Director's Digest
FATS AND PROTEINS RESEARCH FOUNDATION, INC.

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STABILITY OF PSEUDORABIES VIRUS (PRV) IN MEAT AND BONE MEAL AND INTERMEDIATE RENDERING PRODUCTS

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Concerns over persistence of PRV in meat and bone meal (MBM) processed from carcasses of swine have been raised. In view of these concerns, a series of experiments was planned and executed to determine whether it was possible for PRV to survive and be isolated from the intermediate products generated by the rigorous processing steps of rendering leading to the finished MBM product, and whether PRV could be isolated from MBM.

Experiment 1. The worst-case scenario

Twenty swine weighing approximately 115 lb (52.3 kg) each were intranasally infected with 2 ml of a virulent strain of PRV which had a titer of $1X10^8$ median cell culture infectious doses ($CCID_{50}$) per milliliter (ml).

On the fifth day post-infection, tonsils and nasal cavities of all swine were swabbed and swabs were placed into transport medium. The 20 swine were euthanized and immediately transported to National By-Products in Des Moines, Iowa where they were processed as a separate lot through the rendering process. The entrance of the 20 swine into the processing sequence was indicated by incorporation of an FDA approved red marker dye. Tissue samples were obtained from the pooled lot of 20 swine at seven collection points along the processing line (Table 1). Twelve samples were collected at each collection point. The sample containers were sterile, 4-oz glass bottles with screw caps.

A single lot of cattle was sent through the rendering process immediately following the lot of PRV-infected swine. Six samples were collected at the same seven collection points, and six samples were collected at each point.

All samples were chilled with ice packs during the 30-mile trip from Des Moines to the College of Veterinary Medicine in Ames, Iowa.

The eluates from tonsil and nasal swabs from swine infected with virulent PRV were inoculated into cell cultures of swine and bovine kidney cells.[1] Results obtained from these tests indicated that swine sent to the rendering plant were heavily infected with PRV.

Swine and cattle tissues collected at the seven collection points were made into 10% suspensions (w/v) using a special blender.[a] Supernates from the suspensions were inoculated into swine and bovine kidney cell cultures and observed daily for evidence of cytopathic effects (CPE) typical of PRV. Aliquots of all supernates were frozen at minus 80°C.

The results of culturing swine tissues are presented in Table I. No PRV was isolated from the swine tissues using cell culture methods. Likewise, PRV was not isolated from cattle tissues.

Because swine tissue preparations from collection points 1 and 2 were toxic for cell cultures, supernatant fluids from collection points 1, 2, and 3 were thawed from storage at minus 80°C and three inoculum pools were made from samples 1, 3, 5, 7, 9, and 11 from the three collection points. Three groups of ten Balb C mice each were inoculated intraperitoneally with 0.5 ml of each of the three inoculum pools and observed daily for 12 days. All of the 30 mice remained healthy during the observation period.

There are several reasons why PRV was not isolated from PRV-infected swine tissues in this worst-case scenario.

In adult swine, pseudorabies mainly involves the respiratory and central nervous system tissues,[2] a relatively small fraction of the total body weight. It is estimated that dilution alone reduced virus-laden tissues at least 10^{-3} or 10^{-4}. Therefore, dilution was a very important factor in lessening chances of PRV isolation.

The pH of samples of the first three collection points were 6.3 for point 1 (metal detection belt), 6.31 for point 2 (hasher), and 6.96 for point 3 (press). Exposure of PRV to the relatively acid environments from points 1 and 2 were not compatible with optimal conditions for PRV survival.

Samples from collection points 1 and 2 were toxic for cell cultures, and PRV was not isolated in mice from pools of thawed supernates from these sampling points, nor from point 3. It appears very likely that cellular damage caused by the initial steps of the rendering process artificially released autolytic products and enzymes responsible for observed toxic effects on cell cultures. These same substances might also have had toxic and inactivating effects on the virus particles of PRV. The inactivating effect might also account for negative results for isolation of PRV from collection point 3 tissues which were not toxic for cell cultures, but which had a pH value (6.96) closer to neutrality.

The inactivating effects on PRV would also explain why mice did not become infected with PRV from the three inoculum pools.

Experiment 2. Recovery of PRV from experimentally contaminated intermediate rendering products

Because PRV was not isolated from any of the samples from PRV-infected swine in experiment 1, and because toxicity for cell cultures was encountered with samples from collection points 1 and 2, random samples were obtained from collection points 1, 2, and 3 which represented the real-world scenario.

Six 5-gram samples were weighted from tissues from each of the three collection points. A seventh 5-gram sample served as a non-virus contaminated control.

The six 5-gram samples were contaminated with 4.0 ml of PR dilutions of stock virus (titer: 2×10^8 $CCID_{50}$/ml) ranging from 10^{-1} through 10^{-6}, respectively. The tissue virus suspensions and controls were made into 10% suspensions using a blade-type blender.[b] Supernatant fluids from the PRV-contaminated and control tissues and virus dilutions alone were inoculated onto swine and bovine kidney cell culture monolayers and observed daily.

[a]Stomacher Lab-Blender 80, Seward Medical, London, England.

[b]Waring commercial blender, Waring Products Division, Dynamics Corporation of America, New Hartford, CT 06057.

The results of culturing experimentally PRV-contaminated tissues, tissues alone, and virus dilutions alone, are presented in Table 2. Tissues from collection points 1 (metal detection belt) and 2 (hasher) were both toxic for cell cultures either alone or with PRV added to the tissues. However, there were many intact cells in monolayers at 24 hours in the case of sample 3, but no PRV CPE was observed when there was marked PRV CPE in cultures of PRV alone (sample 7). It thus appeared that the effects of toxicity were present at 24 hours even though the effects were not clearly evident. The emerging toxicity was quite likely viricidal to all dilutions of PRV even before toxicity was observed microscopically. The cytopathic effects of PRV were evident in supernates of PRV contaminated tissues from collection point 3 (press). This result was not unexpected since the pH of tissue from this collection point was 6.96 and had earlier been shown not to be toxic for cell cultures (Table 1). The results of this experiment demonstrate however that PRV would not have survived through collection points 1 and 2 to later be isolated from tissues from collection point 3.

Experiment 3. The effect of heat on PRV during the rendering process

- During the various steps leading to the production of MBM, the material entering the plate contact dryer is subjected to gradually increasing levels of heat ranging from 165°F (73.9°C) to an exiting temperature of 233.6°F (112°C).

Five milliliter aliquots of undiluted PRV ($2x10^8$ $CCID_{50}$/ml) in cell culture fluid were subjected to the above two temperatures in 10-minute increments, ranging from 0 to 60 minutes. The heated virus fluids were inoculated onto cell culture monolayers and observed daily for three days for evidence of CPE. The only cultures showing evidence of CPE were the unheated samples (0-time). PRV was thus inactivated at both temperatures during the first 10 minutes of heating.

Experiment 4. The effect of moisture and heat on PRV-contaminated MBM

It is well established that most all materials will be more effectively sterilized by heat if moisture is present than if dry.

The material entering the plate contact dryer contains 50% moisture.[3]

In cooperation with Kent Zimmermann in the laboratory of the National By-Products in Des Moines, Iowa, it was determined by instrumentation[C] how much liquid (pH 7.0 buffered 0.9 M NaCl) must be added to a known weight of dried MBM to endow MBM with 50% moisture—the moisture equivalent of material entering the plate contact dryer in the actual operation.

Using calculations from the above model, 5 ml of PRV ($2x10^5$ $CCID_{50}$/ml) were added to five 5-gm aliquots of MBM and the PRV-MBM mixtures were heated at 165° F (73.9°C) for 0, 10, 20, 40, and 60 minutes. Five milliliter volumes of the same concentration of PRV without MBM were heated for the same time intervals. Ten percent suspensions of all samples and controls were made in sterile buffered NaCl (5gm or 5-ml plus 45 ml buffer). Supernates were inoculated onto cell culture monolayers and observed daily for three days for CPE.

Virus CPE was observed only in the O-time MBM-PRV and control samples.

It was concluded that 165°F (73.9°C) was effective in completely inactivating $2x10^5$ $CCID_{50}$ of PRV in as little as 10 minutes when MBM contained 50% moisture when heated.

Any PRV that survived processing steps prior to entrance into the dryer would be inactivated during drying.

Experiment 5. Survival of PRV in MBM at room temperature.

MBM is generally stored at ambient temperature in a dry environment.

An experiment was done to determine whether PRV could be recovered from experimentally contaminated MBM after short storage at 77°F (25°C, room temperature).

A PRV preparation with a titer of $1X10^8$ $CCID_{50}$/ml was diluted to 10^{-1}, 10^{-3}, and 10^{-6}, and 1.0 ml volumes of the three virus dilutions were added in triplicate to 5-gm aliquots of MBM. One-milliliter volumes of virus dilutions were added in triplicate tubes and served as virus controls. The MBM and added virus were thoroughly mixed and one tube each of the MBM-virus dilution mixtures and controls were immediately placed at minus 80°C (0 day). On days 4 and 8 additional MBM-virus dilution mixtures and controls were placed at minus 80°C. On day 10, all tubes were removed from minus 80° C, made up to 50 ml with sterile diluent, centrifuged and supernates were inoculated in quadruplicate onto monolayers of swine kidney cell cultures and observed daily for CPE. The results of this experiment are presented in Table 3.

It is obvious from this experiment that PRV added to MBM was reduced to undetectable levels within four days, even in the 10^{-1} dilution, whereas PRV was detectable in the 10^{-1} dilutions of the virus control after both 4 and 8 days at room temperature. The viability of PRV is adversely affected by drying and it appears that the relatively high input PRV in the 10^{-1} dilution of the stock virus in this experiment was rapidly dehydrated and thus inactivated.

Experiment 6. Surveillance of MBM for presence of PRV

Twelve different lot numbers of the finished product of MBM produced during a 3-month period were tested for the presence of PRV. The samples of the completed milled MBM were delivered to the testing laboratory at Iowa State University within three hours of final milling. A weighed amount of each MBM lot was made into a 10% suspension (w/v) by blending (with minimal warming), followed by centrifugation. Supernatant fluids were inoculated into eight replicate swine kidney cell cultures and observed at daily intervals for evidence of CPE during a 4-day period.

No evidence of CPE due to PRV nor toxicity to the cell monolayers was observed.

CONCLUSION

From the results obtained in the worst-case scenario (Experiment 1) through the monitoring of the final MBM product (Experiment 6) it is concluded that there is little or no possibility that PRV can survive the rigorous processing steps leading to the production of MBM. Reported by E. C. Pirtle, Ph.D., Research Virologist.

[c]CSC moisture balance, Cat. No. 26680, Central Scientific Co., Inc., Fairfax, VA 22301.

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ACKNOWLEDGMENTS

The expert technical assistance of Ms. D. Murphy was greatly appreciated.

ADDENDUM

In connection with a study in food safety, dilution of PRV-laden swine tissues with noninfected swine tissues will be appraised for effects on titer of PRV in infected swine tissues. This information will be forwarded when available with no additional charge.

Table 1. Results of culturing swine tissue samples in cell cultures (the worst-case scenario).

	Observation in:	
Collection Point	Cell culture	Mice*
1. Metal detection belt	Inocula toxic for cell cultures	0/10
2. Hasher	Inocula toxic for cell cultures	0/10
3. Press	No cytopathic effects	0/10
4. Scraper tank	No cytopathic effects	
5. Dryer	No cytopathic effects	
6. Fat	No cytopathic effects	
7. Stick-water	No cytopathic effects	

*Number of mice dead over number of mice inoculated.

Table 2. Results in cell culture of culturing experimentally PRV-contaminated tissues, virus dilutions alone, and control tissues alone.

	Observation in PRV dilution:					
Sample	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
1. Collection point 1 Tissue + PRV	TFC[a]	TFC	TFC	TFC	TFC	TFC
2. Collection point 1 Tissue alone	TFC	TFC	TFC	TFC	TFC	TFC
3. Collection point 2 Tissue + PRV	NCPE[b]	NCPE	NCPE	NCPE	NCPE	NCPE
4. Collection point 2 Tissue alone	TFC	TFC	TFC	TFC	TFC	TFC
5. Collection point 3 Tissue + PRV	4/4[c]	4/4	4/4	4/4	4/4	0/4
6. Collection point 3 Tissue alone	NCPE	NCPE	NCPE	NCPE	NCPE	NCPE
7. PRV alone	4/4	4/4	4/4	4/4	4/4	4/4

[a]Toxic for cell cultures, 24 and 48 hr readings.
[b]No cytopathic effects, 24 hr (3.) and 48 hr (6.) readings.
[c]Number of cell cultures with CPE over number of cell cultures inoculated.

Table 3. Survival of pseudorabies (PRV) in meat and bone meal (MBM) after storage at 77°F (25°C, room temperature).

Sample	Virus dilution	Cytopathic effect	
		Control	MBM+PRV
Day 0	10^{-1}	4/4*	4/4
	10^{-3}	4/4	4/4
	10^{-6}	0/4	0/4
Day 4	10^{-1}	4/4	0/4
	1 0^{-3}	0/4	0/4
	10^{-6}	0/4	0/4
Day 8	10^{-1}	4/4	0/4
	10^{-3}	0/4	0/4
	10^{-6}	0/4	0/4

*Number of cultures having CPE over number of cultures inoculated.

Project: Supported by the Fats and Proteins Research Foundation, Inc.

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Swine Nutrition Today and in the Next Century[1]

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Gazing into a crystal ball and predicting what lies ahead in the field of swine nutrition in the next century is a difficult task. Many changes have taken place in the nutrition and feeding of pigs during the past 50 years. Wouldn't it be interesting to go back in time to 1947 and listen to a swine nutritionist, speaking at a meeting such as this, attempting to predict what might transpire in swine nutrition in the next 50 years (to 1997)?

That person would not be aware of the discovery of vitamin B_{12} in 1948 that completely revolutionized the way we now feed pigs, using simplified corn-soybean meal diets supplemented with vitamin-mineral premixes. The discovery of broad spectrum antibiotics in 1949 and the rapid adoption of their use in swine diets probably would not have been foreseen. The rapid move toward confinement rearing of pigs, partially because of these two discoveries, was a major trend that occurred during this time period. The discovery of mutant genes, such as the *opaque-2* gene in corn, that resulted in dramatic improvements in the quality of cereal protein would not have been predicted. The techniques of *in vitro* fertilization, freezing and transferring of embryos, and similar technologies would have bordered on science fiction. The recent developments in biotechnology that now give opportunity for the use of porcine somatotropin, new vaccines, and other genetically engineered products would not have been foretold.

Many unforeseen changes, brought about by new scientific discoveries, are likely to occur in the next 50 years. No one has the ability to foresee these new discoveries nor the significance of their application. So we are forced to anticipate and predict changes that may happen in the next century based on trends that are presently occurring and on the science and technology that we understand today.

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[1]*Presented at seminars in Merida, Mexico City, and Hermosillo, Mexico on June 17-19, 1997.*

Current Trends in Swine Production

A number of changes are presently occurring in the swine industry, and these trends will most likely impact how pigs are fed in the 21st century. A major trend in the swine industry is the move toward very large farm units. Over the past 50 years, the number of hog farms in the USA has decreased while the average size of these farms has increased dramatically (Tables 1 and 2). Along with this trend is the rapid movement of large corporate farms into the hog business. According to a recent survey (Freese, 1994), the 10 largest pork producers in the USA (all are corporate farms) own approximately 870,000 sows and produce between 8 and 10% of the hogs marketed annually. Two of these farms produce between two and three million pigs annually. Many of these large integrators have one or more PhD nutritionists on their staff, produce their own feed, and slaughter and process their hogs at their own packing plants.

Multiple-site production (often called off-site production) is rapidly becoming popular, particularly in the large corporate farms. The separation of weaned pigs from the farrowing environment and the subsequent separation of finishing pigs from the nursery environment is an effective means of reducing disease transmission and maintaining a high level of health. Additionally, very early weaning has become popular. Weaning pigs at 11 to 17 days of age reduces the chance of disease transmission from the sow to the pigs and prevents activation of the pig's immune system. These management procedures have a major impact on the nutrition of both the pigs and the sow.

The increased popularity of pig breeding companies also has had a major impact on swine production. Identification of outstanding genetic lines and infusion of superior genetics into pigs has resulted in very lean pigs with rapid growth rates. Also, lines of genetically superior sows that are capable of producing high milk yields and rearing large litters of pigs are becoming more common. Pigs with high lean growth rates and sows nursing large litters of rapidly growing pigs have different nutritional needs than ordinary pigs and sows.

Other changes in the swine industry, such as improved management, housing, and disease control, also have had an impact on swine nutrition programs.

Swine Nutrition in the Next Century

As indicated previously, anticipated changes in the nutrition of pigs can best be predicted from current trends. Some of these trends and anticipated changes are addressed in this section.

Tailoring nutrition to specific needs

In the past, estimates of nutrient requirements by the National Research Council (NRC, 1988) and recommended nutrient allowances by university and feed industry nutritionists were based largely on the body weight (or stage of growth) of the pig. Rate and efficiency of growth and leanness of the carcass were essentially ignored in estimating requirements. The old system of uniform nutrient recommendations for all pigs is no longer adequate or appropriate. Pigs differ in their growth rate and carcass

leanness. As a result, the rate at which they deposit carcass muscle and fat differs among genetic lines.

Genetics. Research conducted at our station clearly illustrates differences that exist in the pig population in terms of lean growth rate (Stahly et al., 1991; Table 3). Lean growth curves have recently been described by Schinckel (1994) and coworkers at Purdue University for different genetic lines of pigs. An example is shown in Figure 1. Their work shows that carcass lean growth rate (or whole body protein accretion rate) accelerates during the growing stage to a body weight of 40 to 70 kilograms, then decreases during the late finishing stage. Since lean tissue consists mainly of protein, pigs having a high rate of lean tissue deposition will require greater amounts of dietary protein (i.e., amino acids) than those of a lower lean tissue deposition rate.

Already, many nutritionists are recommending higher levels of dietary amino acids for high lean growth pigs. It is anticipated that the swine industry will eventually move completely in this direction, with a producer's feeding program being tailored to the genetic potential of the pigs.

Gender. Recent studies have clearly shown that gilts require higher levels of dietary protein and amino acids than barrows during the finishing stage in order to maximize performance and carcass leanness (Cromwell et al., 1993a; Figure 2). The reason, again, is largely due to the slightly higher lean growth rate of gilts coupled with a lower feed intake. Many producers already are separating the sexes and feeding them different diets. It is anticipated that this practice will continue to gain popularity in the future.

Health status. Recent studies at Iowa State (Williams et al., 1993) have demonstrated that pigs raised under extremely clean conditions, where their immune system is not activated, have an exceptionally high ability to grow rapidly and efficiently. As a result, their nutrient requirements are higher than normal in order to support the increased growth rate. Nutritional adjustments will need to be made in the future as more pigs are raised under these conditions of high herd health.

Environment. Studies at our station have shown that environmental temperature affects pig performance (Stahly and Cromwell, 1979, 1986). High temperatures are associated with reduced feed intake and low temperatures are associated with increased feed intake. Ultimately, concentrations of amino acids and probably other nutrients need to be adjusted in order to insure adequate daily intakes of nutrients at given environmental temperatures. In addition, certain nutrients are more efficiently utilized under certain environmental conditions. For example, fat calories are utilized more efficiently when pigs are in a hot environment as compared with a cold environment. In contrast, diets that are high in fiber are utilized better in a cold versus hot environment. Some feed companies are adjusting their diet formulas depending on the season of the year, temperature of buildings, and geographic location. More of this type of diet modification will likely occur in the future as more knowledge is achieved in this area and as producers gain the ability to more accurately

define their environmental conditions.

Carcass modifiers. Several agents have been identified in the past 10 years that have a dramatic effect on growth rate and carcass leanness of pigs. An example is porcine somatotropin, which markedly increases lean growth rate and reduces feed intake (Table 4). Another example is ractopamine, a beta-agonist, which affects pigs in a similar manner (Table 5). Other compounds, although less extensively tested, seem to have a positive effect on carcass leanness. These include chromium picolinate, betaine, and carnitine. Because of the profound increase in lean growth rate, which is accompanied by a decrease in feed intake, it is imperative that higher levels of amino acids be included in the diet for pigs to respond to these metabolic modifiers (Anderson et al., 1987; Goodband et al., 1990). The same can be said for calcium and phosphorus (Carter and Cromwell, 1993), and probably other nutrients as well. Should these compounds be approved by the Food and Drug Administration, nutritional programs will need to change dramatically in the future.

Sow prolificacy. Genetic improvements in sow lines and enhanced breeding systems have resulted in greater prolificacy in sow herds. The top producers are now getting 20 to 25 pigs annually per sow in the breeding herd (compared with 12 to 15 pigs per sow per year a few years ago). This improved productivity results from larger litters farrowed and weaned, increased milk production, earlier weaning, and earlier rebreeding of the sow after farrowing.

The standard nutrient recommendations for nursing sows are no longer adequate for modern sows nursing large litters. Recent studies at our station (Stahly et al., 1990, 1992; Monegue et al., 1993) indicate that dietary lysine must be increased by 25 to 50% above NRC (1988) standards to maximize milk production and litter weight gain, and to minimize sow weight loss during lactation (Table 6). In the future, lactating sows will be fed according to their level of productivity, with nutrient adjustments made for those that are exceptionally prolific.

Diet formulation

Diet formulation will likely change in the next century. Some of this is already taking place, and more will occur in the future. Examples are as follows:

Amino acid basis. In the past, pig diets were formulated on a crude protein basis. This system is still being used to a limited extent. The crude protein system is not really all that bad if corn and soybean meal are the only ingredients. But this system is unacceptable when other ingredients are included in pig diets. A much better system is to formulate diets on a lysine basis. Much of the feed industry is currently using this system. Ordinarily (but not always) the other essential amino acids can be ignored, because lysine will generally be the first limiting amino acid in most practical diets for swine.

A recent trend that is gaining acceptance is to formulate diets on an "ideal protein" basis. This system is based on attempting to ratio the other amino acids to lysine in the same proportion as the amino acids in pork muscle tissue. This system seems to work quite well for growing pigs, but adjustments are needed for finishing pigs, developing boars and gilts, and mature sows to account for a different pattern of amino acids required for maintenance and for milk production in nursing sows. An example of amino acid ratios for three weight classes of growing pigs is shown in Table 7. It is very likely that the feed industry will accept this practice as more information becomes available relative to ideal ratios of amino acids needed at various stages of growth, for gestating sows, and for sows producing varying amounts of milk.

Ultimately, diets in the 21th century will be formulated on an available amino acid basis. This system will take into account differences in biological availability of amino acids, based on the apparent or true ileal digestibility of amino acids, in various feed ingredients. In some instances, this system is currently being implemented, but greater usage is anticipated in the future as more information on feed ingredients becomes available.

Supplemental amino acids. A few years ago, lysine was the only amino acid that was economically feasible to include in pig diets. Today, because of developments in fermentation procedures and increased competition, lysine is inexpensive and is commonly used in pig diets.

Tryptophan, threonine, and methionine are the next limiting amino acids in most pig diets. Methionine is inexpensive and widely used in poultry diets, but it has less value in pig diets because tryptophan and threonine are generally more limiting. Recombinant DNA technology has allowed for the production of tryptophan and threonine at much lower costs than previously, and it is likely that these three amino acids will be available and routinely used in pig diets in the future. One of the major advantages of using amino acid supplements is that the crude protein content of the diet is markedly reduced and less nitrogen is excreted into the environment (Cromwell and Coffey, 1991; Pierce et al., 1994; Carter et al., 1996).

Net energy system. Nutritionists generally express the energy needs of animals and the energy content of feed ingredients on the basis of digestible energy or metabolizable energy. An even better system is the net energy system because it accounts for the actual energy that is derived from feed ingredients. However, due to the lack of data on the net energy content of feedstuffs, this system is not generally used. As more data become available, the net energy system will gain popularity in the next century.

Diets that alter body composition. Consumer attitudes regarding diet-health issues will continue to put more pressure on the swine industry to produce leaner pork. Meat packers will pay greater premiums for lean carcasses and discriminate more severely against fat ones. However, pork can become so lean that tenderness,

juiciness, and palatability are negatively affected. In the future, there will likely be increased emphasis on nutrition and feeding systems that enhance carcass leanness while maintaining desirable eating quality of pork. There could be increased usage of specific fatty acids (such as the omega-3 fatty acids) in diets to achieve an end product that more closely meets consumer demands.

Bioavailable nutrients

As previously indicated, pig diets are generally formulated on a "total nutrient" basis. As more information becomes available, there will likely be a shift toward formulating diets on a "bioavailable nutrient" basis, such as is being done with respect to amino acids in some instances.

The nutrient that has been researched most in recent years, relative to its bioavailability, is phosphorus. Much of the phosphorus in cereal grains and oilseed meals is in the form of phytate and is poorly available to pigs (Cromwell, 1992). For example, the total phosphorus in corn is only about 12% available to pigs. In certain other grains, the phosphorus is considerably more available. For example, the phosphorus in barley, wheat, and triticale is 30 to 50% available. A wide variation in availability of phosphorus exists for other feed ingredients. For example, in oilseed meals, phosphorus availability ranges from near 0 in cottonseed meal and sunflower meal to 25-30% in soybean meal; in animal protein sources, it ranges from 30% in feather meal, to 65-80% in meat meal, and to 90-95% in milk protein sources. In inorganic phosphorus sources, it ranges from 82% in steamed bone meal to 100% in mono- or dicalcium phosphate.

Until recently, pig diets were formulated on a total phosphorus basis. However, most feed companies are now formulating diets on an available phosphorus basis. This system better insures that the phosphorus requirement of pigs will be met while reducing the possibility of over-supplementing the diet with P. It is anticipated that more feed will be formulated on an available nutrient basis as more reliable estimates on the bioavailability of nutrients in feed ingredients is obtained.

Environmentally friendly diets

One of the biggest challenges currently facing the animal industries involves the problem of odor and potential environmental pollution from manure. Most of the concern has focused on nitrogen and phosphorus as potential contaminants. Future concern will probably also encompass trace minerals and perhaps other nutrients. Swine contribute significantly to this perceived problem because pig diets are relatively high in protein (nitrogen), phosphorus, copper, zinc, and other minerals. The current trend of feeding high protein diets further contributes to the problem of nitrogen pollution.

Until recently, diets were often formulated with relatively large excesses of nutrients with little attention being paid to the excretion patterns of non-utilized

nutrients. That practice is changing and will continue to change in the future. More attention will be placed on feeding diets with minimal nutrient excesses. Possible legislation that will limit the amounts of nitrogen, phosphorus, and other nutrients that can be disposed of by land application in certain geographical areas will necessitate the feeding of low protein, amino acid supplemented diets. Phytase (Natuphos®) has now been approved for use in the USA and routine use of this enzyme in pig diets is anticipated, especially in areas were hogs are concentrated and land area for manure disposal is minimal. This enzyme improves the utilization of the phytate phosphorus in grains and oilseed meals (Cromwell et al., 1993b), and thus, reduces phosphorus excretion (Pierce et al., 1994; Carter et al., 1996). More attention will likely be placed on using highly available minerals sources in supplements to reduce mineral excretion.

Models

Increased use of models in developing nutritional programs for pigs is anticipated. Models were used to develop the nutrient standards in the National Research Council's *Nutrient Requirements of Beef Cattle* published in 1996. The Swine Nutrition Subcommittee of the National Research Council has developed models to estimate energy and amino acid requirements of growing-finishing pigs and gestating and lactating sows. This new publication is scheduled for release in early 1998.

The advantage of using a modelling approach is that nutrient needs can be tied to a number of biological factors, such as animal weight, lean growth rate, level of milk production, gender, etc. Commercial models are currently being used by the feed industry to project nutrient recommendations for animals under various environmental conditions. It is anticipated that this trend will continue.

Genetically modified cereals and protein sources

Until recently, plant breeders have paid little attention to the chemical or nutritional aspects of cereal grains, soybeans, and other plants. Most of their emphasis was placed on agronomic characteristics, such as yield, disease resistance, lodging characteristics, etc. That trend is changing. At least one major seed company has initiated an extensive breeding program to develop corn lines that are high in energy, high in lysine and other essential amino acids, and with other traits that have nutritional implications. Research is in progress to biologically engineer the soybean plant to increase the methionine content of soybeans. A mutant gene has been identified that restricts the production of phytate phosphorus in corn and replaces it with inorganic phosphorus. Other exciting genetic changes in plants and plant products undoubtedly lie over the horizon.

Alternative feed ingredients

Corn and soybean meal are still the major ingredients that are used in pig diets. While this probably will not change significantly in the next century, there are times

and conditions when alternative sources of energy and protein are economical to feed to pigs. An example is the increased amounts of meat and bone meal that will likely be available for usage in swine and poultry feeds due to the recent Food and Drug Administration (FDA) restriction of feeding meat by-products to ruminants because of the BSE (mad cow) scare in Great Britain. High quality meat meal or meat and bone meal can successfully be used in swine diets, especially when small amounts of tryptophan also are included.

Novel feed ingredients

Specialized ingredients continue to be developed that make significant contributions to swine nutrition. Several years ago, spray-dried porcine plasma was found to have superior nutritional properties when included in Phase I starter diets for pigs weaned at 1½ to 2½ weeks of age. This product essentially eliminates the postweaning growth check that was once common in early weaned pigs. Today, dried porcine or bovine plasma is routinely used in Phase I diets and allows producers to wean pigs at a very early age.

Spray-dried blood cells, another relatively new feed ingredient, is now commonly used at low levels (2-3%) in Phase II starter diets. It also has excellent nutritional properties. Hydrolyzed animal protein such as Perfect Pro® (Griffin Industries) has recently been developed and has many of the same properties as plasma protein (Lindemann et al., 1996). Products such as this should have widespread usefulness in pig starter diets.

Feed additives

New feed additives will likely be introduced to the swine industry in the future, but their appearance will be at a slower rate than in the past because of the high cost of developing new drugs and the intense scrutiny of the FDA. There has been recent interest in certain oligosaccharides that appear to improve performance of young pigs and alter odor production in the manure. Other feed additives products, such as sarsaponin (from the yucca plant), and products containing mixtures of microbials and enzymes have generated interest because of claims that they will reduce odor in pig manure. Specific enzymes designed to improve digestibility of complex proteins seem to be gaining attention. Other new additives such as these are likely to emerge in the next century.

Summary

Pork will continue to be an important source of protein and energy for the world's population in the next century. The production of pigs for pork will continue to become more specialized. A sound nutrition program will continue to be an important element in a successful pig production system. As new discoveries are made in the next century, pork producers will implement those that improve their production efficiency and enhance the quality of the pork.

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Table 1. Changes in the Swine Industry from 1920 to 1992

	1920	1992
No. farms	5,218,000	2,068,000
No. farms with hogs	4,852,000	253,000
Farms with hogs, % of total	93	12
Avg no. hogs/farm (inventory)	10	215

USDA Statistics

Table 2. Demographics of Swine Production, 1992

Inventory (no. head/farm)	Hog Farms %	Hogs Produced %
1-99	62.0	5.5
100-499	26.0	25.5
500-999	7.3	22.0
1,000+	4.7	47.0

USDA Statistics

Table 3. Differences Among Pig Genotypes

Lean gain genotype:	High	Medium	Low
Daily gain, kg	.91	.89	.82
Feed/gain	2.94	3.10	3.59
Backfat, mm	26.4	30.2	45.4
Loin eye, cm^2	37.8	35.3	28.1
Lean gain, kg/day	.37	.35	.27

Stahly et al. (1991). Each mean represents 90 pigs from five sources, 22-109 kg.

Table 4. Porcine Somatotropin for Finishing Pigs

	Control	pST
Daily gain, kg	.84	.94
Feed/gain	3.31	2.77
Backfat, mm	25.4	17.5
Loin eye, cm^2	29.4	34.7
Carcass lean, %	53.0	57.0

Cromwell (1991). Summary of 7 experiments, 412 pigs, 51-96 kg. Daily pST injections were 3 to 120 μg/kg body weight.

Table 5. Ractopamine for Finishing Pigs

	Control	Ractopamine
Daily gain, kg	.79	.85
Feed/gain	2.95	2.73
Backfat, mm	25.1	22.4
Loin eye, cm^2	33.5	37.3
Carcass lean, %	51.7	54.6

Cromwell (1991). Summary of 6 experiments, 1,383 pigs, 65-104 kg. Ractopamine levels were 2.5 to 30 mg/kg of diet.

Table 6. Dietary Lysine Levels for Prolific Sows

Dietary lysine, %	.60	.75	.90
Dietary protein, %	13.0	15.0	17.0
Postfarrowing weight, kg	204	203	198
Daily feed intake, kg	5.8	6.0	6.1
Daily lysine intake, g	35	45	55
At birth			
No. pigs	12.4	12.1	12.0
Avg weight, kg	1.29	1.37	1.33
At weaning (28 days)			
No. pigs	11.2	11.1	11.1
Avg weight, kg	6.5	7.0	7.2
Litter weight, kg	73.2	77.6	80.1
Sow weight change, farrowing to weaning, kg	-6.6	-1.9	3.6
Milk production, kg/day	9.0	10.3	9.9
Milk protein, %	5.2	5.3	5.6

Monegue et al. (1993). 25 sows per treatment. The .60% lysine diet corresponds to the NRC (1988) estimate of the lysine requirement for lactating sows.

Table 7. Ideal Pattern of Essential Amino Acids for Growing Pigs

Weight range:	5-20 kg	20-50 kg	50-100 kg
	Ideal Pattern of Amino Acids (% of Lysine)		
Lysine	100	100	100
Arginine	42	36	30
Histidine	32	32	32
Tryptophan	18	19	20
Isoleucine	60	60	60
Leucine	100	100	100
Valine	68	68	68
Phenylalanine + Tyrosine	95	95	95
Methionine + Cystine	60	65	70
Threonine	65	67	70

Baker and Chung (1992).