 5,000 pigs corresponding to approx. 1,250 full sibling groups [1], [7].

1981 saw the initiation of test station Bøgildgård that had an annual testing capacity of approx. 2,800 pigs. For years, the station co-operated with some of the older stations, but the four permanent stations were eventually closed. By then, testing of offspring took place solely at Bøgildgård where the intention was to performance-test boars destined for, for instance, AI stations. New technology made it possible to determine pigs' individual feed intake even when they were housed in groups. On breeding farms, performance-testing was implemented of both male and female pigs. Today, approx. 5,000 boars are performance-tested annually at Bøgildgård, while approx. 100,000 young animals are performance-tested at breeding farms [7], [9]. In October 2010, genomic selection was implemented, which is based on sequencing of the pig's genes. Approximately 60,000 sequences can be related to well-known phenotypic recordings. This information can be used in index calculations, but it can also be used to ensure better and earlier selection of boars with a high potential for, for instance, good feed conversion ratio, high daily gain, high lean meat percentage etc. This is expected to improve genetic progress by up to 25%.

4.8.2. Demonstration farms and the Applied Pig Research Scheme

Demonstration farms for pig feeding were established in 1953. These farms were financed by Marshall Plan funds for production-enhancing initiatives. Based on feeding trials at the National

Institute of Animal Sciences (see paragraph 5), the purpose of these farms was to demonstrate to farmers how to feed pigs rationally and economically under practical conditions. Thirty-two demonstration farms of varying sizes were set up, and their task was to demonstrate best practice in terms of feeding of and tending to sows, weaners and finishers. By splitting sows and/or weaners on individual farms, it was furthermore attempted to solve problems related to feeding or treatment (field tests).

The demonstration farms were replaced in 1971 by six observation farms and 30 control farms the aim of which was to demonstrate cost-efficient possibilities under current practical conditions. Trials concerning feeding and environment were conducted on these observation farms.

The Applied Pig Research Scheme for housing and production systems was established in 1975 under the National Committee. The purpose was testing of new types of housing, mechanical aids, and production systems for pigs under practical conditions. Observation farms ceased to exist in 1989, and it was decided to include testing of feedstuffs and diets in the Scheme [7]. Recently, trials have focused increasingly on pigs' health and welfare and on environmental issues relating to production of pigs. Approximately 100 farms are affiliated to the Scheme, and a wide variety of issues are investigated. Examples taken from PRC's Annual Report 2009 include health, welfare, management, housing, environment, nutrition, artificial insemination, economy and strategy. Collaborative projects with Danish research institutes form a significant part of this work [10].

4.8.3. SPF production

SPF is the abbreviation for Specific Pathogen Free, and SPF pigs have a better health status than conventional pigs. This is attributed to the fact that SPF pigs are free of loss-making diseases such as pneumonia, pleuropneumonia, contagious rhinitis, pig dysentery and lice and mange. The first generation of SPF pigs (primary pigs) is obtained by delivering piglets via C-section and subsequently rearing them under clinical conditions whereby they avoid transmission of infections through contact with the sow. Subsequent generations (secondary pigs) are bred, born and reared naturally.

In 1969, the first SPF pigs were delivered via C-section at the Danish Meat Research Institute, and by 1971 SPF was approved as a health and production system under the Cooperative Slaughterhouses. In 1972, the SPF Company founded primary station Grønhøj where primary pigs were reared and following generations were bred naturally. These pigs were then sold to producers wishing to convert to SPF production. Newborn primary pigs were taken directly from C-section in operation theatre to SPF farms where they were reared by nursing sows [7]. In 1987, Grønhøj ceased being primary station.

In 2010, 73% of all Danish sows and 39% of all finishers were estimated to have SPF status. Approximately 3,700 farms are affiliated to the SPF system. The SPF Company is also Denmark's largest carrier of pigs [11].

4.8.4. Artificial insemination

In 1963, boar station Hatting was founded as trial station for artificial insemination (AI). Managed by the Royal Veterinary and Agricultural University, natural mating was compared with AI for a period of seven years with positive results. The capacity of Hatting AI was extended and more AI stations were established. In the period 1970-1992, research and development activities concerning AI were conducted in co-operation with The National Institute of Animal Science. In 1986, Hatting AI became an independent company under the Danish Bacon & Meat Council. From 1990, the company had the disposal of seven AI stations responsible for 82% of semen sale, while the remaining 18% were sold from three private stations. In 2010, 5.4 million semen doses were sold corresponding to 95% of all matings being performed with semen purchased from AI stations. Large sow farms are also seen to use on-farm AI.

Artificial insemination has two main advantages: the risk spreading infections is reduced and it makes it possible to use first-class boars for a large number of sows. Requirements for selection of boars for AI are rather comprehensive as they, through insemination, greatly influence the population of pigs in breeding herds as well as commercial herds. The traits slaughter quality and meat quality and the body condition of the boars therefore weigh heavily when boars are selected [7], [10].

4.8.5. Early weaning

Until the beginning of 1970s, pigs were normally weaned when they were eight weeks old. As sows normally enter heat 4-7 days post-weaning, weaning age influences the number of litters a sow can get a year. A reduction in weaning age from eight weeks to, for instance, four weeks could therefore increase the number of litters per sow/year from 2.0 to 2.4. This improvement corresponds to approx. four piglets per sow/year.

In the period 1974-1994, the average weaning age was reduced from 56 days to 33 and 29 days respectively (see Table 1.3). As expected, farms also witnessed a considerable increase in pigs per sow/year. This progress was the result of an increase in litter size as well as early weaning [12].

Table 1.3. Selected production results for pigs

Year	1974/75	1984/85	1994
Pigs born per litter	9.4	10.3	11.0
Mortality, pigs born	17	14	13
Pigs/sows/year	12.7	18.9	21.7
Weaning age, days	56	33	29

Source: Department of Farm Accounting and Management, Danish Farmers' Union [12].

It was realised in terms of research, development and from practical experience that feeding, housing climate and hygiene among weaners needed to be adjusted to weaning age.

4.9. Production results in pig production

Danish pig production has developed dramatically the last 35 years. All of the above tools and aids for pig producers and their advisors have helped making the Danish pig production industry extremely efficient. As shown in Table 1.4, both sow farmers and producers of finisher have witnessed a considerable increase in productivity.

Table 1.4. Production results

Year	1974/75	1979/80	1984/85	1989	1994	1998/99	2003/04	2007/08
Sows								
Pigs/litter (live)	9.4	9.7	10.3	10.5	11.0	11.6	12.6	14.0
Mortality, piglets	16.7	15.3	14.2	13.4	13.1	12.4	13.3	13.8
Weaned per sow/year	12.7	15.9	18.9	20.6	21.7	22.2	23.5	27.3
Weaning age, days	56	43	33	29	29	29.1	30.5	32.0
Finishers								
Daily gain, g	528	565	682	712	726	778	832 (799)	904 (895)
FUgp per pig, daily	1.80	1.85	2.02	2.05	2.12	2.22	2.35	2.55
FUgp per kg gain	3.4	3.28	2.96	2.88	2.92	2.89	2.85	2.83

Source: Department of Farm Accounting and Management, Danish Farmers' Union [12]. Figures in parentheses are adjusted to 30-100 kg.

The results in Table 1.4 are shown in five-year intervals revealing that the number of pigs per sow/year has more than doubled over the last 35 years from 12.7 to 27.3. The dramatic increase is attributed to progress in the three remaining traits for sows. In particular *pigs born per litter* has increased drastically the last ten years since this trait was included in the breeding index in 1992 [13]. *Mortality of pigs born* dropped the first 25 years, and then increased slightly because of the dramatic increase in litter size. Increasing mortality rates in the farrowing house is an unfortunate trend, and it was therefore decided in April 2004 to include pig survival day 5 (LP5) in the breeding index for the dam lines Landrace and Large White [13]. *Weaning age* dropped drastically from 56 to 29 days during the first 20 years, and then increased moderately to 32 days over the next ten years. However, this figure is slightly misleading as the increasing litter size has enhanced the need for nursing sows to raise weak and surplus piglets. The 32 days is the average nursing period of the sows, whereas the actual weaning age is lower.

Table 1.4 demonstrates that daily gain in the entire finisher period increased from 528 g to approx. 900 g. This is partly explained by an increase in feed dose from 1.80 to 2.55 feed units a day. Despite this, feed conversion ratio, expressed as feed units per kg gain, improved considerably from 3.4 to 2.83. Ongoing improvement of pigs' genetic heritability for meat production thus made it possible to increase the daily feed dose (corresponding to ad lib) without adversely affecting feed conversion ratio and slaughter quality.

5. Organizing of research and development

There are three main institutes/companies in Denmark that conduct research in nutrients and have done so since 1890. The names have changed over the years and mergers have changed the organizing, but as results of the trials were published under the then-names of the institutes, a brief outline of the identity of these institutes is required:

- The Royal Veterinary and Agricultural University: On January 1, 1997, changed names to Faculty of Life Sciences (LIFE) under University of Copenhagen.
- Landøkonomisk Forsøgslaboratorium, later called Statens Husdyrbugsforsøg (in English both were called the National Institute of Animal Science) and then DJF (Danish Institute of Agricultural Sciences): On January 1, 1997, changed names to the Faculty of Agricultural Sciences under University of Aarhus, and on July 1, 2011, to Faculty of Science and Technology under University of Aarhus.
- The National Committee for Management of Pig Breeding, later called The National Committee for Pig Production, and Danish Pig Production: On October 1, 2009, the name was changed to Pig Research Centre, Danish Agriculture & Food Council.

Basic research in pig nutrition and nutrition physiology is handled by the two first-mentioned institutions whereas practical feeding trials primarily take place at DJF, the trial stations under Pig Research Centre and on private pig farms. Trials involving feedstuffs and diets are made under the auspices of the pig industry and in some cases of the feedstuff industry. Extensive co-operation takes place on research and development, and is co-ordinated through Pig Research Committee led by Pig Research Centre and represented by relevant members of the research world. The pig industry co-finances joint projects through bilateral agreements and national research programmes.

6. Research on nutrition and feeding

6.1. Physiology of nutrition is a key discipline in nutrition research

Physiology of nutrition is the science of nutrient composition in organs and tissues. It includes qualitative as well as quantitative nutrient turnover and adjustment of this, and the function of organs in terms of digestion, absorption, turnover, deposition and excretion of nutrients and waste products. It creates the basis for understanding how the ingredients of a diet influence an animal's health and welfare, production and product quality, production economy and the impact of nutrients and waste products on the surrounding environment.

When it comes to the quantitative turnover of nutrients and the adaptation of this (see Figure 1.7), research does not distinguish clearly between nutrition, physiology of nutrition and production, organ physiology and biochemistry. Nutrition involves the chemical composition of feed, quality of the feed, evaluation of the feed, requirements and standards for nutrients and energy, and utilisation of the feed for various purposes (maintenance, growth, reproduction, lactation etc.). Physiology of nutrition involves the chemical composition of feed, digestion, absorption, turnover, deposition and excretion, and effect in body in the different processes. Basic physiology of the organs is the basis for understanding the function of the digestive organs, the function of productive tissues and hormonal regulations of organ functions. Physiology of production involves qualitative and quantitative utilisation of nutrients for production of meat, fat, bones, milk and embryos, including amount and quality of the nutrients, and safety and purity of the products.

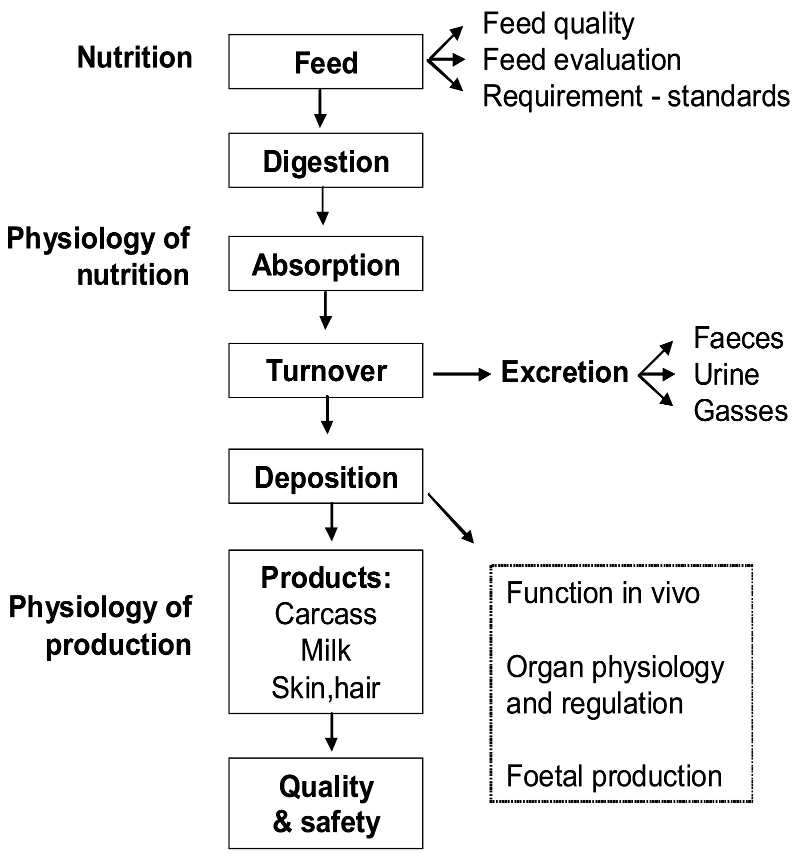

Figure 1.7. Turnover of nutrients divided into the following disciplines: Nutrition, physiology of nutrition, and physiology of production. Gradual transition.

Knowledge of physiology of nutrition is essential in applied research, legislation and regulation, and in the practical implementation of measures improving production when it comes to understanding nutritional measures, animal health and welfare, amount, quality and safety of the products and environmental measures. This basic knowledge is based on national as well as international research, but evaluation of problems related directly to or depending on Danish production conditions require applied research and knowledge nationally and close contact with the industry.

6.2. Development of nutrient research and importance to pig production

Immediately after the establishment of the Trial lab of the National Institute of Animal Science, feed utilisation in the digestive tract, turnover of nutrients in the organism and value of manure of different diets were studied [14]. In 1911, MB Holger Møller was appointed professor of animal physiology at KVL. He was a doctor and realised that improvement of pigs' production performance required thorough knowledge of metabolism and regulation of this. He built respiration chambers for cattle and pigs based on indirect calorimetry oxygen uptake, carbon dioxide excretion and nitrogen excretion via urine were recorded, and thereby the production of heat was calculated. Some of the most significant investigations made with pigs were recordings of turnover of energy and protein, requirement for Vitamins A, B, and D, and utilisation of calcium and phosphorus in growing pigs [14]. Up to 1982, research revolved around developing analyses for amino acids, fatty acids, carbohydrates, vitamins, minerals and hormones; work that was made possible by the development of new techniques and new analysis equipment. Studies were made of turnover of glucoses, amino acids and fatty acids with radioactively labelled substrates and metabolites as well as studies of hormonal regulation of metabolism. New respiration chambers were built for recording of protein and energy turnover in weaners as well as growing pigs on different diets. The invention of the ultra centrifuge made it possible to isolate subcellular cell elements such as mitochondries and endoplasmic reticulum and investigate their function in relation to changes attributed to nutrition. Techniques were also developed for catheterization of vena porta to investigate quantitative absorption of nutrients from the small intestine to the liver [15]. Techniques and methods were refined at both the Faculty of Agricultural Sciences and the Royal Veterinary and Agricultural University as stable isotopes, multi catheterization of different arteries and veins, and laparotomy of various segments of the digestive tract were introduced. The entire analysis area now also includes specific carbohydrates fractions, lipid fractions and individual fatty acids and amino acids. Generally, the problems investigated in nutrient research have always been closely related to current problems or problems expected to arise in the near future in practical pig feeding. For years, the main purpose was to improve productivity and carcass quality; more meat, less fat; higher gain, lower feed conversion; higher litter size at birth and more and bigger pigs at weaning. Lean meat percentage in carcass has now stabilised at approx. 60%; fat percentage is at a minimum, but meat and eating quality still leave room for improvement. Research has at all times formed the basis for improvement of pig production and the various requirements made by authorities, consumers and society.

The importance of livestock nutrition is the centre of attention across the EU and to a large extent in Danish legislation. Feed and feedstuffs must not be harmful to the environment or to the health of human beings and animals. Feed quality and safety is a prerequisite for food quality and safety, and is part of the EU’s from farm to fork strategy for the entire feed and food industry. Examples are the BSE crisis triggered by feeding livestock meat and bone meal from infected cows; conscious or subconscious contamination with toxic or unwanted substances such as dioxin, lead, hormones and hormone substances; and the addition of antibiotic growth promoters to feed, which has now been banned in the EU. Research is required of new initiatives such as GMO and organic production to verify their effect. Another significant reason to focus on livestock nutrition is utilisation of resources. Feed costs constitute 60-70% of the overall production costs. Currently, the environmental impact of nutrients in livestock feed, particularly from intensive pig production with many animals per farm, is receiving a great deal of attention. EU legislation requires sustainability in the production apparatus of the entire farm. Particular the Nitrate Directive and the Plans for the Aquatic Environment pose very extensive requirements to discharge of nitrogen and phosphorus from pig farms. It is therefore essential to be able to feed N and P as close to the requirements of the animals as possible, and to do this we need to know the pigs’ requirements for protein, amino acids and phosphorus as well as the availability and utilisation of these nutrients. Other minerals, such as copper and zinc, may also have an impact on the environment.

Research employs both basal and applied studies. Studies take place at farm level, individual level or group level; studies may be extensive and intensive; they may be in vitro and in vivo of the entire pig, of organs and tissues, cellular or subcellular. Studies may also take place at DNA and RNA levels, and may be performed with the new molecular genetic techniques in the nutrigenomics, metabonomics and proteomics, which are some of the areas growing rapidly within biotechnology.

6.3. Feed trials

Feed trials mainly concern the practical aspects of pig production where the effect is recorded on response factors that can be observed, quantified and analysed. Multiple trial designs exist that can separate the effect of irrelevant factors in the subsequent statistical treatment of the trial material. Feed trials are primarily conducted by Faculty of Agricultural Sciences and Pig Research Centre and include pigs at all stages of their growth. The response factors used are often animals’ growth and feed conversion ratio, slaughter and meat quality, litter size and piglet weight at birth and weaning, sows’ productive traits, including milk performance, prevalence of diarrhoea in piglets at weaning etc. The trials are often extensive rather comprehensive and include multiple replicates, and results are often implemented immediately in production.

When pigs were given whey and skimmed milk, it was realised that they grew faster than when they were given only water in combination with waste from threshing of grain or refuse from the pig house or households, just as the use of grain instead of refuse made the pigs healthier. This was verified in a trial. Results of a feed trial conducted at the Trial lab [16] where the pigs were fed barley and water or barley and dried skimmed milk in the period 20-90 kg liveweight clearly demonstrated the enormous influence on production efficiency of dried skimmed milk rich in protein and essential amino acids (see Table 1.5).

Table 1.5. Results of a feed trial where pigs were fed barley and water (group 1) or barley, water and dried skimmed milk (group 2) from 20 to 90 kg liveweight [16].

Group	**1**	**2**
Dig. protein, g/day	120	231
Lysine, g/day	6.5	16.1
Methionine, g/day	3.4	5.9
Feed units/day	1.66	1.89
Daily gain, g	284	722
Feed units/kg gain	5.95	2.62
Non-productive days	253	97
Feed units, total	416	184
Lean meat %, flank	45.6	60.0
Fat %, flank	43.4	29.3
Loin, content of:		
Fat, %	5.0	2.1
Crude protein, %	20.6	24.4
Lysine, g/16 g N	8.7	8.7
Methionine, g/16 g N	2.8	2.9

Pigs' daily gain increased by 254% and the number of productive days dropped by 156 days whereby the overall feed conversion dropped by 232 feed units (FU). Lean meat percentage increased by 14.4 percentage units, while fat percentage dropped by 14.1 percentage units. The trial clearly demonstrated that the amino acid content in the meat is largely constant.

Numerous trials have demonstrated that the content of protein in feed and the amino acid composition of the protein greatly influence gain, feed conversion and slaughter quality and thereby also production economy.

6.4. Studies on physiology of nutrition

The cornerstones of investigations of physiology of nutrition are feedstuff analyses, digestibility and balance trials and respiration trials. The trials are non-invasive and can be conducted repeatedly throughout a pig's growth period/reproduction cycle. These studies also include laporotomy of the individual segments of the digestive tract and catheterisation of different blood vessels. To be able to monitor the path of a feed component through the digestive tract, blood or lymph and in the individual organs and tissues, it is necessary to be able to analyse the component in the different matrices and possibly be able to label it with, for instance, a colour, or radioactive or stable isotopes. Below, these techniques are described only briefly as other chapters will give a more detailed account of these.

6.4.1. Analyses of feedstuffs

To be able to estimate the value of a given diet, it is necessary to know the chemical composition and analyse the components you wish to evaluate the value or effect of in the body. It is not sufficient to use feedstuff table. However, analyses of the ingredients of a diet will not tell how the feed is utilised in the body. For the last 100 years, nutrient research has focused on evaluation of feedstuffs based partly on feedstuff analyses and partly on digestibility and balance trials.

The Weende analysis is the classic feedstuff analysis method, and is based on analyses of dry matter, crude protein (Nx6.25), crude fat, crude fibre, ash, and calculation of NFE (Nitrogen Free Extract substance = organic dry matter – crude protein – crude fat – crude fibre). It was the most commonly used analysis method up to 20 years ago and formed the basis of evaluation of feedstuffs for pigs. As a result of new knowledge of the chemical components of the fractions and utilisation in the body as well as new analysis techniques, the Weende analysis was replaced by analyses that to a greater extent describe the chemical components. Consequently, NFE and wood pulp are now split into analyses of starch, sugar and dietary fibre, and specific analyses of individual carbohydrate fractions (for more information, see also Chapter 8). Protein content and composition of amino acids greatly influence the protein value of a feed and is characterised by amino acid analyses and amino acid digestibility as described in detail in Chapter 9. The content of fatty acids in the dietary fat influences the feed value of the fat, and the composition of the fatty acids has a huge influence on the taste of the products and the technological quality, visual impression and keeping quality and human health. The importance of dietary fat is described in detail in Chapter 10.

Analyses of mineral nutrients frequently include calcium and phosphorus as the two macro minerals added in the largest amounts, but also iron, selenium and cobber are analysed regularly. Chapter 11 describes the utilisation of minerals in pigs. Analyses of vitamins are not routine analyses; they are very expensive because each vitamin represents a specific substance group that cannot be analysed with other groups. Chapter 12 provides a description of the turnover of vitamins in pigs.

Since 2004, a feed's content of energy was described on the basis of the enzymatic in vitro methods EFOS and EFOSi (see also Chapter 21).

6.4.2. Digestibility trials

By determining the digestibility of the individual feed components, a fairly good impression is obtained of how much of the individual components an animal has absorbed. The digestibility of an ingredient, for instance protein, is determined in a digestibility trial where protein supplied to the animal through the feed and protein excreted in faeces are recorded. The discrepancy is called digested or absorbed protein, and the digestibility coefficient is the percentage of the feed that is absorbed.

However, when determined like this, digestibility coefficient is not really a good expression of the absorbed amount of protein, as the protein discharged in faeces does not alone express undigested protein from the feed. Digestibility enzymes are discharged; cells are rejected and microbial synthesis of amino acids that are excreted in faeces takes place in the small intestine and caecum. The digestibility determined as feed:faeces difference is therefore called apparent digestibility. If N excreted endogenously to the digestive tract is included, it is called true digestibility. In principle, the digestibility of any feed ingredient can be determined like this. Digestibility of protein, fat and carbohydrate is described in later chapters.

6.4.3. Balance trials

The amount of a substance deposited in the body (balance or retention) is determined in balance trials as this is the difference between the feed's content of the substance minus the amount discharged in faeces and urine. For instance protein, for which N is determined in feed, faeces and urine:

NBA = NFE – (NFA + NUR),

where NBA is the N balance, and NFE, NFA and NUR is N in feed, faeces and urine, respectively. The nitrogen balance is expressed in gram.

The protein balance is obtained by multiplying the nitrogen balance by the factor 6.25 as protein contains 16% N on average.

Deposited energy in the body can be determined in a nitrogen and carbon balance. The carbon balance (C balance), which equals carbon deposited in the body, is the difference between C in feed and C in loss from the body:

✍C balance = C in feed – (C in faeces + C in urine + C in CO_2 + C in CH4).

✍C balance is expressed in gram.

C in deposited protein equals deposited g protein multiplied by 0.52 as standard protein contains 52% C. C in N-free material then equals the difference between total amount of deposited C and C deposited in protein. The carbon deposition recorded in N-free material is transformed to calculated fat by multiplying by the factor 1.304 assuming that deposition took place in the form of saturated fatty acids with a carbon content of 76.7%. Energy deposited in fat and in protein is obtained by multiplying the amount of deposited fat and protein by their respective energy values (39.8 kJ per g fat and 23.9 kJ per g protein). Recording of the carbon balance requires recording of carbon dioxide and methane production. Pigs have a low production of methane, and this can be excluded from the calculations, but it is necessary to be able to record the production of carbon dioxide and this requires respiration chambers. N and C balances are therefore often determined in connection with respiration trials.

6.4.4. Respiration trials

In order to obtain a more balanced impression of the quantitative metabolism, balance trials can be combined with recording of air flow in so-called respiration trials conducted in specially built respiration chambers. Respiration chambers are built according to an indirect principle where oxygen intake and carbon dioxide discharge and possibly metane production are recorded while also determining N and C balances. Based on air speed and N discharged in urine, heat production (HE, RQ) is determined according to Brouwer's equation:

HE, RQ, kJ = 16.18 x litre O_2 + 5.02 x litre CO_2 – 5.99 x g N in urine

This is called the RQ method as RQ is the ratio between litre CO_2 excreted and litre O_2 intake.

The production of heat can also be calculated by forming an energy balance in which deposited energy is determined on the basis of carbon and carbon dioxide balances. The production of heat is then expressed as the difference between the energy in the feed and deposited energy – this is called HE,CN. More information on respiration recordings and their application in connection with evaluation of energy in the feed is provided in Chapter 20.

6.4.5. Physiology and microbiology of the digestive tract

At the Faculty of Science and Technology, researchers have for years been investigating the secretion of digestive enzymes from the mucosa of the stomach and from pancreas, and the enzymes in the intestinal mucosa and work during the absorption. These investigations were primarily made on piglets and weaners to understand the changes taking place during and after weaning. The pig's age at weaning is very important, and our understanding has improved of the importance of weaning age and feeding around weaning through a greater insight into the development of the digestive enzymes. Such investigations were made possible through the development of a technique in connection with secretion from pancreas and new analysis methods for determination of amount and activity of enzymes. These investigations and the results are discussed in Chapter 5. For years, scientists at the Faculty of Life Sciences have studied gastrointestinal function in relation to pre- and post-natal development of piglets. The importance of this is discussed in Chapter 6.

The Faculty of Science and Technology has a great deal of experience in examination of the micro flora of the gastrointestinal tract under different feeding conditions. Studies have demonstrated that the micro flora in the stomach and hindgut is highly important for a healthy gastrointestinal environment, which is essential especially after the ban on antibiotic growth promoters. Chapter 7 provides an in-depth description of the determination of the composition of the micro flora and the microbial fermentation of nutrients.

6.4.6. Nutrient uptake in organs and tissue

Scientists at the Faculty of Science and Technology and the Faculty of Life Sciences have for years worked on quantifying nutrient turnover and exploitation in particular in productive tissues, ie. liver, muscle and udder. Besides the studies mentioned on digestibility, balance and respiration, studies have been made with radioactively marked substances such as glucoses and amino acids, and more recently with stable isotopes. Highly complex operation techniques have been developed for introducing catheters in different veins and arteries for recording of arteriovenous difference in, for instance, liver or udder. Differences in substance in the artery and veins are recorded whereby it is possible to record the uptake in the organ. The amount per time unit can be recorded if the blood flow in the organ over time is also recorded. This requires either a catheter technique or the use of a flow cytometer. In sows, it is extremely difficult to record nutrient uptake in the udder as the blood flow of the udder is not as clear as in, for instance, sheep or goats. These investigations are described in Chapters 13, 14 and 17.

Understanding the quantitative nutrient turnover requires insight into the hormonal regulation of this turnover. The regulation of the most important nutrient pools (glucoses, amino acids and fatty acids) has been studied in particular in growing pigs. This is described in Chapter 14.

6.4.7. Nutrigenomics

Pig research has long focused on the correlation between genotype and the feed's effect on growth, metabolism, prevention of disease, fertility and product quality. For both pigs and humans, the concept nutrigenomics can be included in nutrient research. Nutrigenomics includes the entire molecular nutrition research in a systems biological perspective including effect on genes of nutrition/feed and their expression [17]. Systems biology includes biology and new disciplines and tools in biotechnology and gene technology: genomics, genotyping, transciptomics, proteomics and metabolomics and bio informatics. It is expected that mapping of the humane and pig genomes and the establishment of new tools in genetic and biochemical research will increase the understanding of the interaction between nutrition/feed and the genetic constitution. Obtaining new knowledge on this area requires extensive interdisciplinary and inter-institutional as well as international collaboration on apparatus, expertise and results.

6.4.8. The pig as a model animal

Many studies on the physiology of nutrition are so basic and fundamental that they bring new or additional knowledge to basic nutrient research not least concerning the comparative aspects of physiology of nutrition. Rats can also be used as models for pigs, which has been particularly useful concerning digestion, absorption and utilisation of specific nutrient ingredients in studies where it was not possible to produce large amounts of the ingredient. However, pigs are a far better model animal for humans than the rodents commonly used in medical research.

The organ development, physiology and metabolism of pigs are relatively close to those of human beings. A pig with a body weight of 60-70 kg has a heart and circulatory system that in size resemble those of humans. However, one drawback of using production animals is that they grow very fast, which is why long-term studies may be difficult or even impossible to conduct. Instead mini pigs, whose ancestors are Chinese potbellied pigs, are used. A special mini pig, the Göttingen mini pig, has been developed for this purpose and is bred and sold as "Ellegaard Göttingen Mini pig" in Denmark and internationally. This breed is widely used for medical studies.

Model pigs must be particular susceptible to diseases normally only found in humans. Currently, a comprehensive inter-institutional research project lead by PRS involves mini pigs. Several lines of transgene and cloned pigs have been born with genes causing Alzheimer's and arteriosclerosis, and pigs with psoriasis genes are underway [10].

7. Communicating and implementing results from research projects

The overall purpose of research in the physiology of nutrition and feeding trials with pigs is primarily to produce results that immediately or in the long term can be utilised in the production of pigs. The target group for communication and implementation of results from this type of research is therefore authorities, pig producers, pig advisors, teachers, and feedstuff suppliers. In order to stay inspired and maintain a network in the various areas, national as well as international co-operation is necessary.

Danish pig producers are quick to implement new research results. Implementations will often take place on the farms, but may in some cases also take place in the feedstuff industry. Numerous examples demonstrate how the implementation of new research results has resulted quickly in the expected improvements in pig production.

An example of implementation of research results is the project "Optimum feeding of sows". This has been an effort area for approx. 40 years, since 1970. Both at DIAS and PRC, a variety of short-term and long-term trials on optimum feeding of sows has been conducted. The results of these trials were routinely implemented in the production. For the past 40 years, our knowledge on feeding strategies and composition of feed for gestating sows, lactating sows, and empty sows has improved significantly, and it is clear that new knowledge was successfully implemented [18].

The recommendations for optimum feeding of sows as well as weaners and finishers change over time. Recent examples include the regard made to the excretion of nutrients in faeces and urine, and pigs' general health and wellbeing. Pigs' utilisation of particularly N and P in the feed and the feed's satiating effect and influence on pigs' gastrointestinal health are therefore highly relevant criteria when dealing with optimum feeding. Several projects have documented that, for instance, finely ground low-fibre diets may damage pigs' gastrointestinal health, whereas high-fibre diets may enhance satiety and behaviour. These results were quickly implemented by pig producers as well as the feedstuff industry [19], [20].

8. Nutrient research in pigs: the future

Nutrient research in pigs in Denmark is very successful due to a variety factors such as close cooperation between the different players. Nutrient research was previously granted a great deal of financial aids through annual public basic appropriation.

When the Danish Institute of Agricultural Sciences merged with Aarhus University, things changed, and grants are no longer a certain source of income. This makes it difficult to obtain funding for practical trials and for studies of physiology of nutrition with pigs with the aim of improving production. However, it is still possible to apply for and be granted funding for improvement of product quality, environmental improvements and animal welfare. It is also possible to use the pig as a model animal for humane diseases or disorders.

However, there is no doubt that nutrient research in pigs will become an integral part of system biology, and research will therefore still contribute to the development and sustainability of pig production. Generally, the present physical framework and available know-how for these tasks are very good.

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