Midwest Swine Nutrition Conference Proceedings

Indianapolis, Indiana — September 5, 2001

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PURDUE UNIVERSITY

THE OHIO STATE UNIVERSITY

MICHIGAN STATE UNIVERSITY
FOUNDED 1855

UK

The following organizations have contributed financial support to the Midwest Swine Nutrition Conference

Akey, Inc.
Alltech, Inc.
Elanco Products, Inc.
Hubbard Feeds, Inc.
Purina Mills, Inc.
United Feeds, Inc.

▼ Table of contents

▶ Organic selenium for swine and implications for improving human health

Don Mahan, Professor, Animal Sciences
Ohio State University, Columbus, OH 43210

Summary

Organic selenium (Se) is indigenous in the grains fed to swine, but in many areas of the United States the grains and forages contain low Se levels, requiring Se supplementation to swine diets. Although FDA has approved incorporating sodium selenite or selenate to livestock feeds, the Se/vitamin E deficiency is still reported in the Midwest. Organic Se is an alternative source of Se and is available in several forms, but Se-enriched yeast is the form where most of the research has been conducted.

Organic Se has shown several advantages when fed to swine. Organic Se whensupplemented at 0.30 ppm Se results in: 1) a higher placental transfer of Se to the developing fetus, 2) a higher mammary transfer of Se to colostrum and milk, 3) increased pork muscle Se content, and 4) higher pork quality [lower drip loss, and reduced paleness of pork muscle] compated to inorganic Se.

Immunological responses of animals seem to be increased with dietary levels of inorganic Se and vitamin E that are provided above the animals requirement. Immunological studies of swine fed organic Se are lacking.

Contrary to early reports, Se has been shown to reduce the rate of cancer in humans, probably acting as a preventative rather than as a cure. Other health benefits result from supplemental Se, but the required daily intake is not well defined. The added value of the higher Se content in pork when swine have been fed organic Se has potential promise for the pork industry.

Introduction

Inorganic selenium (Se) currently is approved in the United States and can be added to livestock diets as sodium selenite or sodium selenate but not to exceed a supplemental level of 0.30 ppm Se (FDA, 1974, 1987). Field conditions of mulberry heart disease and sudden deaths of pigs are frequently reported signs on many swine farms that have been associated with the Se and vitamin E deficiency. These deficiency signs have continued even though inorganic Se has been approved by the FDA. This suggests that the dietary level of either Se or vitamin E may be inadequate or their utilization may be poor. The supplementation of swine diets with higher than approved levels of either nutrient has not completely prevented the problem, suggesting other factors may be involved in causing the problem.

There has been increasing interest in other forms of Se compounds, namely organic Se, in an attempt to prevent the continued onset of the deficiency. Supplemental organic forms of Se, other than grain sources, are not currently approved in the United States, but the approval is pending on at least some products. Organic Se is in wide use in many countries including Canada. The questions that arise from feeding organic Se are: 1) How does the body use organic Se compared with the inorganic form, 2) Is the organic product more effective with swine and if so how does it work, and 3) Will the added cost justify its use with pigs and could it possibly improve human health?

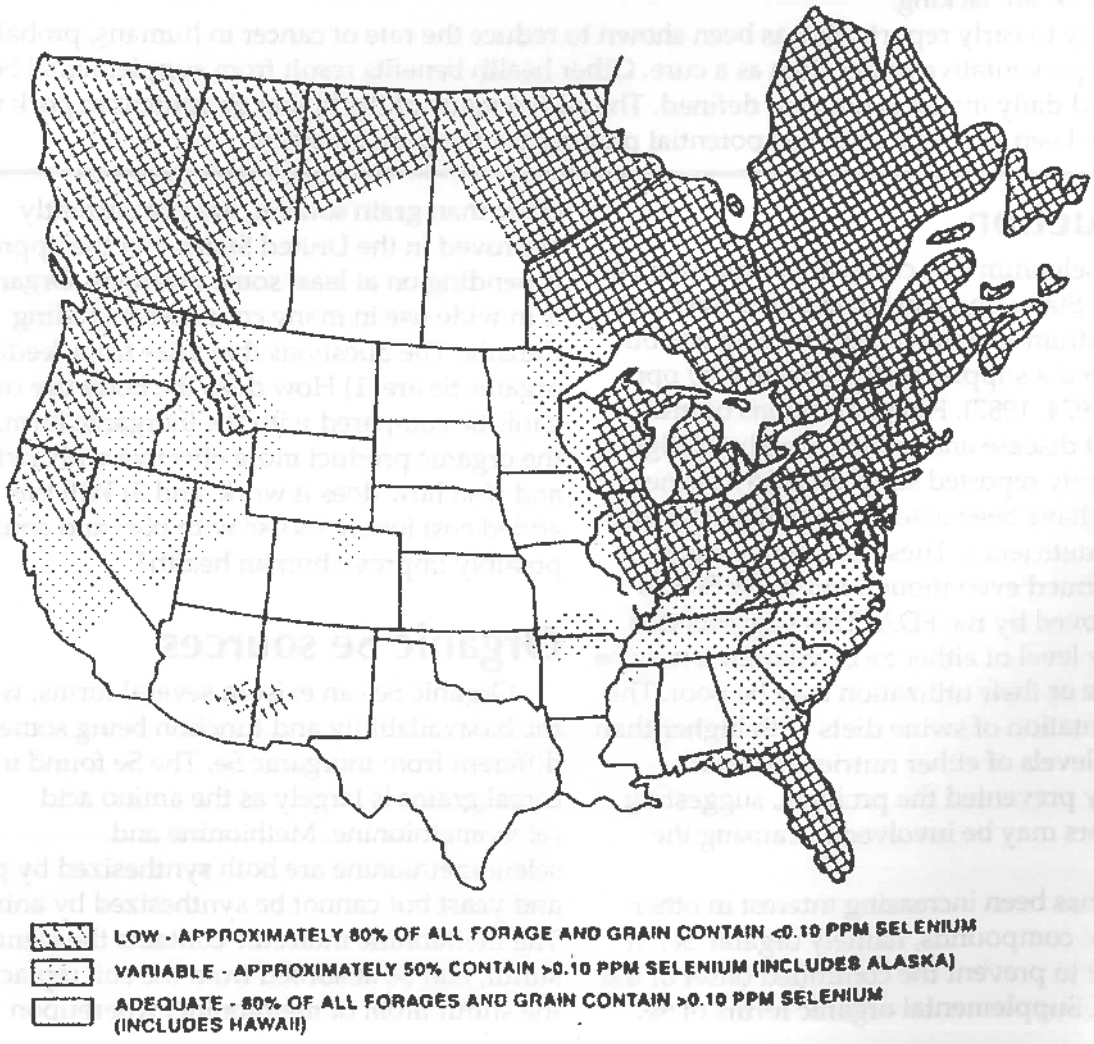
Organic Se sources

Organic Se can exist in several forms, with the bioavailability and function being somewhat different from inorganic Se. The Se found in cereal grains is largely as the amino acid selenomethionine. Methionine and selenomethionine are both synthesized by plants and yeast but cannot be synthesized by animals. The methionine molecule contains the element sulfur, and Se absorbed from the soil replaces the sulfur atom of methionine, whereupon it

forms selenomethionine. Plants do not require Se for their growth, and therefore the amount of Se in the grain is in proportion to the soil's "available" Se and soil conditions that permit its absorption. The higher the amount of Se absorbed, the greater the selenomethionine to methionine ratio in the grain is. It has been estimated that approximately 50 percent of the Se in the grain and yeast protein is as selenomethionine (Olson et al., 1970; Kelly and Power, 1995), with the remainder in various amino acid analogs. Methionine is considered an essential amino acid for the pig and thus is a dietary requirement. Methionine and selenomethionine both appear to have an equal substitution rate in the tissues of animals and the ratio of both forms are found in the tissue proteins in the direct proportion to that fed.

Soil conditions and the soil's Se content limit the uptake of Se by plants. Almost all of the grains and forages grown in certain areas of the United States and Canada have an inadequate level of Se for animals. Figure 1 shows the regions of the United States and Canada where the grains and forages contain low Se concentrations. When the grains grown from various states were fed to swine and the loin Se concentrations compared, it was demonstrated that the organic Se became incorporated into the loin muscle in proportion to that found in the grains (Figure 2). It is therefore of interest to note that those areas where Se is adequate in grains, the deficiency in swine or other livestock is less prevalent. Because most of the Midwest does not provide an adequate quantity of Se, these locally-grown grains subsequently produce the deficiency in animals.

▼ Figure 1. Selenium concentration in grains and forages in the United States and Canada.



To correct the Se deficiency problem, various countries (e.g., Finland, New Zealand) have chosen to add Se to crop fertilizers in an attempt to incorporate Se into the grains and forages. The Se incorporated in these grains would be in the organic form (i.e., selenomethionine and amino acid analogs), wherupon it would become incorporated into the animals' body tissues. Applications from 4 to 10 grams Se per acre have been used (> 10 years), and there has been no reported soil buildup or animal toxicities that have resulted from this practice. Most countries, however, have preferred to add Se to the animals diet. Incorporation of inorganic Se is now routine in most livestock diets in much of the United States. The continued deficiency that is occurring in many livestock herds supports the continued evaluation of alternative methods of supplying Se to their diets.

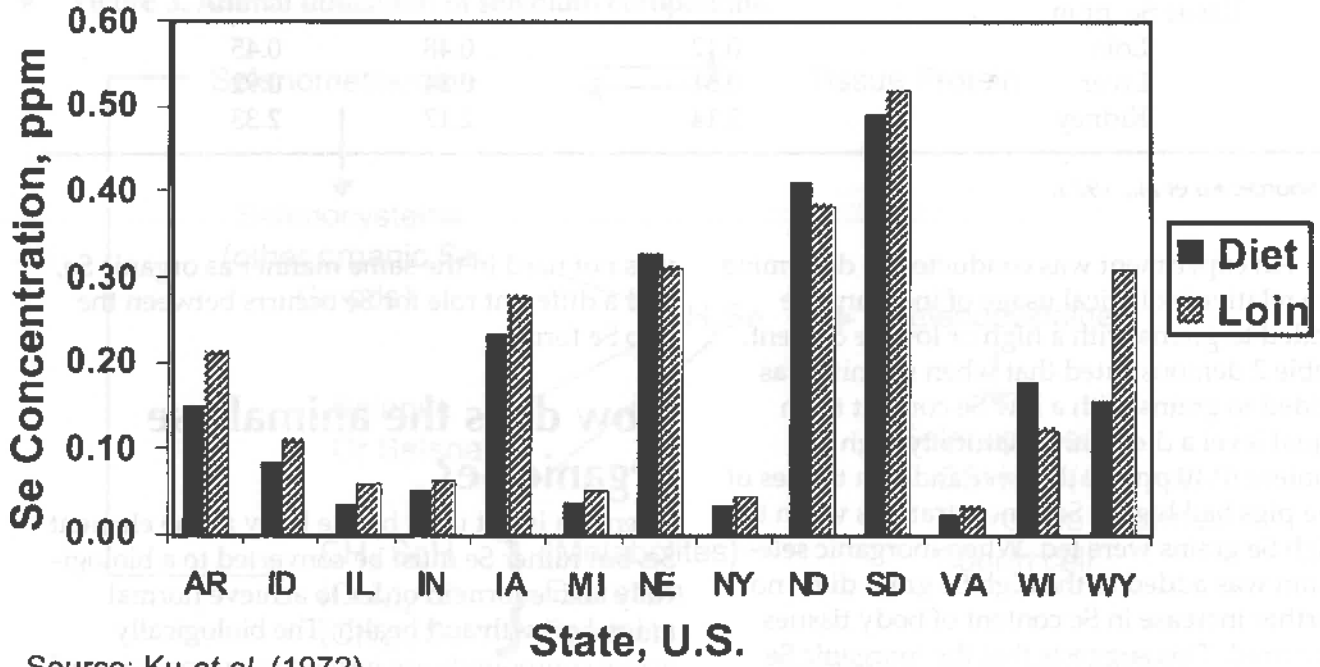
Recently, the treatment of seeds with Se has been shown to increase the Se content of various grains. Our studies have demonstrated that when a Se-treated corn was raised in Ohio during the 2000 growing season, the results demonstrated a 200-percent increase in the Se content (Table 1). Although the Se level in the corn was below that required by the pig, it does demonstrate that Se can be incorporated into grains and plants without fertilization of the entire field. However, there appeared to be a lower germination rate, stand count, and yield of the Se-treated corn seed. The effects of increasing the Se content of other grains by this Se treatment procedure have shown similar responses.

Pure DL selenomethionine has also been synthesized using biotechnological techniques, but the product is currently expensive. The responses of animals fed this product are similar to those fed high Se containing grains.

The incorporation of Se into the protein of the yeast cell has also been shown to increase the Se content to over 1000 ppm Se. This has the advantage that small quantities of the concentrated product can be added to the diet to meet the animals' Se requirement. The type of Se produced in the Se-enriched yeast product is largely selenomethionine (Kelly and Power., 1995) with the profile of Se compounds in the product being similar to that present in grains. This product has been approved in Canada and much of the world, but its approval in the United States is pending.

Another form of organic Se is the amino acid chelate, where Se is chemically bound to the amino acid glycine or lysine. There has not been any swine research conducted known to this author with this product.

▼ **Figure 2. Relationship of dietary selenium to loin selenium content.**



Source: Ku *et al.* (1972)

▼ **Table 1. Effect of treatment of corn seed on subsequent selenium grain content.** [a]

Item	Non-treated	Treated [b]	Change, %
Seed			
Se content, ppm	0.029	410	>1000%
Germination, % [c]	100	94	- 6%
Planting and Growth			
Planting rate, seeds/acre	30,000	30,000	0
Stand counts	28,000	25,800	- 8%
Leaves Se content (silk stage), Se ppm			
Lower leaves	0.037	0.134	+ 262 %
Upper leaves	0.016	0.760	+ 375 %
Grain (maturity)			
Yield, bu/acre (dry)	162.8	149.9	- 8 %
Se content, ppm	0.017	0.053	212 %

[a] *The corn was grown in an approximate 10-acre plot (each plot was around 5 acres) in Wooster, Ohio, during the 2000 growing season.*

[b] *Treatment of the corn was courtesy of Grow-Tech*

[c] *Conducted by Department of Crop Science/Seed Biology Program (Columbus). The study was done in four replicates of 50 seeds each (courtesy of Mr. Andy Evans).*

▼ **Table 2. Effect of inorganic selenium added to two origins of feed grains on resulting tissue selenium in finishing swine.** [a]

	Feed origin:	Michigan	South Dakota	
	Grain Se, ppm:	0.04	0.40	0.40
Item	+ Selenite, ppm:	0.40	0	0.10
No. pigs		4	4	4
Tissue Se, ppm				
Loin		0.12	0.48	0.45
Liver		0.61	0.84	0.92
Kidney		2.14	2.17	2.33

[a] *Source: Ku et al., 1973.*

An experiment was conducted to determine the relative biological usage of inorganic Se added to grains with a high or low Se content. Table 2 demonstrated that when selenite was added to grains with a low Se content to an equal level a diet with a naturally high Se content (0.40 ppm), the liver and loin tissues of the pigs had higher Se concentrations when the high Se grains were fed. When inorganic selenium was added to the high Se grain diet, no further increase in Se content of body tissues occurred. This suggests that the inorganic Se was not used in the same manner as organic Se, and a different role for Se occurrs between the two Se forms.

How does the animal use organic Se?

Selenium is not used by the body as the element Se, but rather Se must be converted to a biologically active form in order to achieve normal animal growth and health. The biologically active compounds are termed selenoproteins, of

which there are currently six known forms. Both inorganic and organic Se can be used for the synthesis of these selenoproteins. After consumption, organic Se can either be incorporated into actively growing body protein tissues or catabolized to selenocysteine (Figure 3). Tissue turnover of selenomethionine can potentially be used later by the animal.

All dietary forms of Se are metabolized to the reduced form of Se (H_2Se) where it is incorporated into a new molecule of selenocysteine. It is this latter seleno amino acid that is the true precursor of all known biologically active forms of the selenoproteins. Selenocysteine has been called the 21st amino acid because of its essential role for the formation of the selenoproteins (Raymond, 2000). Selenate or selenite can also be converted to H_2Se, whereupon it follows the same pattern for forming selenocysteine as does organic Se. The question is whether selenomethionine or the other organic Se compounds provide any additional benefit to the animal in order to justify its use that cannot be achieved from inorganic Se or by adding more inorganic Se to the diet.

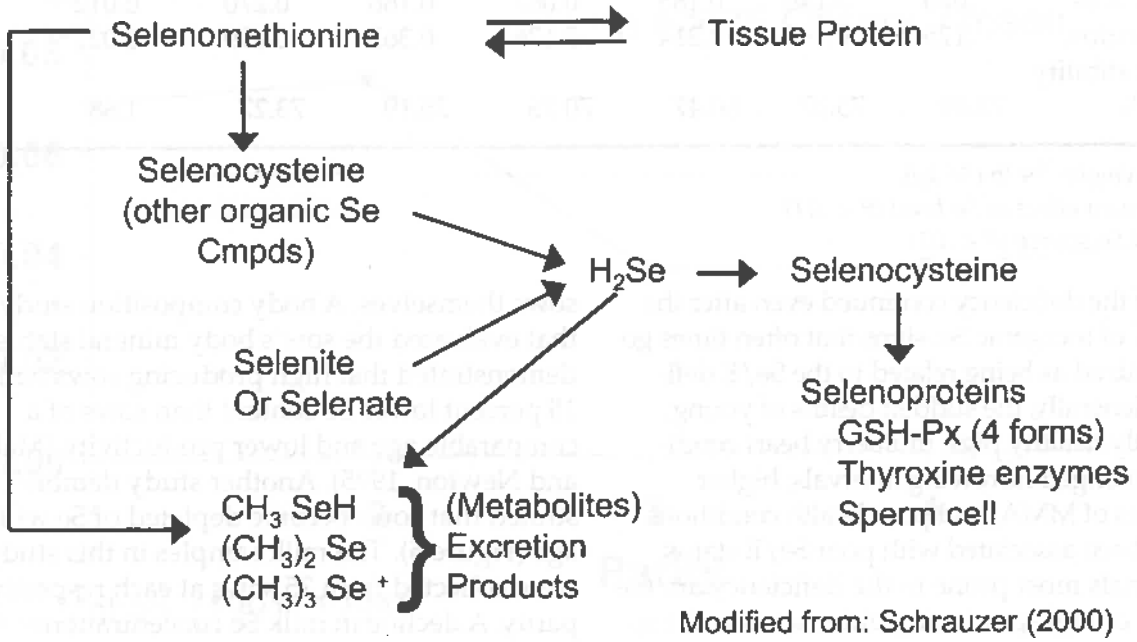
One of the active selenoproteins in the body is the enzyme glutathionine peroxidase (GSH-Px). This enzyme is used by the cell to prevent oxidative damage to the cells contents. The enzyme can be measured in various tissues, but whole blood, serum, or plasma has generally been used to reflect its level in the body. This enzyme increases in response to the dietary level, but plateaues when the production of the enzyme is optimum. Figure 4 demonstrates that both Se sources are effectively used to produce this enzyme. Although this enzyme has generally been used to estimate the pig's requirement for Se, it probably underestimates the body's Se need, as other selenoproteins have been found to respond to higher dietary levels of Se.

Although the pig may not use additional inorganic Se when supplemented at high dietary levels (Table 2), the question arises as to what happens when an excess is fed. A digestibility study conducted with grower pigs evaluated the excretion patterns of organic and inorganic Se sources at various dietary levels (Table 3). The results demonstrated that as the dietary level of selenite increased, more Se was excreted in urine. Total Se excretion averaged 20 percent more when inorganic Se was the Se source fed, suggesting that feeding higher dietary levels of inorganic Se results in higher excretion rates, principally through the urine.

Current status of the Se problem

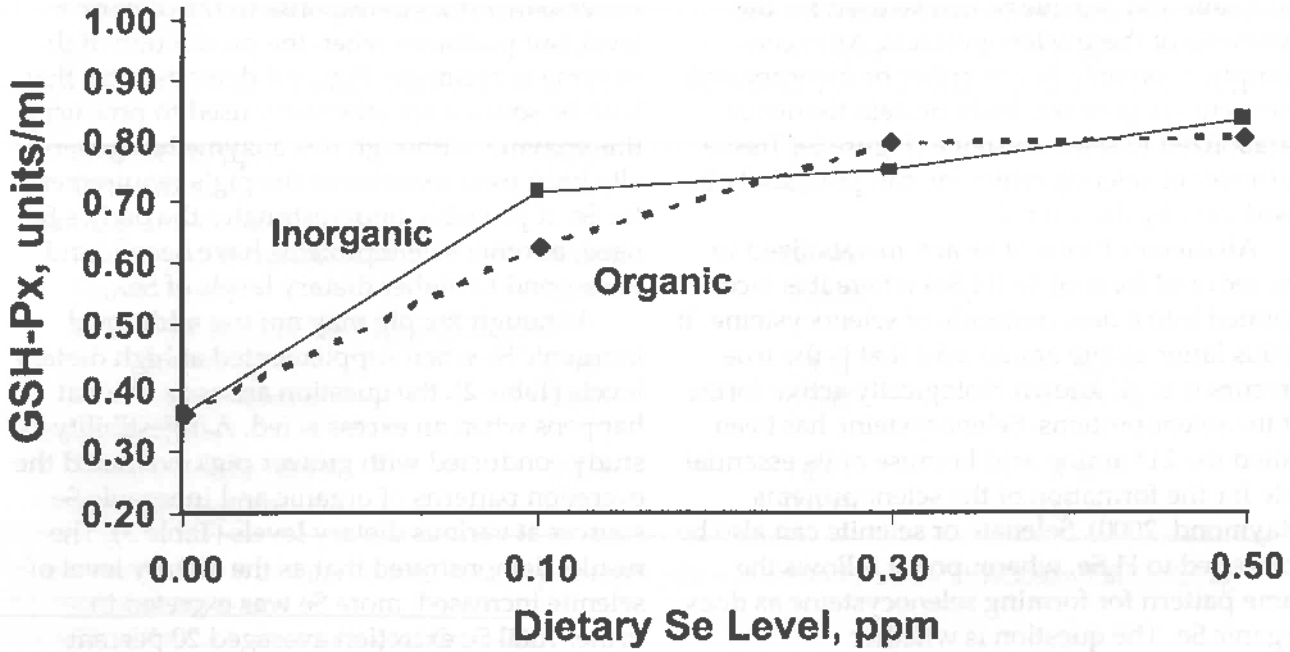
Most swine producers demonstrated the Se and vitamin E problem prior to 1975. This was greatly reduced after inorganic Se was added to swine diets. However, lower but frequent occur-

▼ **Figure 3. Animal utilization of selenium compounds.**



Modified from: Schrauzer (2000)

▼ **Figure 4. Effect of inorganic or organic Se on Serum GSH-Px activity in growing swine.**



Source: Mahan and Parrett (1996)

▼ **Table 3. Effect of digestibility and retention of various levels of selenite and organic (yeast) Se in growing pigs.**

Item	Selenite, ppm			Organic Se, ppm			SEM
	0.1	0.3	0.5	0.1	0.3	0.5	
No. pigs[a]	6	6	6	6	6	6	--
Se balance, mg/d							
Intake	.271	0.576	0.941	0.299	0.670	1.006	0.011[bc]
Urine	.076	0.233	0.442	0.036	0.139	0.238	0.019[bcd]
Feces	.070	0.146	0.185	0.087	0.166	0.270	0.012[bcd]
Retention	.125	0.198	0.314	0.176	0.365	0.499	0.022[bcd]
Digestibility							
%	73.89	75.07	80.47	70.76	75.19	73.27	1.68

[a] *Initial Weight: 79 lb (36 kg).*
[b] *Linear main effect of Se level (P < .01)*
[c] *Effect of Se source (P < .01)*

rences of the deficiency continued even after the approval of inorganic Se; signs that often times go unrecognized as being related to the Se/E deficiency. Generally, the sudden deaths of young, apparently healthy pigs; mulberry heart conditions; prolonged farrowing intervals; higher incidences of MMA; and poor health conditions have all been associated with poor Se/E status.

Animals most prone to the deficiency are the progeny of high-producing older sows and the sows themselves. A body composition study that evaluated the sow's body mineral status demonstrated that high producing sows had an 18 percent lower Se content than sows of a comparable age and lower productivity (Mahan and Newton, 1995). Another study demonstrated that sows become depleted of Se with age (Figure 5). The milk samples in this study were collected from 75 sows at each respective parity. A decline in milk Se concentrations

occurred over several parities. The decline in tissue and milk Se coincides with the reported higher incidence of the deficiency in both older sows and thier progeny.

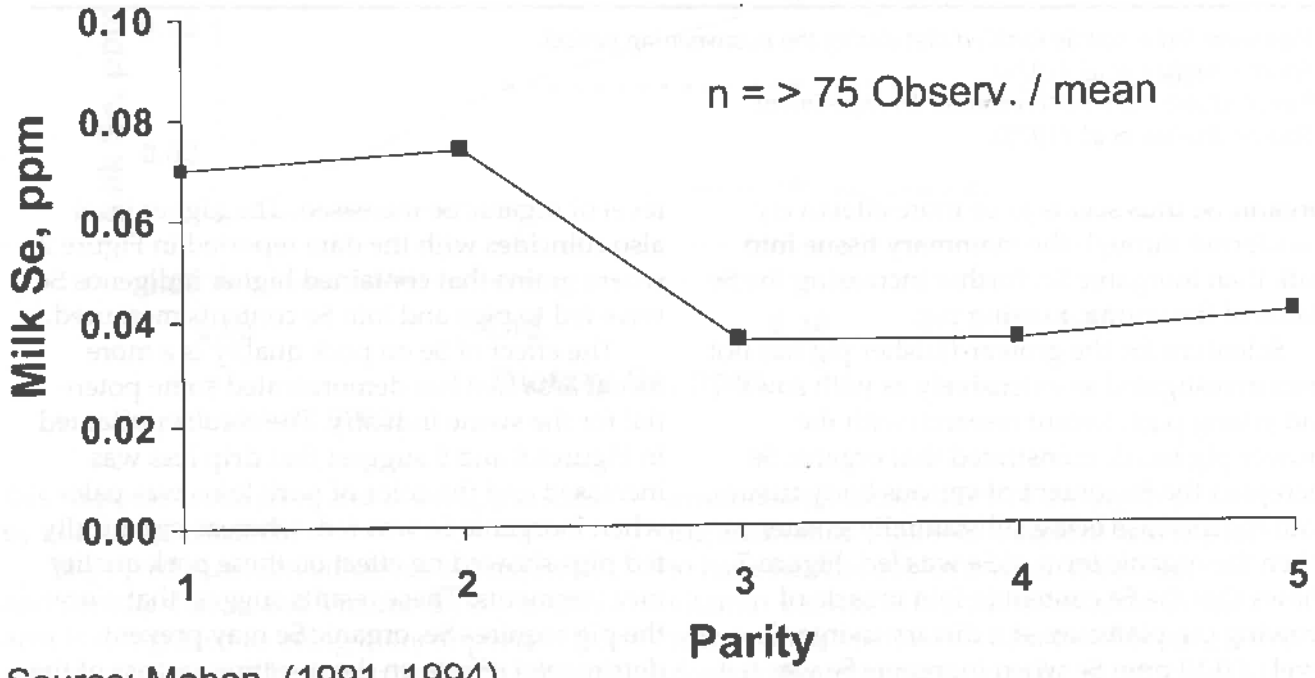
The effect of organic and inorganic Se in swine

A high Se status in both the sow and young pig should be important in preventing the deficiency onset. Consequently, in the first study we compared the deficiency onset in the pigs from sows fed diets with or without Se. The results presented in Table 4 demonstrated that the young weanling pig from sows fed Se did not experience the Se deficiency as soon postweaning or have tissue depletion of Se as rapidly as pigs from sows not fed Se.

A subsequent experiment evaluated the effects of feeding either inorganic or organic Se to reproducing sows and then evaluated these effects on their progeny. Table 5 presents both neonatal and weanling pig data demonstrating that newborn pigs (prior to colostrum consumption) had higher liver and loin Se concentrations when the organic Se source was fed. In both cases the feeding of 0.30 ppm Se to the pregnant sows resulted in higher pig tissue Se concentrations, demonstrating that when more Se was fed, more was transferred to the developing fetus, but more Se was also retained in young pigs when the sows were fed organic Se. Although this table also reflects an apparent difference in body weight of pigs, there was no difference in pig weights when the entire group of pigs was compared. The results in these tables demonstrated that the Se status of pigs at birth and weaning can affect the Se/Vitamin E deficiency onset and that pigs from sows fed organic Se are better able to prevent the deficiency onset resulting in pigs of a higher Se status at both birth and weaning.

Providing adequate Se to the neonate and nursing pig can be done either by increasing the sows dietary Se levels, or injecting Se/E mixtures into sows and pigs. Because the dietary route is less laborious, the effect of adding the organic or inorganic Se on milk Se concentrations were evaluated. Figure 6 demonstrated that the Se content of milk increased when both dietary sources were increased, but the magnitude of increase was clearly greater when the organic Se source was fed. Feeding the combination of organic and inorganic Se (each provided at 0.15 ppm) showed that milk Se contents were similar to sows fed organic Se at 0.15 ppm.

Figure 5. Selenium content of sow milk (21-day postpartum)



Source: Mahan, (1991, 1994)

▼ **Table 4. Effect of sow dietary selenium level on carry-over effects on their progeny during the postweaning period.** [a]

Item	Sow dietary Se	
	Basal (no added Se)	Basal (+0.10 ppm Se)
Experiment 1 [b]		
28-day postweaning	6	6
No. pigs killed	6	0
Skeletal muscle, %	67	0
Liver necrosis, %	100	0
Heart, enlarged, %	50	0
Gastric ulcers, %	83	0
56-day postweaning		
No. pigs killed	0[c]	5
Skeletal muscle, %	–	40
Liver necrosis, %	–	100
Heart, enlarged, %	–	40
Gastric ulcers, %	–	100
Experiment 2 [d]		
Pig serum Se, ppm		
Weaning	0.020	0.047
14-d	0.012	0.038
28-d	– [c]	0.030
42-d	– [c]	0.054
Liver Se, ppm		
14-d	.051	.113
42-d	– [c]	.016
Heart Se, ppm		
14-d	.046	.084
42-d	– [c]	.047

[a] *Pigs were fed a non Se fortified diet during the postweaning period.*
[b] *Source: Mahan et al. (1974).*
[c] *Pigs died and were not continued on experiment.*
[d] *Source: Mahan et al. (1975).*

Organic Se thus seems to be more effectively transferred through the mammary tissue into milk than inorganic Se, further increasing the Se status of the young, nursing pig.

Selenium for the grower-finisher pig has not been investigated as extensively as with sows and young pigs. Recent research with the grower pig has demonstrated that organic Se increased the Se content of various body tissues, with the increase being substantially greater when the organic form of Se was fed. Figure 7 shows that the Se content in loin muscle of growing pig plateaues at a dietary inorganic level of 0.10 ppm Se when inorganic Se was fed, but continued to increase linearly as the dietary level of organic Se increased. The higher level also coincides with the data reported in Figure 2, where grains that contained higher indigenos Se were fed to pigs and loin Se contents measured.

The effect of Se on pork quality is a more recent area that has demonstrated some potential for the swine industry. The results presented in Figures 8 and 9 suggest that drip loss was increased and the color of pork loins was paler when inorganic Se was fed, whereas organically fed pigs showed no effect on these pork quality measurements. These results suggest that since the pig requires Se, organic Se may prevent detrimental effects on the resulting carcass of the market pig. The reason that inorganic Se causes

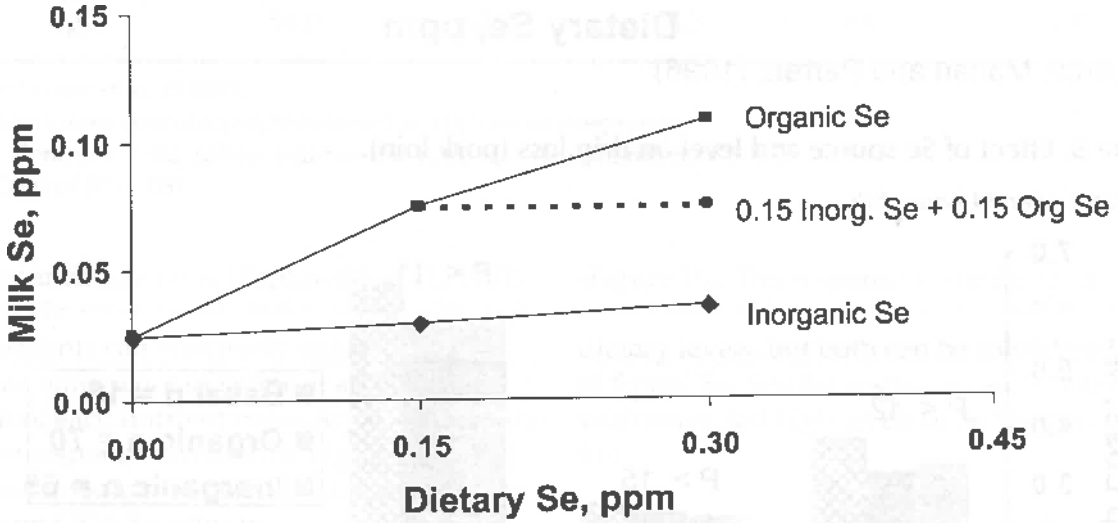
▼ **Table 5. Effect of inorganic selenite and an organic selenium (yeast) source fed to first parity gilts on various selenium measurements of the progeny.**

Item	Selenite, ppm 0.1	0.3	Organic Se, ppm 0.1	0.3	SEM
		Neonatal			
No. pigs [a]	5	5	6	3	—
Weight, lb.	2.29	2.65	2.75	3.24	0.28
Loin Se, ppm	0.041	0.058	0.067	0.088	0.007
Liver Se, ppm	0.238	0.253	0.281	0.312	0.037
		Weaning, 21-day			
No. litters bled	9	9	11	9	—
Serum GSH-Px, units/ mL [b]	0.44	.051	0.46	0.44	0.04
Serum Se, ppm [b]	0.062	0.075	0.082	0.102	0.005
Tissue Se					
No. pigs killed	8	6	6	7	—
Weight, lb.	13.8	13.5	14.9	14.3	0.95
Loin Se, ppm	0.101	0.121	0.129	0.244	0.021
Liver Se, ppm	0.352	0.388	0.353	0.509	0.032

[a] *Neonatal pigs were killed prior to the consumption of colostrum.*
[b] *Serum GSH-Px activity and serum Se content reflects the average of three pigs per litter.*
Source; Mahan and Kim (1996).

▼ **Figure 6. Effect of Se source and level on milk Se content (average 7 and 14 days).**

Sows fed the treatment diet from 109 day gestation through lactation.



Source: Mahan, 2000.

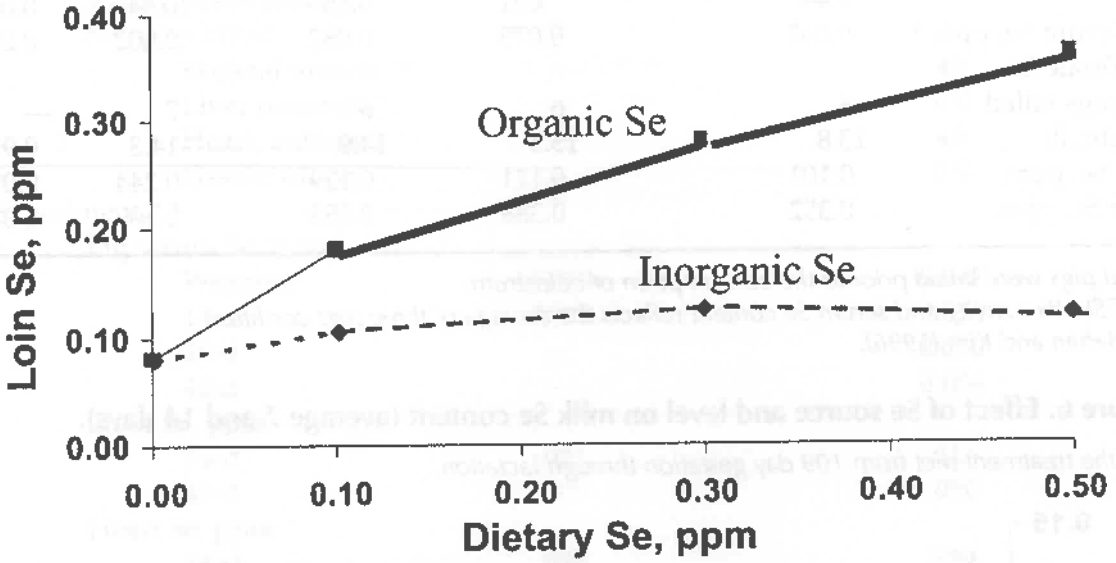
this response is not clear and is being pursued by additional research.

Improved nutrition enhances animal health, and the role that Se and Vitamin E play in this area is recognized as being more important than previously thought. Both nutrients enhance the immunological capability of the pig in producing antibodies. Pigs will therefore be less prone to have health problems when their Se and vitamin E status is high. Almost all of the research conducted in this area has, however, been done with inorganic Se, and no comparative

organic Se source studies have been reported in swine.

A sow study with late-term sows (Hayek et al., 1989) demonstrated that the injection of high concentrations of vitamin E or Se or their combination increased the IgA, IgM, and IgG antibodies in colostrum (Table 6). Further work (Wuryastuti et al., 1993) demonstrated that the immuno responsiveness of the blood lymphocytes increased and the phagocytic and microbicidal activity of blood polymorphonuclear cells were enhanced when high levels of Se and Vitamin E were fed to gestating sows (Table 7). These workers also demonstrated that the phagocytic and microbiocidal activities of colostrum and milks from these sows were elevated when Se and vitamin E were fed (Table 8). Similar responses have been demonstrated in young pigs where weanling pigs were injected with or fed diets containing Se or vitamin

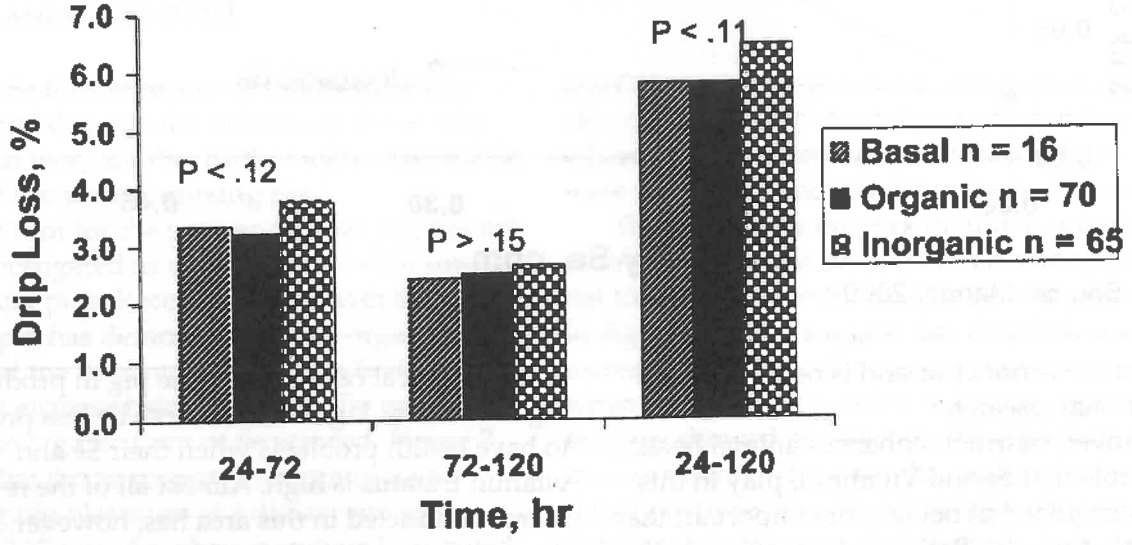
▼ **Figure 7. Deposition of inorganic or organic Se (loin muscle of grower pigs).**



Source: Mahan and Parrett, (1996)

▼ **Figure 8. Effect of Se source and level on drip loss (pork loin).**

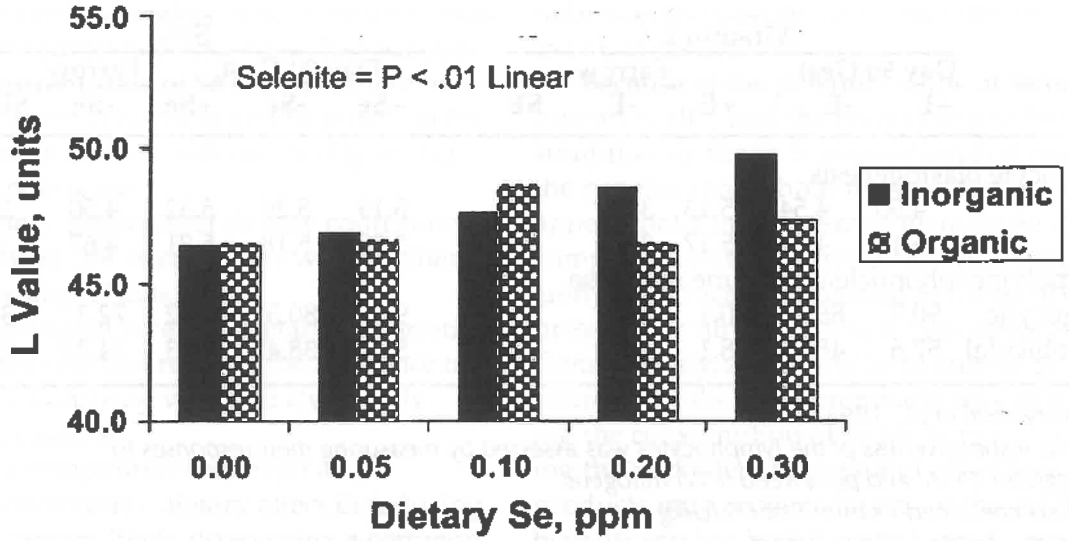
Loins collected after 24-hour chill.



Source: Mahan, Cline, and Richert (1998)

▼ **Figure 9. Effect of Se source on pork color (Hunter L value).**

Loins collected after 24-hour chill.



Source: Mahan, Cline, and Richert (1998)

▼ **Table 6. Effect of selenium and vitamin E on Immunoglobulin levels in sow colostrum [a]**

Immunoglobulin	Treatment [b] Control	Vitamin E	Se	Vit. E + Se	SEM
IgA	13.8	12.7	14.5	12.4	1.9
IgM	8.4	9.8	10.0	9.6	0.8[c]
IgG	54.0	63.9	64.3	64.1	7.0

[a] *Source: Hayek et al. (1989).*

[b] *Treatments intramuscularly administered at 100 day of pregnancy. Control = 1 mL saline; Vitamin E = 1000 IU -tocopherol; Se = 5 mg*

[c] *Se vs Control (P < .05).*

E higher antibody titres (Peplowski et al., 1981). Collectively, these results indicate that although both nutrients can effectively enhance the immunocompetence of swine at all ages, the amount of each nutrient necessary to achieve the immune response seems to be higher than that which is necessary to meet the dietary need for maximum GSH-Px activity.

Toxicity of Se has been a concern since the early 1900s where high dietary levels of Se in some of the western states clearly demonstrated reduced animal growth and reproductive problems. A recent study that evaluated the toxicity of organic and inorganic Se sources in swine demonstrated that both Se sources can be toxic when fed at dietary levels greater than 5 ppm Se (Figure 10). The response to the inorganic Se form seems to be more severe at initially higher dietary levels, but both can be considered toxic at 5 ppm Se. Similar responses were obtained with sows fed high levels of Se for their entire life.

Added Se value to pork and implications for human health

In the early 1940s a report was published that demonstrated that high levels of dietary Se produced liver cancer in rats (Nelson et. a., 1943). From this report selenium's potential carcinogenic effects were widely publicized.

▼ Table 7. Effect of vitamin E and Se on blood lymphocyte blastogenesis, blood polymorphonuclear cell (PMN) phagocytic activity and PMN microbicidal activity in adult sows. [a b]

Item	Vitamin E [c]					Se[d]				
	Day 90 Gest.		Farrow			Day 90 Gest.		Farrow		
	+E	-E	+E	-E	SE	+Se	-Se	+Se	-Se	SEM
Lymphocyte blastogenesis										
PHA [a]	4.90	4.54 [e]	5.13	3.93*	.22	5.19	5.20	5.32	4.50	.21
PW [a]	5.19	4.64 [e]	5.17	3.79*	.20	5.28	5.18	5.31	4.67	.23
Blood polymorphonuclear immune response										
Phagocytic	90.7	86.2 [e]	90.1	83.8*	2.3	92.9	80.5*	90.2	72.2 [e]	3.2
Microbicidal	57.6	48.7 [e]	58.1	40.6*	2.6	53.1	38.4*	56.3	34.3 [e]	2.9

[a] *Source: Wuryastuti et al., 1993.*
[b] *The immuno responsiveness of the lymphocytes was assessed by measuring their responses to phytohemagglutin (PHA) and pokeweed (PW) mitogens.*
[c] *Fortified diets contained vitamin E at 60 IU/kg.*
[d] *Fortified diets contained Se at .3 ppm.*
[e] *P < 0.05*

▼ Table 8. Phagocytic and microbicidal activities of polymorphonuclear (PMN) cells of colostrum and milk from sows fed diets from breeding to four days postpartum.

Diet	Phagocytic activity [a]		Microbiocidal activity [b]	
	Colostrum	Milk	Colostrum	Milk
Neg. control (No E/Se)	35.2 ± .9[d]	21.2 ± 2.5	3.2 ± 2.7[d]	1.2 ± .1[d]
Control (+E/Se)	50.2 ± 5.4	27.5 ± 3.0	6.2 ± .8	2.7 ± .2
(-E)	43.6 ± 3.2	23.7 ± 1.5	3.6 ± .6[d]	2.2 ± .5
Control (+E/Se)	44.6 ± 8.3	30.2 ± 5.0	6.2 ± 1.0	2.4 ± .1
(-Se)	33.4 ± 5.1	19.9 ± 3.4	2.6 ± .6[d]	1.6 ± .4

[a] *Percentage of PMN cells containing two or more yeast particles.*
[b] *Percentage of PMN cells containing two or more dead yeast particles.*
[c] *Control diets were fortified with vitamin E (IU/kg) and Se (.3 ppm) while treatment diets deleted one or both nutrients.*
[d] *Significantly (P < .05) different from respective control.*
Source: Wuryastuti et al., 1993

Since that time additional studies have subsequently failed to confirm that finding, but it caused the governments to regulate Se as an additive. The essentiality of Se as a dietary requirement for animals was established in 1957 (Schwarz and Foltz), and in 1969 it was further established that Se had an inhibitory effect on cancer development in humans (Shamberger and Frost).

Although the scientific literature is beginning to more fully examine the effects of inorganic and organic Se on arresting cancer in humans, most of the studies have been conducted with inorganic Se. The desire to use organic Se is related to its lower toxicity effects when compared to the inorganic source. The one recent report that has stimulated a great deal of interest in the medical field is the research conducted by Clark et al. (1996). They reported that of those cancers evaluated, a reduction in the incidence of cancers by approximately 50 percent occurred with greater effects on prostate cancer (Figure 11). In that study the individuals consumed a daily intake of 200 µg Se from Se-enriched yeast.

Because of the tremendous potential impact of this report, the study is currently being repeated in the European countries where they normally have low intakes of Se. A recent review by Spallholz (2001) (< 50 mg/day) has summarized the current state of Se's involvement in arresting cancer in humans and its potential for other related human health issues (Figure 12). His major points are:

1. Low dietary ingestion of Se may contribute to an increased risk of cancer (as well as other health-related effects)
2. Supranutritional levels of dietary Se ingestion likely prevents and reduces the incidence of naturally-occurring viral and chemically induced cancers.
3. Selenium compounds that exert a chemopreventative dietary effect in reducing various cancers likely do so using a common mechanism.

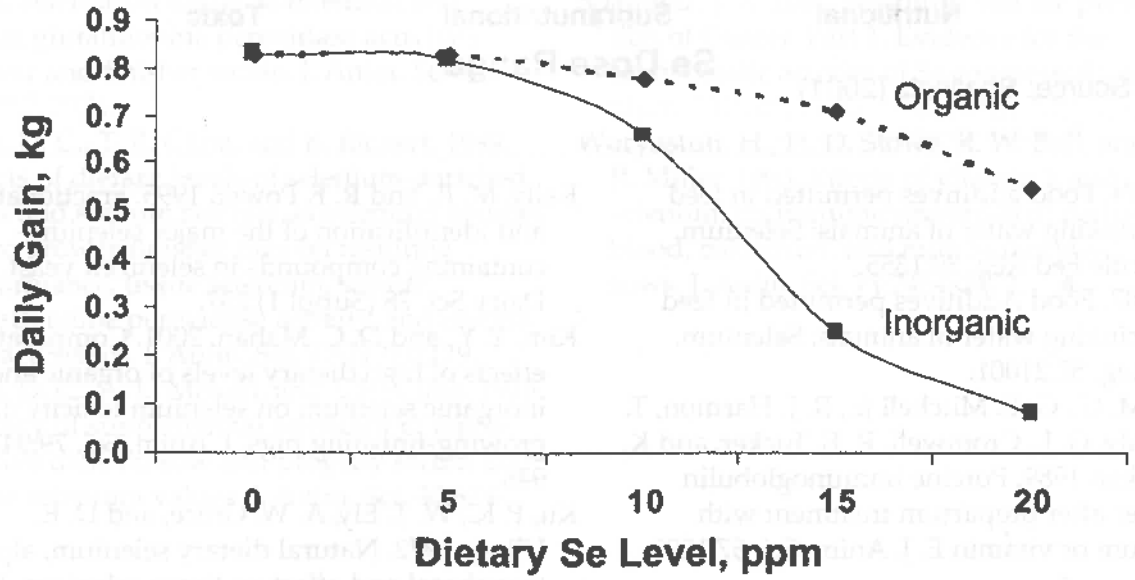
Although Se may be involved in the prevention of cancer, there are apparently other health benefits associated with the element. The children of deficient women seem to be more prone to disease, it may have an inhibitory effect on the HIV virus, it may reduce the incidence of miscarriage, it enhances sperm motility (animals and humans), and Se been implicated in reducing the risk of cardiovascular disease (Raymond, 2000). Although the form and amount of Se necessary to prevent or reduce the incidences of these health problems is currently unknown, the potential of this element has changed dramatically over the past 40 years from one of toxicity to one of essentiality.

Because of the potential value of Se on human health, and the inadequacy of Se consumption by the U. S. population and many of the peoples throughout the world, it would appear that a mechanism to increase Se consumption would be through the consumption of animal products that contain Se. Most of the Se present in grains, fruits, and vegetables is low. Consequently, supplying Se in animal products seems to be the most promising way of enhancing the consumption of Se for humans. Increasing the Se content of pork and other animal products may prove to be one of the great side benefits serving both livestock producers and humans.

References cited

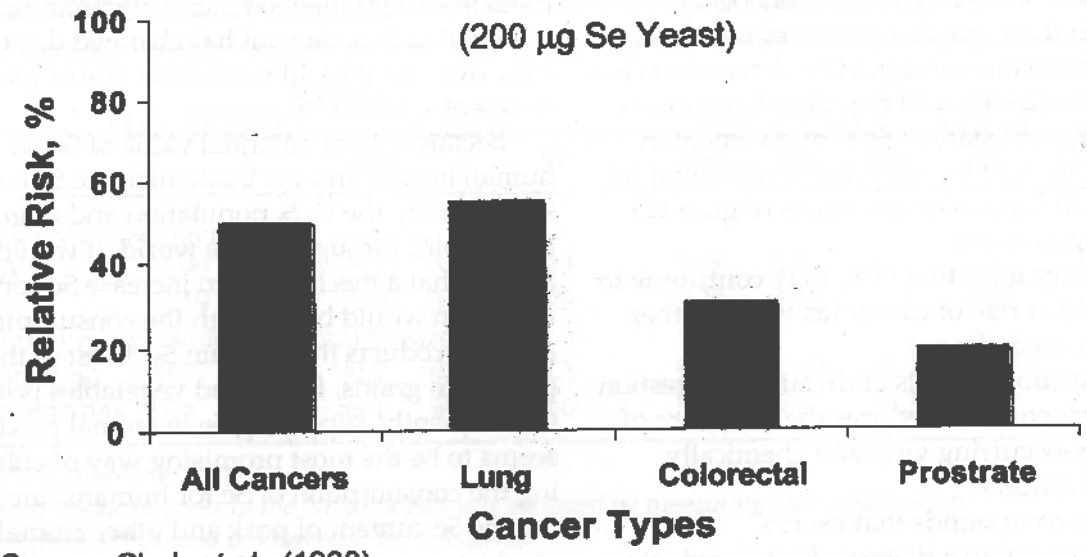
Clark, L. C., G. F. Combs, Jr., B. W. Turnbull, E. H. Slate, D. K. Chalker, J. Chow, L. S. Davis, R. A. Glover, G. F. Graham, E. G. Gross, A. Krongrad, J. L. Leshar, Jr., H. K. Park, B. B. Sanders, Jr., C. L. Smith, and J. R. Taylor. 1996. Effects of selenium for cancer prevention in patients with carcinoma of the skin. J. Am. Med. Assoc. 276:1957-1985.

▼ **Figure 10. Effect of dietary levels of inorganic or organic Se on toxicity responses in swine.**



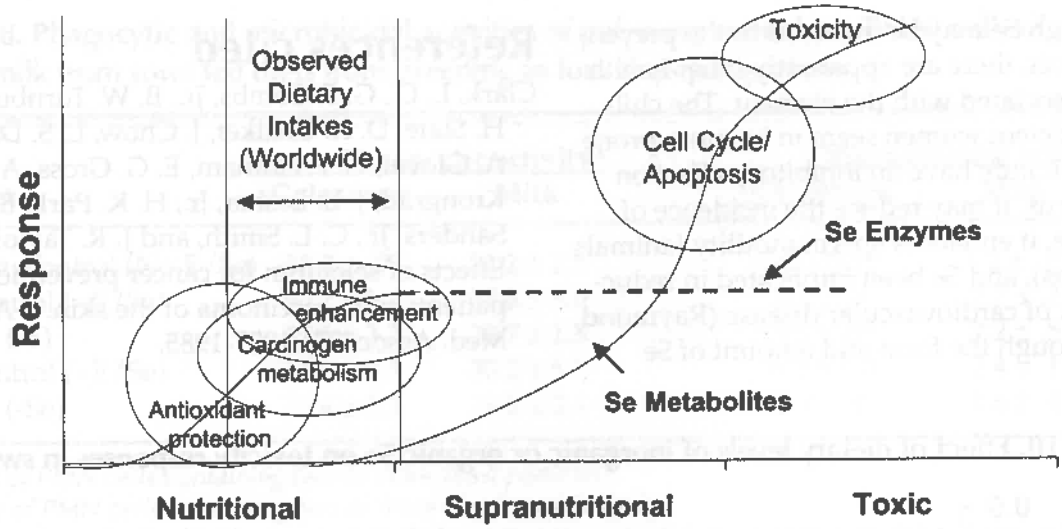
Source: Mahan and Kim (2001)

▼ **Figure 11. Incidence of cancer in Se-treated subjects vs. placebo**



Source: Clark *et al.*, (1996)

▼ **Figure 12. Relative uses of Se by the body from deficient to toxic dietary levels.**



Source: Spallholz (2001)

FDA. 1974. Food additives permitted in feed and drinking water of animals: Selenium. Final rule Fed Reg. 39:1355.

FDA. 1987. Food Additives permitted in feed and drinking water of animals: Selenium. Fed. Reg. 52:21001.

Hayek, M. G., G. E. Mitchell Jr., R. J. Harmon, T. S. Stahly, G. L. Cromwell, R. E. Tucker, and K. B. Barker. 1989. Porcine immunoglobulin transfer after prepartum treatment with selenium or vitamin E. J. Anim. Sci. 67:1299-1306.

Kelly, M. P., and R. F. Power. 1995. Fractionation and identification of the major selenium-containing compounds in selenized yeast. J. Dairy Sci. 78 (Suppl 1):237.

Kim, Y. Y., and D. C. Mahan. 2001. Comparative effects of high dietary levels of organic and inorganic selenium on selenium toxicity of growing-finishing pigs. J. Anim. Sci. 79:942-948.

Ku, P. K., W. T. Ely, A. W. Groce, and D. E. Ullrey. 1972. Natural dietary selenium, alpha-tocopherol and effect on tissue selenium. J. Anim. Sci. 34:208-211.

Because of the tremendous potential impact of this report, the study is currently being repeated in the European countries where they normally have low intakes of Se. A recent review by Spallholz (2001) (< 50 mg/day) has summarized the current state of Se's involvement in arresting cancer in humans and its potential for other related human health issues (Figure 12). His major points are:

1. Low dietary ingestion of Se may contribute to an increased risk of cancer (as well as other health-related effects)
2. Supranutritional levels of dietary Se ingestion likely prevents and reduces the incidence of naturally-occurring viral and chemically induced cancers.
3. Selenium compounds that exert a chemopreventative dietary effect in reducing various cancers likely do so using a common mechanism.

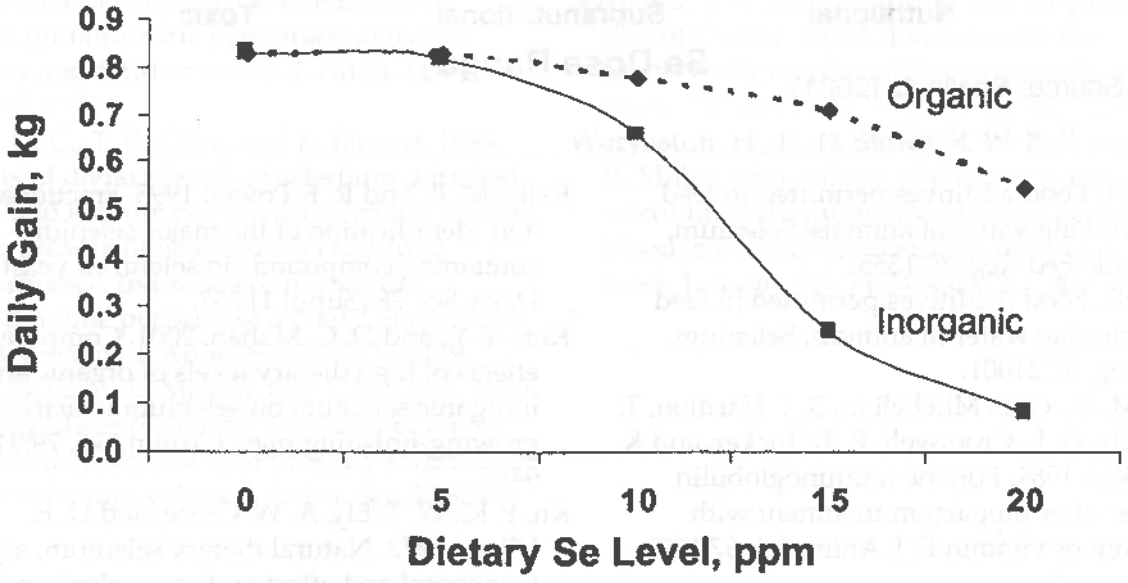
Although Se may be involved in the prevention of cancer, there are apparently other health benefits associated with the element. The children of deficient women seem to be more prone to disease, it may have an inhibitory effect on the HIV virus, it may reduce the incidence of miscarriage, it enhances sperm motility (animals and humans), and Se been implicated in reducing the risk of cardiovascular disease (Raymond, 2000). Although the form and amount of Se necessary to prevent or reduce the incidences of these health problems is currently unknown, the potential of this element has changed dramatically over the past 40 years from one of toxicity to one of essentiality.

Because of the potential value of Se on human health, and the inadequacy of Se consumption by the U. S. population and many of the peoples throughout the world, it would appear that a mechanism to increase Se consumption would be through the consumption of animal products that contain Se. Most of the Se present in grains, fruits, and vegetables is low. Consequently, supplying Se in animal products seems to be the most promising way of enhancing the consumption of Se for humans. Increasing the Se content of pork and other animal products may prove to be one of the great side benefits serving both livestock producers and humans.

References cited

Clark, L. C., G. F. Combs, Jr., B. W. Turnbull, E. H. Slate, D. K. Chalker, J. Chow, L. S. Davis, R. A. Glover, G. F. Graham, E. G. Gross, A. Krongrad, J. L. Leshar, Jr., H. K. Park, B. B. Sanders, Jr., C. L. Smith, and J. R. Taylor. 1996. Effects of selenium for cancer prevention in patients with carcinoma of the skin. J. Am. Med. Assoc. 276:1957-1985.

▼ **Figure 10. Effect of dietary levels of inorganic or organic Se on toxicity responses in swine.**



Source: Mahan and Kim (2001)

▶ Nutrient requirement of pigs fed Paylean™

Cory Herr, Alan Schinckel, and Brian Richert, Department of Animal Sciences
Purdue University, West Lafayette, Indiana 47906

Summary

Amino acid requirements increase substantially while feeding Paylean™. The dietary lysine level needs to be increased by 0.3 to 0.4 percentage units for total lysine levels from current farm levels usually fed to 180-lb. pigs. Recommended lysine levels for Paylean™-fed pigs would be 1.0 to 1.1 percent for barrows and 1.1 to 1.2 percent for gilts. This level could be decreased after 14–21 days to levels near 0.75 and 0.85 percent lysine for barrows and gilts, respectively. Other essential amino acids need to be increased as well, to maintain an ideal amino acid ratio to maximize lean tissue synthesis. There is no evidence that increasing dietary energy levels beyond that of a normal corn-soy diet would elicit an additional Paylean™ response.

Other nutrients that may need to be increased are vitamin and trace mineral levels. There is some data to indicate an increased need for B vitamins with high lean gain pig while feeding Paylean™ in order to promote lean-tissue deposition. As a method of insurance, it is recommended that the vitamin and trace mineral levels be increased to levels that would be fortified to grower diets with similar dietary CP levels (1-1.2 % Lys). There is no increase in bone mass with Paylean™, and so the need to increase Ca and P above normal inclusion levels for the finishing pig is not merited.

Introduction

Over the last ten years (1990-2001), consumer demand for lean pork has caused a shift in what type of animal a producer markets and how producers are paid for their animals. The U.S. pork industry has selected for a heavier muscled, leaner animal with increased average daily gain and decreased feed consumption compared to pigs of the past.

Consumer demand also has changed how producers are paid for their pigs. Processing plants now pay producers for a combination of carcass weight and lean percentage rather than just live weight. In recent years, hot carcass weight has replaced live weight in the payment grid. This type of payment has forced swine producers to change the type of product they are producing so pork-processing companies can meet consumer demand.

One technology that will help producers provide the lean pork that consumers are demanding is the use of repartitioning agents or beta-agonists. Beta-adrenergic agonist compounds alter an animal's metabolism by shifting nutrients to lean muscle accretion and away from fat accretion. One of these beta-agonists which has recently gained approval (Dec., 1999) and used for pigs in the United States, is a compound known as Ractopamine HCl (RAC), marketed under the trade name Paylean® by Elanco Animal Health.

Beta-andrenergic agonists: Mode of action

Beta-adrenergic agonists are in a class of compounds known as phenethanolamines that have been shown to improve the growth and body composition of livestock (Moloney et al.,1991; Mersmann, 1998). Phenethanolamines are referred to as repartitioning agents because their effects enable the animal to shift nutrients towards lean tissue accretion and away from fat accretion (Bergen and Merkel, 1991). The phenethanolamine compounds studied the most include cimaterol, clenbuterol, salbutamol, zilpateral, and RAC (Moloney et al.,1991; Mersmann, 1998). When using RAC , there is an increased rate of gain, improved feed efficiency and an increased carcass leanness and dressing percentage (Moody et al., 2000).

The beta-agonists begin with the activation of the beta-adrenergic receptor on the cell surface. The activated receptor couples with the Gs proteins, and the activation of adenyl cyclase occurs. Adenyl cyclase converts adenosine triphosphate (ATP), producing cyclic adenosine monophosphate (cAMP). Cyclic adenosine monophosphate produces effects by binding to the regulatory subunits of protein kinase A, which releases its catalytic subunit. This catalytic subunit of protein kinase A then regulates intracellular enzymes through phosphorylation to elicite the previously mentioned metabolic shifts in adipose and muscle tissues (Mersmann, 1988, 1999; Moody et al., 2000).

Nutritional response: Past research

Considerable attention has been focused on the use of beta-adrenergic agonists in farm livestock. Previous literature cited has demonstrated that these repartioning agents change the metabolism of an animal in a manner that increases lipolysis and/or decreases lipogenesis in adipose tissue and increases protein accretion in muscle tissue. Due to the metabolic changes that occur when beta-adrenergic agonists are administered, changes in nutritional requirements must also be considered to accommodate these changes in tissue metabolism.

Protein

Two factors affect the dietary requirements of animals fed beta-adrenergic agonists. The first is the dramatic increase in protein accretion that occurs when feeding these compounds (Moloney et al., 1991; Moody et al., 2000). An assumption can be made that with this increase in protein deposition when feeding beta-adrenergic agonists, dietary CP requirements are also increased. In perhaps the most complete study analyzing the relationship between dietary protein and a beta-adrenergic agonist, Dunshea et al. (1993b) looked at the effects of six increasing dietary protein levels (8.5-22.2 percent CP) while feeding 0 and 20 ppm RAC. They observed that while feeding 20 ppm RAC, ADG increased with increasing dietary crude protein levels, with ADG reaching a plateau at a 19.5 percent CP level. Carcass protein accretion rate was maximized at the same level as ADG, however, fat-tissue gain decreased linearly as dietary CP increased and was minimized with the 22.2 percent CP diet. This increased protein deposition required a dietary CP level of at least 3 percentage units more than the control pigs. In conclusion, Dunshea et al. (1993b) found that the biological efficiency of protein use was unchanged when feeding RAC, however, the pigs fed RAC had a greater CP requirement. Other studies have observed that growth performance parameters and carcass characteristics were increased as dietary CP was increased in the diet while feeding beta-adrenergic agonists (Jones et al., 1992; Mitchell et al., 1994). It is interesting to note that Mitchell et al., (1991) observed that increased dietary CP levels (18 percent CP vs 12 percent CP) had no effect on ADG, F:G, and carcass measurements while feeding RAC when the pre-treatment dietary CP levels were deficient.

The second factor that affects an animal while feeding a beta-adrenergic agonist is the reduction in feed intake observed, resulting in a decrease in total nutrient intake. Even though this factor has not been studied, investigators have suspected that a lowered dietary CP intake decreases protein accretion and overall performance in animals fed a normal dietary CP diet in conjunction with beta-adrenergic agonists, (Mitchell et al., 1991, 1994; Dunshea et al., 1993b). Overall, the evidence indicates that dietary CP levels need to be increased approximately 3 to 4 percentage units when feeding beta-adrenergic agonists, depending on the lean accretion rates of the animal.

Energy

After amino acids, the dietary energy may be the next limiting factor when feeding beta-adrenergic agonists. Increased energy intakes, in late-finishing swine, up to 9.5 Mcal/d of ME, resulted in an increase in lean-tissue accretion, a decrease in fat tissue accretion, and improved feed efficiencies. However, when RAC was added to the diet (44.7 mg/d, approx. 20 ppm equivalent), no response to higher dietary energy levels were observed in lean-tissue accretion. In contrast, those pigs fed RAC in combination with increased dietary energy levels, fat-tissue accretion and ADG increased linearly and lean efficiency improved linearly as

energy increased in the diet (to 9.5 Mcal/d of ME, Williams et al., 1994). In 1988, Jones et al. reported an improvement in carcass leanness and growth performance of late-finishing pigs fed 20 ppm RAC in diets with and without 5 percent added fat to the diet with identical dietary CP levels. There was no improvement to RAC with the 5 percent added dietary fat. Pigs fed supplemental fat and RAC, however, may have had an inadequate amino acid intake.

The limited amount of information available concerning the relationship between dietary energy levels and beta-adrenergic agonists indicates that energy levels do not need to be increased in the diet when feeding beta-adrenergic agonists. Basal dietary energy levels appear to be sufficient (approximately 8-9 Mcal of ME/d) to maximize lean gain. The lack of needing to increase the energy density of the diet does seem logical based on the decrease in carcass fat (Jones et al., 1988; Watkins et al., 1990; Williams et al., 1994) caused by the increase in lipolysis and/or decrease in lipogenesis. Beta-adrenergic agonist's ability to repartition energy towards protein accretion is the primary factor allowing dietary energy levels to remain unchanged.

A second factor sparing dietary energy is the amount of energy required for lean deposition compared to the amount required for lipid deposition. Noblet et al., (1999) reported the energy cost for protein deposition was 37.0 MJ of ME per kg of protein, and the energy cost of lipid was 47.7 MJ of ME per kg of lipid. This converts into approximately 2.23 Mcal of energy for 1 kg of lean tissue and 10.3 Mcal /kg of fat tissue. This would indicate that the shift to increased protein and lean tissue accretion that occurs with beta-adrenergic agonist is another factor that would spare dietary energy.

Current research

With today's higher lean accretion rates, the adequacy of a 16 percent CP diet for pigs fed Paylean™ needs to be reevaluated. Most pigs are also phase-fed to improve growth rates, leanness, and cost efficiency. A phase feeding program that would match the projected lean accretion curve expected with Paylean™ may yield even greater growth and leanness response as compared to only feeding 16 percent CP diets.

In a project conducted at Purdue University (Herr et al., 2000), four dietary treatments were formulated to be fed over a six-week period; treatments 1, 2 and 3 were fed throughout the six-week trial, while treatment 4 changed weekly. Treatments were as follows:

1) 16 percent CP control diet (no Paylean™) with a 0.82 percent lysine level.
2) 16 percent CP diet containing 18 g/ton of Paylean™, with a 0.82 percent lysine level.
3) 18 percent CP diet containing 18 g/ton of Paylean™, with a 0.97 percent lysine level.
4) A phase fed diet sequence containing 18 percent CP with a 1.08 percent lysine level during weeks one and four, a 20 percent CP diet containing 1.22 percent lysine was fed during weeks two and three, a 16 percent CP diet containing a 0.94 percent lysine level was fed during week five, and a 16 percent CP diet containing a 0.82 percent lysine level was fed during week six.

All diets in treatment four contained 18 g/ton of Paylean™. This phase feeding (CP, lysine) sequence was designed to match the previous lean accretion curves where pigs fed Paylean™ increased fat-free lean gain by 50 percent in weeks two and three and then the Paylean™ response declined to 11 percent by week six on Paylean™.

Average daily gain and F:G were improved during week's one, two and three, as CP and lysine levels were increased while feeding Paylean™ (Table 1). Pigs grew 15 percent faster in week one ($P<.05$) while decreasing ADFI by 5.2 percent ($P<.05$) and F:G by 16 percent ($P<.05$) when comparing the control diet to the phase fed + Paylean™ diet. During the second week, pigs grew 14.1 percent faster ($P<.05$) while decreasing ADFI by 6.7 percent ($P<.05$) and F:G by 18.4 percent ($P<.05$) when comparing the phase fed + Paylean™ treatment to the control treatment. During weeks three and four, ADFI was significantly decreased ($P<.05$) when comparing the control and phase fed + Paylean™ diets, however only numerical improvements were seen in ADG and F:G with Paylean™. No significant differences were observed in week five, however all pigs fed Paylean™ had numerically reduced ADG compared to the control pigs, and pigs on the phase fed diet showed the greatest decrease in growth performance.

▼ **Table 1. Effect of Paylean™ and dietary crude protein levels on weekly ADG, ADFI, and F:G in late finishing pigs.**

	16% CP (Control)	16% CP + Paylean™	18% CP + Paylean™	Phase + Paylean™	Std. Error
Initial Wt. , lb	153.1[a]	153.1[a]	153.3[a]	154.5[a]	.827
Week 1					
ADG, lb/d	2.72[b]	2.82[b]	3.07[a]	3.13[a]	.078
ADFI, lb/d	6.40[a]	6.20[a]	6.10[a]	6.07[a]	.136
F:G	2.25[a]	2.13[a]	1.94[b]	1.89b	.045
g Lys/d	24.0	23.1	26.9	29.8	
BW, lb	172.2[b]	172.8[b]	174.8[ba]	176.5[a]	.809
Cost/lb gain, $	.1410[a]	.1324[ab]	.1282[b]	.1263[b]	.004
Week 2					
ADG, lb/d	2.56[b]	2.48[b]	2.71b[a]	2.92[a]	.083
ADFI, lb/d	6.67[a]	6.41[a]	6.28[a]	6.22[a]	.143
F:G	2.61[a]	2.61[a]	2.32[b]	2.13[b]	.071
g Lys/d	25.0	23.9	27.7	34.5	
BW, lb	190.1[b]	190.1[b]	193.7b[a]	196.9[a]	1.07
Cost/lb gain, $	.1633[ab]	.1680[a]	.1538[b]	.1507[b]	.005
Week 3					
ADG, lb/d	2.43[a]	2.53[a]	2.56[a]	2.61[a]	.066
ADFI, lb/d	6.44[a]	6.19[a]	6.33[a]	6.11[a]	.185
F:G	2.67[a]	2.45[a]	2.49[a]	2.34[a]	.078
g Lys/d	24.2	23.1	27.9	33.8	
BW, lb	207.1[b]	207.6[a]	211.6[a]	215.2[a]	1.12
Cost/lb gain, $	.1673[a]	.1530[a]	.1651[a]	.1656[a]	.006
Week 4					
ADG, lb/d	2.38[a]	2.38[a]	2.48[a]	2.43[a]	.117
ADFI, lb/d	6.32[a]	5.93[ba]	5.60[b]	5.55[b]	.144
F:G	2.69[a]	2.50[a]	2.27[a]	2.31[a]	.106
g Lys/d	23.7	22.1	24.7	27.2	
BW, lb	224.6[a]	224.2[a]	229.0[a]	232.1[a]	1.81
Cost/lb gain, $	.1626[a]	.1570[a]	.1506[a]	.1465[a]	.009
Week 5					
ADG, lb/d	2.09[a]	1.88[a]	1.86[a]	1.67[a]	.118
ADFI, lb/d	6.34[a]	5.65[a]	5.48[a]	5.94[a]	.264
F:G	3.20[a]	3.21[a]	3.09[a]	3.58[a]	.129
g Lys/d	23.8	21.1	24.2	25.4	
BW, lb	238.7[a]	237.4[a]	241.9[a]	243.8[a]	2.28
Cost/lb gain, $	.2000[a]	.2012[a]	.2050[a]	.2273[a]	.010

[a,b] Means in a row with different superscript differ, P<.05 (Student-Newman-Keuls)

Four- and five-week overall performance is shown in Table 2. From 0 to 4 weeks, ADG and F:G were all improved as the level of CP and percent lysine were increased. Phase- fed + Paylean™ pigs showed significant improvements (P<.05) in ADG and F:G compared to the control and control + Paylean™ treatments. From 0-5 weeks, significant improvements were not seen in ADG as CP and percent lysine levels increased, due to the greatly reduced performance during week 5 by the 18 percent CP + Paylean™ and phase fed + Paylean™ pigs.

▼ **Table 2. Overall performance summary for week's 0-4 and 0-5 of pigs fed Paylean™ and varying crude protein levels.**

Overall	16% CP (Control)	16% CP + Paylean™	18% CP + Paylean™	Phase + Paylean™	Std. Error
0-4 Wk					
ADG, lb/d	2.55[b]	2.54[b]	2.70[ba]	2.77[a]	.052
ADFI, lb/d	6.39[a]	6.13[a]	6.03[a]	5.95[a]	.124
F:G	2.55[a]	2.44[a]	2.26[b]	2.17[b]	.034
BW, lb	224.6[a]	224.2[a]	229.0[a]	232.1[a]	1.81
Cost/lb gain, $	1569[a]	.1515[a]	.1480[a]	.1479[a]	.003
0-5 Wk.					
ADG, lb/d	2.44[a]	2.41[a]	2.53[a]	2.55[a]	.052
ADFI, lb/d	6.38[a]	6.04[a]	5.92[a]	5.94[a]	.141
F:G	2.68[a]	2.59[a]	2.42[b]	2.45[b]	.044
BW, lb	238.7[a]	237.4[a]	241.9a	243.8a	2.28
Cost/lb gain, $	.1635[a]	.1575[a]	.1552[a]	.1581[a]	.003

[a,b] Means in a row with different superscript differ, P<.05 (Student-Newman-Keuls)

▼ **Table 3. Effect of Paylean™ and dietary crude protein on carcass characteristics in late finishing pigs.**

	16% CP (Control)	16% CP + Paylean™	18% CP + Paylean™	Phase + Paylean™	Std. Error
Slaughter BW, lb	248.6[b]	246.3[a]	250.5[c]	251.7[d]	
HCW, lb	188.3[b]	189.2[b]	188.9[b]	192.0[a]	.927
10 th Rib BF, in*	.78[a]	.64[b]	.64[b]	.59[b]	.035
LEA, in*	7.02[b]	7.37[ba]	7.23[ba]	7.56[a]	.162
% Lean*	54.26[b]	56.31[a]	56.09[a]	57.01[a]	.575
% Yield	75.5[b]	75.8[b]	75.7[b]	77.0[a]	.370

[a,b] Means in a row with different superscript differ, P<.05 (Student-Newman-Keuls)

However, F:G was still better for the pigs fed Paylean™ and 18 percent CP or the phase fed feeding program compared to the control and the control + Paylean™ treatments (P<.05). These four and five week summary's indicate that improvements are made when feeding the phase fed + Paylean™ diet, compared to the other three treatments, during the first four weeks on Paylean™. But, these improvements are lost during the fifth week when Paylean™ was fed in conjunction with this phase feeding program to yield a similar response as the 18 percent CP + Paylean™ treatment.

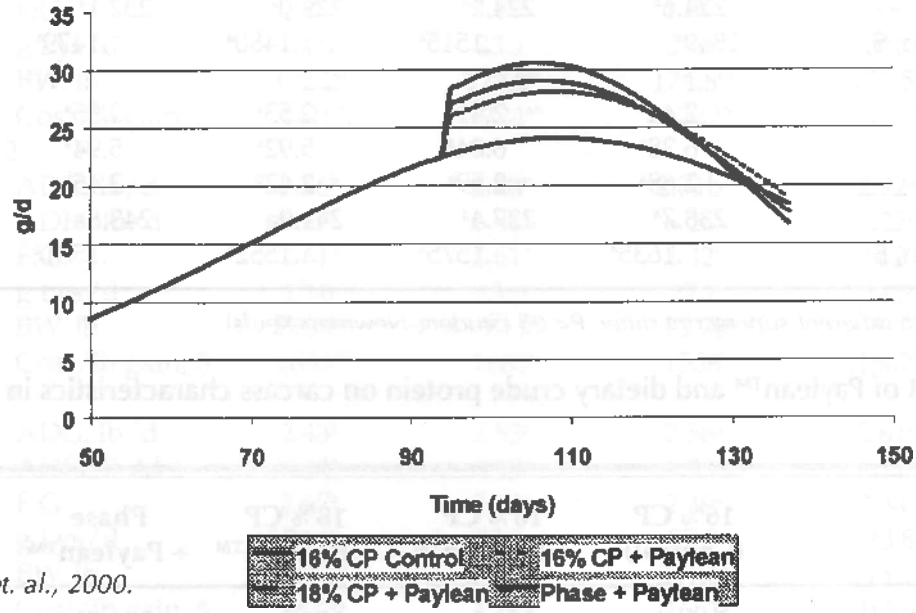
Pigs fed Paylean™ had reduced 10th rib fat depth (P<.05) and an increased percent lean (P<.05). LEA and percent yield were significantly higher (P<.05) in those pigs that were fed the phase-fed treatment containing Paylean™ when compared to the control treatment (Table 3).

Results from this trial would indicate that a four-week late finishing program, feeding Paylean™ in conjunction with the phase-fed treatment, would yield the best return on investment. Performance improvements during these four weeks would compensate for the higher diet costs and result in a lower cost/lb of gain, compared to the control pigs. The increase in carcass premium/pig of nearly $3.00, would be expected to pay for the added Paylean™. How-

ever, the pigs fed Paylean™ with the phase feeding program were 5.1 lbs. heavier in the same amount of time, and were leaner with a similar diet cost per lb. of gain.

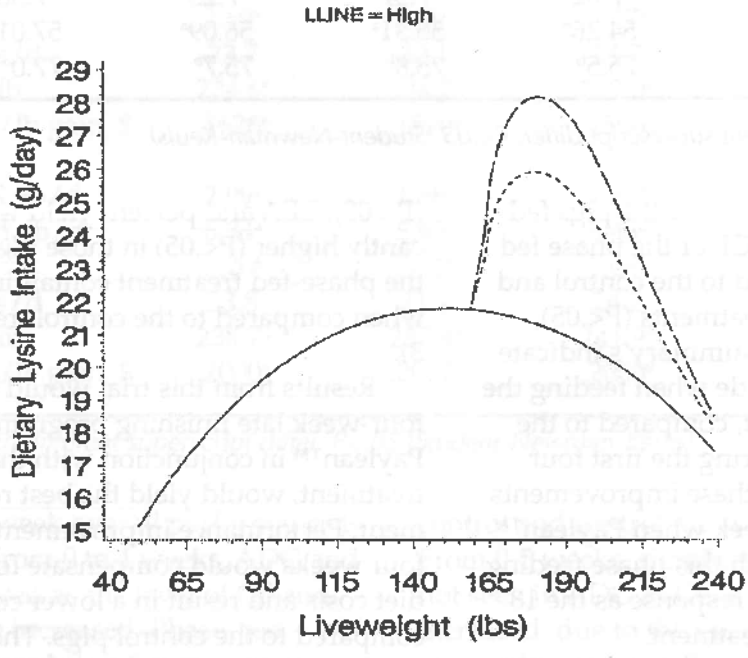
Utilizing ADG and serial ultrasound backfat thickness and loin eye area values to model the nutrient requirements of these pigs, the lysine requirements were increased to approximately 30 g/d while being fed Paylean™, whereas the controls needed only 24 g/d at the start of the trial (Figure 1). As Paylean feeding time increased, the requirement for increased lysine intakes declined to match the protein accretion rates of the pigs, so as the level of dietary lysine required is similar to the controls after 5-6 weeks on Paylean (18 g/d). These levels are slightly

▼ Figure 1. Estimated lysine requirements while feeding varying dietary CP levels.



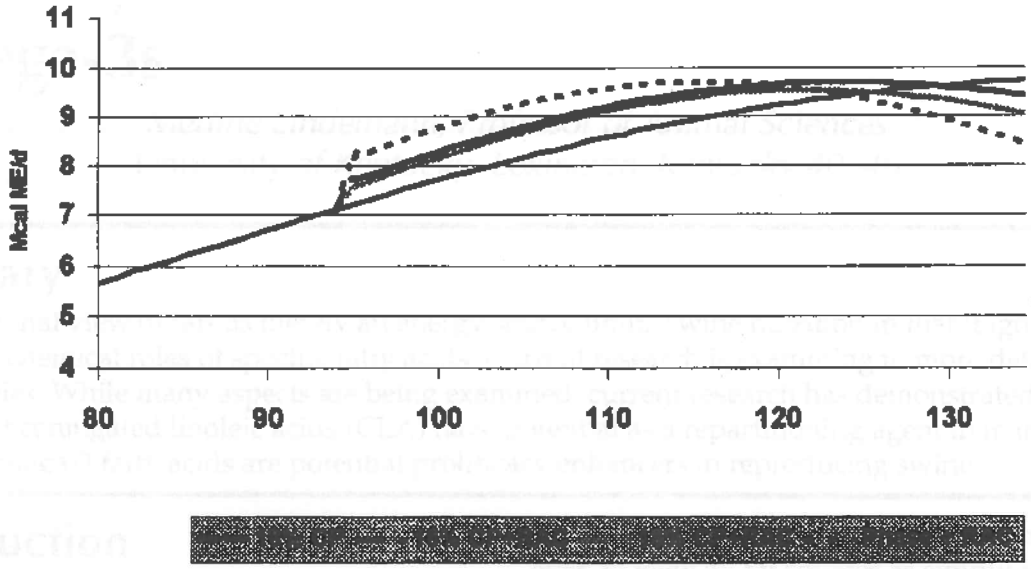
Source: Herr et. al., 2000.

▼ Figure 2. Estimated lysine requirements while feeding three levels of Paylean™.



Source: Schinckel et. al., 1992.

▼ **Figure 3. Energy requirements while feeding Paylean™.**



Source: Herr et. al., 2000.

higher than previously estimated (Figure 2) and are likely related to increased lean accretion rates of the control pigs (1992 vs 2000).

The energy requirements for the lean and adipose tissue deposition rates in the Herr et. al., 2000 trial (Figure 3), indicate that approximately 9.5 Mcal of energy per day was required to maximize the Paylean response and the level was only slightly higher than the controls. This level is similar to 6 lb/d feed intake of a 1600 Mcal DE/lb diet. ▲

▶ Fatty acid nutrition of swine: CLA and Omega-3s

Merline Lindemann, Professor of Animal Sciences
University of Kentucky, Lexington, Kentucky 40546

Summary

The traditional view of fats as merely an energy source limits swine nutrition in that it ignores the unique biochemical roles of specific fatty acids. Current research is examining in more detail some of these roles. While many aspects are being examined, current research has demonstrated fairly clearly that conjugated linoleic acids (CLA) have potential as a repartitioning agent in market swine and that omega-3 fatty acids are potential prolificacy enhancers in reproducing swine.

Introduction

This century has been one of tremendous advancement in the field of nutritional sciences. A century ago the knowledge existed for the animal's need for energy, protein, calcium, phosphorus, and salt. A need for little else was known or, if known, it was not recognized as something to be universally supplemented. An understanding of vitamins, specific amino acids, and the trace elements was absent. The critical nature of ratios (such as Ca:P or of amino acids to lysine) was also absent in the formulations. The current state of understanding is markedly advanced. However, a danger exists that after periods of great advancement, it is relatively easy to believe that all has been discovered and that little opportunity remains for further improvements. This perspective is arrogant. Strict adherence to this perspective can limit one from further knowledge needed to provide the competitive advantage to survive hard economic periods when others are forced to exit the industry. Two particular areas within the general area of fats that may see significant further developments in the next few decades are the areas related to conjugated linoleic acids (CLA) and specific fatty acid needs, particularly the omega-3 fatty acid, of pigs.

Fat sources

Fat has traditionally been viewed primarily as an energy source. It is an excellent energy source, having an energy value more than twice that of the cereals that are the primary energy sources for pig and poultry production. However, to view all fat sources as simply energy sources limits this area of nutrition. To use another nutrient area as an example, we do not view all minerals the same—calcium is not the same as zinc, nor can iron replace copper for all functions, and, even more specifically within a single mineral, iron oxide is not the same as iron sulfate because one is thought to be absolutely unavailable (the oxide form) while the other is viewed as a premier iron source because it is so highly available (the sulfate form). So, if all minerals are not the same, and all nitrogen sources are not the same (the amino acid lysine is not the same as methionine or tryptophan), then why should we think that all fat sources are the same?

It has been known for a long time that each fat source has a unique fatty acid (FA) profile. These profiles differ with regard to the chain length of the FA (specifically how many carbon atoms are present) as well as the specific number and location of certain bonds (in particular the unsaturated or double bonds) within the FA. This different fatty acid profile affects how hard the fat is (liquid, semi-hard, or hard) which also affects carcass fat quality. But the FA profile also affects certain body functions, because there are certain fatty acids that the body can not make and must obtain from the diet. This particular need is related to the lack of certain enzymes in animals that can change the length and bonding of the different fatty acids. Failure to provide these certain fatty acids (the longer chain fatty acids with double bonds in certain locations)

does not mean that the animal will die immediately because the body is very adaptive. But it does mean that there may be losses of efficiency or added stresses or susceptibilities to disease that would not occur if the fatty acids were supplied.

The 1988 NRC Nutrient Requirements of Swine discussed the need for essential fatty acids (EFA) that must be supplied in the diet in a single paragraph. The paragraph ends, after stating that the only EFA of concern is usually present in adequate amounts, with the statement that "Therefore, the main concern is the use of lipids as an energy source." The publication does list a value for the amount of the EFA needed and it does not list the FA profile of any ingredients be they grains, byproducts, or fats themselves. The recent 1998 revision of the NRC Nutrient Requirements of Swine has a slightly longer single paragraph dealing with the FA profile which does recognize that there may be need for specific types of FA but concludes with the same basic statement about the primary concern with the use of lipids as energy sources. However, the recent publication does make the very useful addition of a table that gives a much more thorough presentation of the different FA profiles of many fat sources and of several characteristics of those fat sources. While there may not have been sufficient research to allow the review committee to make changes in the requirement estimates for swine, the addition of this table does begin a process that will eventually culminate in the setting of more specific FA requirements in the future. These changes in requirements will be one of the advances of the next century.

Background on CLA

Conjugated linoleic acids (CLA) are a naturally occurring group of isomers of linoleic acid. These isomers differ from the normal structural configuration of linoleic acid in that the position and shape of the double bond(s) is altered. The standard nomenclature for linoleic acid would be cis-9, cis-12 octadecadienoic acid. The two most common isomers of this fatty acid with two double bonds would be cis-9, trans-11 and trans-10, cis-12. These, and other less common isomers, occur naturally in many foods with the greatest incidence found in the meat and milk of ruminant animals. Fatty acids are generally hydrogenated in the rumen and these CLAs are intermediates in the hydrogenation of linoleic acid that happen to be absorbed and incorporated into body tissue and milk prior to complete hydrogenation in the rumen.

Interest in CLA began in earnest in the mid-1990s when research demonstrated that thier inclusion in the diet stimulated the immune system, protected against certain types of cancer, and protected against atherosclerosis. In addition to these health-related responses, supplementation of diets for rats (Chin et al., 1994) and mice (Park et al., 1997) resulted in a repartitioning of nutrients toward lean deposition and away from fat deposition. Associated with this change in carcass composition was an improved feed efficiency and, in some cases, growth rate.

Research results of note with CLA

One of the first research studies conducted with pigs was conducted in Alberta (Dugan et al., 1997). Researchers used a simple two-treatment experiment that examined either a rich source of linoleic acid (sunflower oil) or a source of CLA fed to pigs during the period of 135–233 lbs. A tendency for an improvement in feed efficiency (Table 1) was noted as well as clear increases in lean percentage and decreases in fat percentage. In addition to the effects on the loin, numerical increases in the lean percentage of the shoulder, boston butt, ham, and belly were noted ($P<.05$) with concomitant decreases in fat percentage of all of those carcass portions (except the belly where the fat percentage was not presented). These types of changes would have an obvious impact on total saleable primal cut product.

These types of results have been confirmed in several subsequent studies. One of the most recent studies from Iowa State University (Thiel-Cooper et al., 2001) used multiple levels of CLA to examine dose responsiveness of pigs fed 57–255 lbs. (for the sake of comparison to the Alberta study, the highest level of the ISU study was 1.67 percent CLA oil which had 60 percent CLA to provide a total of 1 percent CLA [the exact level supplied by the Alberta study]). There was a very clear response in the ISU study

▼ Table 1. Effect of CLA addition to finishing swine diets.

Diets:	Sunflower	CLA
Growth performance		
ADG, lb	2.22	2.22
ADF, lb	6.78	6.42*
Feed/Gain	3.07	2.89*
Carcass response		
Total lean %	60.4	61.8**
Total subcutaneous fat %	22.1	20.6**
Total intermuscular fat %	4.65	4.80
Loin lean %	19.4	20.1**
Loin subcutaneous fat %	9.12	8.56**
Loin intermuscular fat %	1.21	1.24

Adapted from Dugan et al. (1997)
Sunflower oil and CLA oil inclusion rate of 2%; CLA oil had 50% of the fatty acids as CLAs.
** P<.10; ** P<.05.*

▼ Table 2. Growth performance response of pigs to graded levels of CLA.

Dietary CLA %:	0.00	0.12	0.25	0.50	1.00
ADG, lb **	2.07	2.05	2.10	2.14	2.24
ADF, lb	5.90	5.58	5.62	5.79	5.79
Feed/Gain **	2.84	2.72	2.68	2.70	2.60

Adapted from Thiel-Cooper et al. (2001)
*** Linear effect, P<.05.*

(Table 2) with regard to ADG and feed/gain. Regarding carcass effects, Table 3 provides the wholesale-ready product weights from the study which again demonstrates clear increases in saleable product. This appears as if it may be a win-win situation with improved growth performance for the producer and improved saleable product (and less trim) for the packer.

In addition to the benefit in lean percentage, there is the potential benefit that the meat from supplemented pigs may provide humans with CLA through its incorporation into the tissue of the pig. As mentioned earlier, the CLA originate naturally in the rumen, are absorbed, and then are incorporated into milk fat and tissue fat of the ruminants. Likewise in mature swine, dietary CLA are incorporated into adipose tissue and milk of gestating and lactating sows (Bee, 2000). Bee (2001) examined the potential for CLA supplementation to impact tissue levels of CLA in market animals by feeding several oils over the weight range of 154–218 lbs. He observed numerical advantages in growth performance (Table 4) and also demonstrated the CLA incorporation into backfat and muscle tissue fat. This, then, presents the possibility of creating a product that can potentially impact human health through its fat content. While this initial work with CLA is very promising, further research is needed.

Baumgard et al. (2001) report that CLA supplementation of dairy cows does reduce milk fat synthesis due to the down-regulation of certain enzymes; this same potential should

▼ **Table 3. Wholesale-ready product weight from pigs fed graded levels of CLA.**

Dietary CLA %:	0.00	0.12	0.25	0.50	1.00
Finished ham, lb *	16.6	17.0	17.3	17.6	18.0
Finished loin, lb *	17.7	18.3	19.0	18.9	19.3
Finished picnic, lb	5.8	6.1	6.2	6.1	6.3
Finished butt, lb **	5.4	5.1	5.4	5.5	5.9
Finished belly, lb **	11.4	10.8	11.4	11.9	13.0

Adapted from Thiel-Cooper et al. (2001)
** Linear effect, P<.10; ** Linear effect, P<.05.*

exist in sows. The most appropriate time to initiate feeding and the proper level of supplementation in differing situations (diets that already have added fat; diets of different grains and, therefore, fatty acid profile; etc.) have not all been defined at present.

Background on omega-3 fatty acids

Omega-3 fatty acids exist naturally in the food/feed supply. They are fatty acids that have the first double bond located at the third carbon atom from the methyl end of the fatty acid. Alternatively, omega-6 and omega-9 fatty acids have the first double bond located at the sixth and ninth carbon atom, respectively, from the methyl end of the fatty acid. Feedstuffs have varying amounts of each of these types of fatty acids. The source of greatest content of the omega-3 fatty acids is marine (fish) oil. Warm water fish and cold water fish vary in the fatty acid profile, largely because of the food supply upon which they feed. Of additional discussion in the omega-3 area is not only the omega-3 bonding but the chain length of the fatty acids. Some plant sources have more omega-3 fatty acids than other plant sources, but the omega-3s in all plant sources tend to be almost exclusively linolenic acid (18:3). Longer chain omega-3s such as eicosapentanoic acid (EPA, 20:5) and docosahexanoic acid (DHA, 22:6) are found strictly in marine sources.

The interest in omega-3 fatty acid nutrition originates from a health perspective. Epidemiological surveys revealed that some cultures (such as Eskimos) had extremely high fat intakes (blubber for example) but have experienced low frequencies of atherosclerosis. Normally, high fat intake would be associated with high degrees of arterial clotting. The absence of the clotting raised questions that pointed to the fact that the fatty acid profile of the fat intake was equally as important as the level of fat intake. Additional items of interest related to these fatty acids are that retinal and brain tissue hava a disproportionately higher content of omega-3 fatty acid level compared to the rest of the body, suggesting a specific need of certain tissues for these fatty acids. Some early research was related to the effects of gestational fat intake on visual acuity of offspring or learning ability of offspring. A further item of note related to overall fat level in the body is that some female athletes with extremely low fat intake and low body-fat content cease menstruation which may reinitiate upon restoration of more typical body composition. Related to male reproduction is the fact that DHA is quite high in sperm, functioning in cell membrane integrity and fluidity.

Research results of note with omega-3 fatty acids

Much of the current research in the area of omega-3s continues to be in health-related areas. A major interest is in the potential ability of the particular fatty acid levels or the ratio of fatty acids on the response of various aspects of the immune system. This will be an area of continued research for an extended time. An area that can be capitalized on now, however, is in the area of reproduction. One of the first examinations of the potential of this fat source was conducted at the University of Alberta (Fengler et al., 1990). While results were not conclusive

▼ **Table 4. Effect of dietary CLA supplementation on tissue CLA content.**

Dietary oil:	CLA oil	Sunflower Oil	Lard
Growth performance			
ADG, lb	2.20	2.09	2.05
Feed/Gain	2.81	2.95	3.00
Carcass measurements			
Lean percentage	56.8	57.5	56.9
Fat percentage	12.6	13.6	13.0
Loin fat depth, in. **	0.56	0.72	0.69
Fatty acid profiles, %			
Backfat			
SFA **	44.6	40.6	40.0
MUFA **	37.7	41.0	45.9
PUFA **	17.7	18.4	14.1
CLA **	4.2	Traces	Traces
Loin muscle			
SFA **	41.7	38.2	37.3
MUFA **	44.9	46.6	49.9
PUFA	13.4	15.2	12.8
CLA **	1.5	n.d.	n.d.

Adapted from Bee (2001); oil levels are 2% of the diet with the CLA oil containing 59% CLA.
SFA - saturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; n.d. - not detectable.
*** Treatment differences, P<.05.*

with regard to improvements in reproduction, an interesting observation was made that embryos differed in their content of certain omega-3 FA. As has been stated, some types of fish oils are particularly rich in the longer-chain omega-3 FA. Coupled with these facts was the anecdotal information from Northern Europe and from South Africa that putting fish meal in reproduction diets was worth a 5 percent improvement in conception rate and added one-half pig per litter. The sum of this information resulted in a study at Virginia Tech (Perez Rigau et al., 1995) evaluating several sources of fat in gestation diets to determine if oil/fat supplementation would enhance embryo survival in pregnant gilts and to determine if the response, if observed, was related to their omega-3 FA content.

Three experimental diets were used which contained 4 percent added fat either as coconut oil (CO), soybean oil (SO), or menhaden oil (MO). A fourth diet containing corn starch (SR) approximately isoenergetic to the oil diets was used as an energy control. Statistically, percentage fetal survival did not differ according to dietary treatment (Table 5) but the numerical responses were consistent with the anecdotal information of 5 percent in conception rate and one-half pig/litter. The ratio of omega 3/omega 6 FA was higher in conceptus tissue (not shown) than in maternal plasma, which suggested a possible importance of the omega 3 FA. The ratio was higher ($P < .05$), as expected, for the MO diet compared with the other diets. Subsequently, a total of 46 sows were used in three trials to further evaluate the effects of MO on fetal survival percentage relative to the corn starch control diet; the results again (Table 6) demonstrated no statistically significant differences in fetal survival percentage due to the MO addition. The high fetal survival percentage observed in gilts on all the treatments and the unequal ovulation rate in sows on different oil diets precluded definitive conclusions regarding the effects of supplemental oil on fetal survival.

▼ **Table 5. Effects of dietary treatments on reproductive traits of gilts fed various sources of supplemental oil.** [a]

Diets :	SR	CO	SO	MO
Age at breeding, d	218	216	216	221
Wt at breeding, lb	284	282	281	281
Wt at slaughter, lb	329	330	323	322
Corpora lutea, n	14.3	13.8	13.6	14.0
Total fetuses, n	11.6	11.8	11.1	12.2
Live fetuses, n	11.0	11.1	10.4	11.8
Live fetal survival, %	77.1	80.7	76.7	84.8

Adapted from Perez Rigau et al. (1995)
[a] Where SR = starch; CO = coconut oil; SO = soybean oil; MO = menhaden oil. SR diet isocaloric to the oil supplemented diets.

▼ **Table 6. Effect of menhaden oil on fecundity by study.** [a]

Response:	Total Fetus		Live Fetus		Total Survial %		Live Survial %		Conception Rate	
Diet:	SR	MO	SR	MO	SR	MO	SR	MO	SR	MO
Trial Parity										
1 1	12.1	11.7	11.2	11.5	84.0	80.1	78.1	78.9	11/11	11/11
2 1	11.1	12.6	10.7	12.1	78.8	93.7	75.9	90.2	7/9	8/9
3 3	10.2	12.3	7.8	9.8	51.5	73.1	37.9	59.6	5/7	6/6
4 3	12.9	13.3	11.7	10.8	67.5	64.4	61.6	52.6	7/9	10/10
5 3	11.3	11.2	10.0	10.4	71.3	63.9	62.7	59.7	6/7	5/7
Average:	11.5	12.2	10.3	10.9	70.6	75.2	63.2	68.2	36/43	40/43

Adapted from Perez Rigau et al. (1995) No dietary differences were detected, P > .05.
[a] Where SR=starch and MO=menhaden oil.

However, again, the numerical responses were consistent with the anecdotal information of 5 percent improvement in conception rate and one-half pig/litter.

Even though differences for fetal survival across treatments were not significant, embryo survival in Trial 2 was higher ($P < .06$) for gilts fed MO than for the controls, 93.7 percent vs 78.8 percent, respectively. The addition of slaughtered sows to assess the specific effects of the MO on fetal survival did not clarify the issue. Both total and live pig survival percentages were greater after three trials ($P < .03$), but did not differ after the five trials. Attempts to extract the most information from these sow trials by comparing only matched littermates on the two treatments magnified the litter size response to MO but did not change the statistical significance. It should be noted that while statistical significance varied throughout the trials, the numerical response was close to the anecdotal reports being 0.6 - 0.8 live fetus, 5–7 percent in fetal survival rate, and 10 percent in conception rate.

The mean response in litter size and conception rate observed by Perez Rigau et al. (1995) is similar to that of Palmer et al. (1970) who reported that the addition of 6 percent whole menhaden fish meal for two parities resulted in 0.9 more live pigs/litter at birth than from

▼ **Table 7. Effects of a tuna oil product on factors related to reproduction.**

	Control	Supplemented
Boars		
Sperm concentration (106 per ml)	502	584*
Total sperm per ejaculate (109)	74.1	83.4*
Percentage alive	78	88
Motility score	3.9	4.5*
Gilts bred with semen from the boars		
Number bred	246	232
Conception rate, %	83	90
Born live per litter	10.2	10.6*
Total fecundity (Born alive per 100 services)	846	954*

** Differed from control group, P<= .05.*

control sows (P < .05). They also observed an increase of 8.2 percent in sows farrowing as a percentage of sows bred for sows fed the fish meal diet. The increase in oil content of the gestation diet would indicate that the fish meal contained about 5 percent oil. It has been pointed out, however, by Baker et al. (1974) that the basal diet in the Palmer et al. (1970) study did not contain supplemental vitamin E or selenium and that the addition of the fish meal would be a favorable source of both nutrients. Baker et al. (1974) did not observe improvements in reproductive performance when adding 3 percent menhaden fish meal to gestating diets.

With respect to boar nutrition, the high content of DHA in sperm has resulted in studies examining the effects of supplementation of boars on sperm response as well as response of females inseminated with that sperm. Results of a commercial study using 35 boars and 478 gilts are given in Table 7. The magnitude of response observed in the gilts is consistent with the previously discussed studies but the supplementation was only to the males that supplied semen for insemination, not in the female.

Further research certainly is warranted with both male and female swine to investigate the role of omega-3 FA in the development of the fetal pig and the possible influence of these FA on fetal survival in swine, as well as in boar production and longevity. These research studies may reveal the linoleic acid is not the only essential fatty acid with respect to reproduction and may result in future changes in the NRC in the nutrient area of fats.

References cited

Baker, D. H., B. A. Molitoris, A. H. Jensen, and B. G. Harmon. 1974. Sequence of protein feeding and value of alfalfa meal and fish meal for pregnant gilts and sows. J. Anim. Sci. 38:325.

Baumgard, L. H., J. K. Sangster, and D. E. Bauman. 2001. Milk fat synthesis in dairy cows is progressively reduced by increasing supplemental amounts of trans-10, cis-12 conjugated linoleic acid (CLA). J. Nutr. 131:1764.

Bee, G. 2000. Dietary conjugated linoleic acids alter adipose tissue and milk lipids of pregnant and lactating sows. J. Nutr. 130:2292.

Bee, G. 2001. Dietary conjugated linoleic acids (CLA) affect tissue lipid composition but not de novo lipogenesis in finishing pigs. J. Nutr. (in press).

Dugan M.E.R., J. L. Aalhus, A. L. Schaefer, and J.K.G. Kramer. 1997.The effect of conjugated linoleic acid on fat to lean repartitioning and feed conversion in pigs. Can. J. Anim. Sci. 77:723.

Fengler, A. I., S. K. Baidoo, and F. X. Aherne. 1990. Improving embryo survival by dietary supplementation of oils in early gestation. 69th Annual Univ. of Alberta Feeders Day Report, p 7.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, D.C.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press, Washington, D.C.

Palmer, W. M., H. S. Teague, and A. P. Grifo, Jr. 1970. Effect of whole fish meal on the reproductive performance of swine. J. Anim. Sci. 31:535.

Perez Rigau, A., M. D. Lindemann, E. T. Kornegay, A. F. Harper, and B. A. Watkins. 1995. Role of dietary lipids on fetal tissue fatty acid composition and fetal survival in swine at 42 days of gestation. J. Anim. Sci. 73:1372.

Thiel-Cooper, R. L., F. C. Parrish, Jr., J. C. Sparks, B. R. Wiegand, and R. C. Ewan. 2001. Conjugated linoleic acid changes swine performance and carcass composition. J. Anim. Sci. 79:1821. ▲

▶ Animal protein by-product ingredients in swine rations

Gary G. Pearl
Fats and Proteins Research Foundation, Bloomington, Illinois

Summary

Animal byproducts have been an important ancillary companion to livestock and poultry production for over a century. The protein ingredients processed as a result of their production have been subject to innumerable research studies throughout this period. Their historic contribution has been evident. Challenges and concerns have appropriately been met via the dedicated scientific community that has persistently provided guidance and answers for their most effective and efficient utilization. It has not been until the recent years of BSE discussions that the challenges outpaced the science decisionmaking regarding their use that were necessitated by innumerable factors that differ greatly from those that exist in our country. All of the industries involved in the production of meat in the US have accepted and complied with the regulations in place that are based primarily on science-based facts modified to incorporate safety factors. Within these regulatory guidelines, animal protein ingredients can be used as high quality feed ingredients. To do otherwise, the industries and the consuming public are challenged with decisions that demand conversion from a utilization society to that of facing a disposal problem.

Animal byproducts have been an important protein source to livestock and poultry industries for many years. Reliance on their nutrient contributions during the initial development of the science of animal nutrition places significance on their importance as a historic milestone. In one of the first animal nutrition experiments reported, Professor Plumb of Purdue University in 1901 demonstrated significant, although not statistically analyzed data, decreases in the time required for swine to reach slaughter weight following the addition of animal protein tankage to traditional, exclusively ear corn diets. Other researchers followed by adding dried blood to tankage, which improved performance even more and lead to the development of digester tankage, starting the long and continual progress made in swine nutrition. These early successes spurred research using animal byproducts as diet ingredients, as well as basic animal nutrition, in all species. It was quickly realized that the so-called value-added products could result from the ancillary recycling of heretofore discarded materials; a practice that has thus been in existence for over a century.

Many changes have taken place in the nutrition and feeding of pigs during the past century. Most of the factors associated with the pig and its production have changed dramatically, particularly accelerated during the past decade. Historically there have been at least two primary influences that have altered the role that animal proteins provided for swine rations. The discovery of vitamins and other previously referenced "unidentified growth factors", accompanied by their subsequent syntheses, and the agronomic development of soybeans. These factors revolutionized swine ration formulas and feeding programs into simplified corn-soybean diets supplemented with vitamin-mineral premixes. Though not always resulting in the most efficient or cost effective results, the simplicity of the "mix-mill," "corn-soy," "on-farm mixed" diets allowed "these simple" diets to become the standard system for grow-finish swine feeding programs. Animal protein ingredients were essentially relegated to special use, commercial supplements, and pre-mix programs within the swine market. Their alternative utilization as protein sources by the developing integrated poultry industry, adopted and utilized least or best cost feeding programs much

earlier than the other species. This process essentially took advantage of the lower cost of ingredients and production. The poultry industry is still a major utilizer of animal protein, using over 36 percent of all production.[1]

During the last decade the swine industry has become more like that of poultry, in that central feed manufacture has again become the norm, and animal protein ingredients are generally a part of the feed ingredient matrix for compounding diets. Corn and soybean meal remain the major ingredients used in pig diets. Current formulation systems where animal proteins are offered use nearly the maximum established levels of meat and bone meal to provide protein amino acids, energy, and minerals for swine diets. On the basis of their nutrient merit, animal byproducts continue to be important feed ingredients for all species, including swine, extending to the future.

The continued use of animal byproducts will probably be influenced more by factors other than their nutrient contributions. The global communication process, in which an incident someplace becomes an incident everywhere, is a major factor. The bovine spongiform encephalopathy (BSE) hysteria resulting from the outbreaks in the European Union, in which 99.9 percent of all cases have been in the United Kingdom or directly linked to animal or product movement from the UK, is an excellent illustration. The illustration was renewed with the worldwide attention given to the foot and mouth disease (FMD). Thus the future of animal byproduct ingredients will be determined more by perception, regulatory activities, international trade manipulations, opportunistic marketing practices, and either by the support or non-support of the animal industries sector, than by their nutritional merits.

There are no scientific reasons that animal protein ingredients are not safe feed ingredients for livestock and poultry rations. The US and our North American neighbors have responded to the European BSE issues responsibly. Beginning in 1986, import restrictions were implemented, as were surveillance programs to detect any presence of BSE within our boundaries. These controls have been enhanced. In 1997 FDA rules prohibited the use of certain mammalian proteins for use in cattle and other ruminant feeds (Title 21-CFR 589.2000) were implemented. To supplement the FDA compliance inspections, third party certification programs have been developed by feed manufacturing, rendering, and beef packing industries to assure that restricted protein ingredients are not included in ruminant diets. All of these responsible "firewall" actions directed at consumer confidence for food safety were implemented despite the scientific fact that BSE has not been reported in the US.

The feed ingredient restrictions do not affect feeds other than for ruminants. Thus all animal protein ingredients are available for use in swine diets. BSE transmission studies at The Veterinary Laboratories Agency, Weybridge, UK reported that pigs receiving oral challenges of 400 grams of BSE infective brain stem material at three different times during their growth cycle were subsequently sacrificed over a 2–7 year period with no infectivity found in assayed tissues. Similar transmission studies have likewise been conducted with chickens at the Weybridge laboratories. The challenge studies consisted of oral, intracranial, and intraperitonal inoculations. The oral challenge consisted of 5 grams of BSE infected brain stem given by esphageal intubation into the crop at 4 weeks, 5 weeks, and 6 weeks of age. The parental challenge consisted of 50 (ml intracranial and 1 ml intraperitoneal. Inoculated chickens were taken to a 57-month endpoint with no infectivity found in the tissues at endpoint. Tissues were also sub-passaged back into chickens and mice with negative findings. Both clinical and subclinical transmissions were concluded to be negative.[2]

One longstanding expressed concern and image-tarnishing perception is the association of microorganism contamination of animal byproducts. Though there are a number of excellent baseline studies that illustrate bacterial contamination can occur in all feedstuffs, animal protein sources are often singled out. The salmonella sp. have been of major concern. A comprehensive study completed by the US Food and Drug Administration in 1997 involved 100 animal protein processors providing 3030 samples and 68 vegetable protein processors providing 1500 samples. The sampling plan was designed to detect one salmonella organism in 278 gms. of product. The sensitivity of the testing procedure can be best compared to the

▼ **Table 1. FPRF Project 99A-5 Tentative raw material culturing.**

Bacterial Isolations*	Winter	Summer
a) Clostridium spp	30/42	30/42
b) Clostridium perfringens	30/42	30/42
c) Listeria spp	33/42	31/42
d) Listeria monocytogenes	4/42	3/42
e) Campylobacter spp	19/42	6/42
f) Campylobacter jejuni	15/42	2/42
g) Salmonella spp	37/42	34/42
h) Sevovar distribution will be available		
i) E. coli has been monitored and found to be a significant contaminate of the raw material.		

**Numerical Colony Forming Unit (CFU) determinations was not achievable in all cases due to severe overgrowth of cultures.*

knowledge that a single mouse fecal pellet can contribute up to 250,000 salmonella cells when serving as a contaminate source. Several thousand colony forming units are required for intestinal colonization depending on specific serovars.[3]) This FDA surveillance report indicated all feed ingredients have potential for containing salmonella organisms. It further indicated that the exclusion of one of these product categories (animal vs. plant) in favor of the other in formulating feed is not a valid approach to ensuring a salmonella-free feed.[4][5] The FDA study demonstarted that all ingredients can be contaminated and highlighted the need for an all inclusive biosecurity program based on Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) principles. In a recent presentation, Lynne Underhill of the Canadian Feed Regulatory Agency presented a summary of salmonella isolations from feed ingredients and feed for a period of 1996–1999 by their agency. Of the major ingredient classes, salmonella isolations were made from, 18 percent oil seed, 20.5 percent rendered animal products, 22 percent fish meal, and 5 percent feed grain.

Bacterial contamination concerns have expanded into the genera of commonly isolated foodborne pathogens. In the US, primary concern has been directed at the coliform group, Clostridium sp., Salmonella sp., Listeria monocytogenes, and Camplybacter sp. (jejuni). A study conducted at the University of Illinois by primary investigator Dr. Fred Troutt is in the final stages of completion. The study involved 17 rendering facilities in seven Midwestern states randomly selected to statistically block for raw-material species, source, and processing. An overview of the findings indicates that raw materials derived from animal production are highly contaminated with the commonly identified foodborne pathogens. Table 1 is illustrative of that fact.

To prevent interference in any of the scientific publication procedures for this research project, final results will not be discussed in this written paper. However processing conditions of the time/temperature rendering processes provide a biosecurity advantage not afforded by other alternatives, with the exception of incineration. The thermal death times of the referenced foodborne pathogens and the heat transfer conditions of rendering systems can be correlated to provide assurance and the illustration of the innumerable reduction and elimination of foodborne pathogens commonly found in the raw materials of the animals that are afforded by the rendering process but has not been validated by other associated methods of byproduct or fallen animal disposal.[6]

In other studies completed by Dr. Eugene Pirtle at Iowa State University, the psuedorabies virus (PRV) was inactivated in properly processed meat and bone meal from naturally-infected swine as well as tissue experimentally inoculated with PRV prior to processing via rendering. Again biosecurity assurances that are not accompanied via burial, composting, extruding, or landfill applications are very evident. [7]

The advent of marketing programs that promote "No rendered animal byproducts use," "no animal protein," and other natural/organic food claims, though opportunistic, are not founded on science-based decisions. Unfortunately retail executives, politicians, and regulators do not take their first advice from the microbiologists, epidemiologists, or toxicologists; but rather they take their decision-making clues from the dollar opportunities and the most vocal populous. Animal production has historically been focused on the production of wholesome, safe, readily available, and economical products for human consumption. Ancillary to the production of meat is the fact that an approximate 50 billion pounds of raw byproducts are also produced. Of the approximate 100 million hogs slaughtered annually in the United States, only 45–50 percent of the average 262-lb slaughter weigh hog is used for food. The remaining bone, viscera, skin, fat and other trim tissue must find a "home." The "home" can be burial, incineration, landfill, composting, extrusion, or rendering. With the exception of rendering all are very unacceptable either due to human and animal health, or environmental, ecological, or economical challenges. What are the "no animal byproduct" advocates proposing to do with the 54 billion annual pounds? If placed in landfills it has been established that over one fourth of all the current US landfill space would be required. Further, if loaded on trucks, the annual quantity would require all lanes, entrances, and exits on Interstate 80 extending from New Jersey to San Francisco to be occupied. This illustration is offered only to serve as a reminder to all of the animal industries sector that current alternatives to rendering and the utilization of rendered animal byproducts as feed ingredients simply are not available. The economic impacts undoubtedly can be absorbed by our affluent society and the domestic consumer. Our competitive position for exporting pork, in a market in which the US is already considered to be "high-priced" in many parts of the world, will undoubtedly be less favorable. However, the disposal inferences associated with all of "the half hogs" will be dramatic. Perhaps there are future options, but in today's environment there is a dependent relationship between utilizing the byproducts and sustaining animal agriculture.

Animal protein ingredients

Animal protein ingredient supplements and fats, as illustrated, have long been utilized by the feed industry primarily for their protein (amino acid) content, their mineral content, and their energy contributions. Though there are over 125 individual animal byproducts listed in the American Feed Control Officials (AAFCO) 2000 Ingredient Manual, meat and bone meal, meat meal, poultry meal, Hydrolyzed feather meal, fish meal, and the respective fat sources are the primary products resulting from the rendering process. All of these ingredients can contribute nutritionally and be utilized in swine diets.

▼ Table 2. Digestibility coefficients of selected amino acids in meat and bone meal as reported in literature since 1984.

Amino Acid	1984 [1]	1989 [2]	1990 [3]	1995 [4]	1997 [5]	2000 [6]
Lysine, %	65	70	78	92	71	87.5 - 92
Threonine, %	62	64	72	89	-	80.2 - 88.9
Tryptophan, %	-	54	65	-	70	86.4
Methionine, %	82	-	86	91	-	87.4 - 92
Cystine, %	-	-	-	71	-	76.4

[1]Jorgensen et. al. 1984. Determined at the ileum of pigs. [2]Knabe et. al. 1989. Determined at the ileum of pigs. [3]Batterham et. al. 1990. Determined at the ileum of pigs. [4]Parsons. 1995. High quality meat and bone meal in poultry using the precision fed cockerel balance assay. [5]Bellaver, Easter, Parsons 1997 determined at the ileum of pigs. [6]FPRF Reports. 2000. Upper range values for MBM as determined via Ileal, intestinal & cockeral assays. (Cromwell, Parsons, Klopfenstein projects)

Meat and bone meal—meat meal

Meat and bone meal (MBM) is probably the most commonly used animal protein ingredient in swine rations. It is also supplied in the largest quantity. MBM by ingredient definition must contain a minimum of 4 percent phosphorus with a calcium level not to exceed 2.2 times the actual phosphorus level. Ingredients of lower phosphorus content must be labeled as meat meal (MM). Both ingredients have protein levels that exceed 50 percent. Even though a standard protein level is not required, products must be labeled with a guaranteed protein as well as minimum phosphorus, minimum and maximum calcium, and minimum crude fat levels. A very antiquated AAFCO specification calls for a maximum of 12 percent pepsin indigestible residue and not more than 9 percent of the crude protein as pepsin indigestible. Databases for most co-products are difficult to interpret. Though it is important to reference compositional tables for nutrient contributions of ingredients, databases for rendered animal products in particular are often dated and do not reflect changes in processes and raw material controls. Table 2 is illustrative of historical databases for representative amino acid digestibility coefficients.

Many data sets are taken from research that intentionally have assembled products from a variety of sources and are designed to illustrate wide ranges of variability to meet specific research objectives. MBM and MM are often combined into common databases. This is illustrated in Table 3, referencing compositional data on 29 samples of MBM. Though the products were identified as MBM, over 50 percent were below phosphorus minimums. These samples were characterized as to basic raw material content (Table 4) and ileal digestibility values were determined for all significant amino acids (Table 4).[8] The interest among nutritionists for precision and accuracy is ever-present. Variability as determined by standard deviation is also referenced in Table 3. Variability has been determined to be significantly lower when ingredients are obtained from common sources. A recent report at the 2001 Maryland Nutrition Conference illustrated that fact.[9] Analyses derived from 657 MBM samples provided a mean of 47.7 percent for crude protein with a ±3.1 standard deviation (SD). Common sourced samples analyzed 46.5 percent ± 2.2 (N=27), 47.0 percent ± 2.0 (N=61), 46.5 percent ± 2.0 (N=99), 50.2 percent ± 2.6 (N=166) and 46.0 percent ± 1.9 (N=140) respectively. Again it is interesting to note the MBM description even though only one source met MBM specifications for minimum protein. In the same analytical summary, 571 samples of soybean meal provided a protein mean of 44.5 percent with a SD of ± 1.4.

By regulation, the trade procedures must differentiate among Restricted Use Protein Products (RUPP), and those of porcine and the other non-restricted materials. Additionally, the products are differentiated by different compositional values. The market has likewise placed a premium on non-RUPP animal protein. Scott et.al. evaluated 13 commercially available procine meat and bone meal products from both independent renderers and commercial packing plants in lamb-digestion studies for the following variables: crude protein, undegradable intake protein, meatbolizable protein, apparent nitrogen digestibility, and true nitrogen digestibility, primarily to respond to their use in ruminant rations.[10] Those values are summarized in Table 6, and yielded concentrations of crude protein that ranged from 53.5 percent to 65.5 percent. Levels are generally higher in crude protein for porcine-derived MBM when compared to other species raw material sourced product, due primarily to an associative lower ash content. Knabe (1996) summarized databases supplied by a number of commercial sources. Ingredients were segregated into those meals containing at least 4.4 percent phosphorus (MBM) and those meals with less than 4.4 percent phosphorus (MM). Table 7.[11] The meat meals were about 3 percentage units higher in protein, .20 percentage units higher in lysine, but 2.3 and 1.2 percentage units lower in calcium and phosphorus respectively. Both types of meals contained 10.7 percent fat. Tables 8–9 demonstrate that, as crude protein increases in meals, amino acid content also increases, but the relationship is not perfect. In this review the correlation coefficients for the essential amino acids ranged from 0.57 for tryptophan and histidine to 0.78 for leucine and threonine.

In today's marketplace, most suppliers of both MBM and MM can provide greater detail on mean values and specificity of nutrient

▼ **Table 3. Compositional data for MBM received through Fats and Protein Research Foundation [1] [2]. FPRF Directors Digest #285**

Sample	DM	CPAIS	CPDM	Fat	Ash	Ca	P	Thr	Cys	Met	Lys	Trp
MBM1	96.86	57.20	59.05	13.56	26.85	6.70	3.09	2.02	0.53	0.93	3.24	0.40
MBM2	97.38	47.50	48.78	24.10	35.99	10.24	4.36	1.28	0.41	0.53	1.93	0.19
MBM3	95.91	59.08	61.60	24.37	20.93	6.09	2.70	1.99	0.60	0.85	3.09	0.37
MBM4	95.64	55.21	57.73	15.95	29.59	8.57	3.80	1.83	0.55	0.89	2.90	0.27
MBM5	98.02	55.06	56.16	17.06	26.15	6.93	3.57	2.10	0.59	1.04	3.04	0.35
MBM6	97.52	55.76	57.17	16.62	26.93	7.19	2.56	2.06	0.67	0.91	3.16	0.36
MBM7	95.17	46.29	48.64	17.27	32.13	8.72	4.11	1.49	0.48	0.61	2.31	0.17
MBM8	96.01	55.26	57.56	15.41	30.15	8.90	4.06	1.92	0.54	0.93	3.01	0.37
MBM9	94.40	47.13	49.92	16.05	30.07	7.51	4.86	1.69	0.45	0.81	2.65	0.32
MBM10	97.72	53.02	54.25	13.51	29.97	8.90	4.25	1.76	0.53	0.75	2.64	0.26
MBM11	98.40	57.05	57.97	16.48	25.01	6.53	3.31	2.12	0.45	0.98	3.21	0.31
MBM12	94.75	57.17	60.37	16.33	23.18	6.78	3.35	1.95	0.59	0.88	3.23	0.33
MBM13	94.73	57.04	60.21	15.35	25.09	8.01	3.96	1.84	0.51	0.79	3.00	0.33
MBM14	96.28	48.02	49.87	15.45	28.47	7.91	3.51	1.54	0.53	0.55	2.35	0.26
MBM15	93.19	55.04	59.06	19.87	23.44	7.16	3.52	1.82	0.79	0.75	2.65	0.25
MBM16	96.29	45.88	47.65	19.63	23.39	6.50	3.25	1.66	0.53	0.61	2.49	0.25
MBM17	95.19	53.39	56.08	15.84	27.26	7.54	3.57	2.01	0.56	0.88	3.34	0.40
MBM18	94.43	48.90	51.79	18.47	27.95	7.12	3.68	1.95	0.41	0.78	2.80	0.36
MBM19	97.32	47.15	48.44	10.99	37.57	11.80	5.57	1.38	0.41	0.57	2.18	0.23
MBM20	No sample submitted											
MBM21	93.03	47.90	51.48	17.90	30.03	8.42	4.17	1.51	0.41	0.64	2.37	0.27
MBM22	96.59	56.00	57.97	14.68	22.87	6.52	3.34	2.10	0.65	0.88	3.19	0.36
MBM23	95.53	52.24	54.68	13.21	29.08	8.19	4.00	1.63	0.51	0.68	2.65	0.28
MBM24	95.83	56.14	58.58	15.61	21.75	6.02	3.08	1.99	0.50	0.88	3.22	0.42
MBM25	95.35	51.32	53.82	25.03	28.83	8.94	4.09	1.77	0.42	0.81	2.85	0.32
MBM26	97.05	55.89	57.59	12.62	27.88	8.18	3.77	1.96	0.51	0.89	3.21	0.33
MBM27	94.91	47.48	50.03	18.24	28.54	9.74	4.72	1.41	0.34	0.60	2.35	0.27
MBM28	96.53	55.43	57.42	18.56	19.32	5.26	3.06	1.91	0.56	0.80	3.19	0.34
MBM29	97.62	49.58	50.79	16.99	31.62	10.01	4.98	1.53	0.42	0.64	2.49	0.28
MBM30	96.04	58.52	60.93	15.97	20.65	6.36	3.37	2.06	0.84	0.84	2.90	0.32
AVG	95.90	53.60	55.92	17.00	26.44	7.58	3.67	1.83	0.58	0.78	2.87	0.32
STDS	1.44	5.99	6.52	3.26	6.20	1.96	0.89	.032	.033	0.14	1.49	0.08
MAX	98.40	59.08	61.60	25.03	37.57	11.80	5.57	2.10	0.84	1.04	3.34	0.40
MIN	93.03	45.88	47.65	10.99	19.32	5.26	2.56	1.28	0.34	0.53	1.93	0.17

[1] DM-DRY MATTER: CPAIS=CRUDE PROTEIN IN AS BASIS:: CPDM-CRUDE PROTEIN IN DM BASIS.
[2] AOCS Official Methods of Analyses (14th Edition) Association of Analytical Chemists, Washington, DC 1984. University of Illinois, Dept. of Animal Sciences Laboratory, Urbana, Illinois.

content than obtained from compositional tables. The greater than desired processor-to-processor variation suggests that feed formulators may be well served to modify nutrient contents based on the origin of the ingredient. Today's suppliers can provide more exacting amino acid profiles and digestibility, as well as other ingredient specifications, than can be acquired from standard compositional tables. A review of the most frequently referenced composition tables, however, indicates that the 1998 Nutrient Requirements of Swine is very representative and provides minimum value and a margin of safety for the descriptions of meat

▼ **Table 4. Average digestibility for MBM received through Fats and Proteins Research Foundation. FPRF Directors Digest #285**

		Crude Protein	Lysine	Tryptophane	Methonine & Cystine
MBM	1	69.13	68.60	67.34	61.55
MBM	2	66.43	71.72	73.46	64.74
MBM	3	66.03	65.57	67.33	61.45
MBM	4	73.84	76.07	72.40	68.41
MBM	5	60.63	57.05	61.65	51.99
MBM	6	76.24	77.75	73.95	69.51
MBM	7	73.00	78.20	76.74	69.27
MBM	8	74.00	75.24	72.68	71.29
MBM	9	75.59	79.35	68.75	73.25
MBM	10	67.52	67.64	74.23	61.56
MBM	11	55.68	50.10	53.62	57.36
MBM	12	75.19	77.74	74.11	71.32
MBM	13	72.59	77.24	78.20	68.56
MBM	14	78.95	82.48	76.23	70.45
MBM	15	74.28	80.46	78.27	65.54
MBM	16	60.48	63.83	53.06	52.52
MBM	17	76.92	78.30	72.32	70.43
MBM	18	69.66	68.38	69.74	67.94
MBM	19	69.83	76.31	76.67	68.05
MBM	20	No sample submitted			
MBM	21	65.45	67.47	63.98	65.74
MBM	22	59.46	61.42	63.04	49.42
MBM	23	65.91	71.26	71.91	61.78
MBM	24	65.67	63.38	57.19	57.11
MBM	25	65.56	66.34	66.92	66.18
MBM	26	68.05	69.57	72.04	65.07
MBM	27	70.13	76.59	79.73	77.72
MBM	28	62.95	63.42	65.18	63.68
MBM	29	63.74	70.14	76.59	65.29
MBM	30	68.80	73.58	67.11	49.56
AVG		68.68	70.87	69.70	64.3
SBM		80.02	83.14	79.06	77.26

[1] *Ileal T-cannula procedure as described by Easter and Tanksley (1993) and Bellaver (1989).*

meal rendered (MM) and rendered meat with bone (MBM).[12]

Most recent data and composition tables reflect a significant increase in the available phosphorus derived from meat and bone meal. Traylor and Cromwell have provided a series of reports to indicate that phosphorus true bioavailability is comparable to that of monosodium phosphate.[13] Assurance of bioavailability exceeding 90 percent, using various experimental procedures (i.e. slope ratio and balance retention), both growth and bone evaluation parameters, and varying particle size of MBM, was demonstrated. The value of the highly available phosphorus content of MBM is often understated in establishing its true economic value and the benefits it provides in meeting the pigs phosphorus requirements. This is particu-

▼ **Table 5: Composition and processing descriptions for MBM received through Fats and Proteins Research Foundation. FPRF Directors Digest #285**

Sample	Species	Components	Cooking Time	Cooking Temp.	Drying Time	Drying Temp	Grind
MBM-1	90% beef, 10% pork	-	-	-	2½	225°F	10 Mesh
MBM-2	100% beef	75% offal, 25% bone		290–300°F	20 ton/hr. feed		#8
MBM-3	100% pork	offal & bone	45 min	130° C		No heat	1-2 mm
MBM-4	12% pork,38% beef, 50% poul.	85% soft, 15% bone	4hrs.	260°F	-	-	10Mesh
MBM-5	65% beef, 20% poul. 10% swine, 5% fish	90% soft, 10% bone	1hr.	280/300°F	-	-	10 Mesh
MBM-6	⅓ beef, ⅓ pork, ⅓ poul.	-	45 min.	260° F	-	-	8 Mesh
MBM-7	60% beef, 40% pork	100% offal	20 min.	257°F	-	-	8 Mesh
MBM-8	45% beef, 55% poul.	55% Viscera, 45% bone	13½min	155°F 2311	-	-	8 Mesh
MBM-9	100% beef	82% soft, 18% bone		Low temp.	45 min.	240°F	10 Mesh
MBM-10	100% beef	82% soft 18% bone		Low temp	45 min.	240°F	10 Mesh
MBM-11	28% beef, 33% pork, 38% poul., 1% fish	42%viscera, 23% fat 22% bone, 10% muscle,3% skin		260/290°F		-	-
MBM-12		No information obtained					
MBM-13	100% pork	No processing information obtained					
MBM-14	90% beef, 10% pork	49% offal, 22% fat, 25% bone, 4% skin & trim	20 min.	250°F	-	-	10 Mesh
MBM-15	14% beef, 77% pork, 9% poul.	70% offal, 15% bone 15% fat		1 1/2 hrs.	240°F	-	- -
MBM-16	70% beef, 30% pork	50% offal, 20% bone 25% shop fat, 5% Rest. Grease bottoms		1hr.	280°F	-	10 Mesh
MBM-17	75% beef, 23% pork, 2% poul.	50% offal, 15% fat, 15% bone, 20% meat		30 + min	270°F	290°F	at press 1.7 mm
MBM-18	100% beef	40% offal, 45% fat, 15% bone		30 + min	270°F	290°F	at press 1.7 mm
MBM-19	100% beef	80% bone, fat & offal 20% tissue		30 min	280°F	-	10 Mesh
MBM-20		No Sample Submitted					
MBM-21	60% beef, 40% pork	40% offal, 60% fat trim & bone	65 min	280°F	-	-	10 Mesh
MBM-22	30% beef, 30% pork, 40% locker plant		3½ hr	260°F	-	-	5/16
MBM-23	40% beef, 60% pork	67% meat, 30% bone		90 min	270°F		12 Mesh
MBM-24	98% beef, 2% poul.	80% bone, fat & offal		30 min	280°F		10 Mesh
MBM-25	15% beef, 20% pork, 65% poul.	65% offal, 27.5% bone, 7.5% fat		No Time	260–280°		F10 Mesh
MBM-26	75% beef, 25% pork & poul.	65% offal, 30% bone, 5% fat		No Time	260–280°F		10 Mesh
MBM-27	100% pork	-	2½ hrs.	230°F	-	-	-
MBM-28	30% beef, 70% pork	-	30 min	195°F	30 min.	212°F	10 Mesh
MBM-29	98% beef, 2% pork	75% offal, 25% bone		_	290–300°F	-	10 Mesh
MBM30	10% beef, 90% pork	-	20min	262°F	-		10 Mesh

▼ **Table 6. Concentrations of crude (CP), undegradable intake (UIP), and metabolizable (MP) protein and percentage apparent (AND) and true (TND) nitrogen digestibility of 13 porcine meat and bone meal products.**

Product Number	CP[a]	UIP[ab]	MP[ac]	ASH[a]	AND[a]	TND[a]
1	54.6	41.5^{de}	19.3	29.2	62.1^{de}	77.8^{de}
2	56.0	46.4^{ef}	27.1	26.6	63.0^{def}	80.7^{def}
3	63.0	53.3^{g}	33.3	26.7	62.5^{def}	80.0^{def}
4	54.8	63.0^{h}	38.5	29.1	61.5^{d}	75.5^{d}
5	59.7	53.8^{g}	31.1	21.4	62.0^{de}	77.3^{de}
6	60.9	50.7^{fg}	27.5	21.3	61.9^{d}	76.8^{d}
7	65.5	52.2^{g}	40.0	25.5	64.8^{g}	87.8^{g}
8	64.7	52.5^{g}	36.1	24.8	63.7^{efg}	83.6^{efg}
9	62.9	49.7^{fg}	30.5	29.3	63.0^{def}	80.8^{def}
10	53.5	48.6^{fg}	30.0	27.8	63.0^{def}	81.4^{defg}
11	54.9	39.7^{d}	21.3	24.8	63.2^{defg}	81.6^{defg}
12	61.9	49.3^{fg}	28.0	28.3	62.2^{de}	78.7^{de}
13	60.5	45.6^{ef}	31.9	25.9	64.1^{fg}	86.3^{fg}

[a]CP and ASH as percentage of DM; UIP and MP as percentage of CP; AND and TND as percentages.
[b]Measured by the ammonia release procedure.
[c]MP = UIP - (100-TND).
[defgh]Values within a column with unlike superscripts differ (P < .10).
Protein Evaluation of Porcine Meat and Bone Meal; Scott, Mass, Wilson, Klopfenstein and Lewis, University of Nebraska. 2000 University of Nebraska Beef Report and FPRF Directors Digests #293 and 300.

larly important in addressing nutrient management for environmental purposes.

Meat and bone meal is not intended to serve as the exclusive protein source for swine rations. Its complimentary contributions at inclusion rates of up to 7.5 percent in grower diets and 10 percent in finishing diets support excellent performance with economic benefits. Research with pigs fed diets containing MBM has shown that growth performance was depressed with increasing levels in the diet.[14][15][16] Speculation was that performance reduction was due to the increased intake of minerals (e.g., Ca and P), reduced palatability, or a poorer balance of amino acids. More recently, Cromwell and Batterham et.al. found that the reduction in performance of pigs fed diets containing MBM was due to a deficiency in available tryptophan.[17][18] These researchers demonstrated that optimal growth performance could be achieved with the inclusion of 0.03 percent synthetic tryptophan for every 10 percent of MBM included in the diet. The application of least cost formulation and ideal protein modeling systems provides for a much greater opportunity to use and evaluate alternative ingredients such as meat and bone meal and meat meal. Additionally, more exacting composition data from the industry is extremely beneficial. The foundation has projects in progress that are believed to assist in a more accurate, easily acquired nutrient profile. One such project is entitled "Techniques for Monitoring the Nutritional Value of Animal Meals" by Dr. Theo van Kempen at North Carolina State University. It is also refreshing to note that a number of antinutritional compounds and contaminates such as trypsin inhibitors, goitrogenic compounds, gossypol, mycotoxin, aflatoxin, glucosinolates, tannins, lectins, phytates, lathyrism, oxalates, nitrates, alkaloids, cyanogens, oligosaccharides, or other non-starch polysaccharides are not problematic in animal proteins.

Blood Meal

The dried blood meals are an excellent example of product improvement. Protein content and its digestibility has been greatly improved as the industry moved from vat drying processes to spray drying techniques. Most blood meal

▼ **Table 7. Mean protein fat, calcium, phosphorus, and amino acid contents of meat and bone meal and meat meal[a, d]**

	Meat and bone meal[b]			Meat meal[c]		
Nutrient, %	n	Mean	SD	n	Mean	SD
Crude protein	255	51.4	2.64	171	54.0	2.93
Crude fat	78	9.99	1.01	171	7.69	1.16
Calcium	255	4.98	.38	171	3.88	.41
Phosphorus	255	4.98	.38	171	3.88	.41
Arginine	61	3.60	.35	22	3.34	.57
Histidine	62	.92	.19	22	.95	.28
Isoleucine	62	1.40	.25	22	1.58	.21
Leucine	62	3.10	.47	22	3.32	.49
Lysine	64	2.64	.36	22	2.85	.47
Methionine	39	.70	.14	7	.79	.18
Cystine	7	.46	.23	7	.45	.26
Phenylalanine	62	1.67	.22	20	1.98	.58
Threonine	64	1.65	.23	22	1.74	.33
Tryptophan	29	.26	.05	2	.29	.05
Valine	62	2.11	.34	22	2.44	.43

[a]As-fed basis. Data for protein, fat, calcium and phosphorus from commercial sources. All amino acid values are from data reported by universities.
[b]Protein, fat, calcium and phosphorus contents for meals having at least 4.4% phosphorus. The mean protein content of meals analyzed for amino acids was 50.5±4.3.
[c]Protein, fat, calcium and phosphorus contents for meals having less than 4.4% phosphorus. The mean protein content of meals analyzed for amino acids was 54.9±2.1.
[d]Rendered Feeds in Swine Feeding, Dr. D.A.Knabe, Texas A & M University, FPRF Directors Digest #273.

▼ **Table 8. Regression of amino acid contents and crude protein in meat and bone meal and meat meal[a]**

Amino acid	n	Equation	r
Arginine	70	y = .8515 + .0546 x	.70
Histidine	70	y = -.4639 + .0278 x	.57
Isoleucine	70	y = .4802 + .0373 x	.67
Leucine	70	y = -1.1133 + .0841 x	.78
Lysine	70	y = -.3367 + .0591 x	.69
Methionine	45	y = -.3125 + .0202 x	.66
Phenylalanine	68	y = -.2145 + .0377 x	.63
Threonine	70	y = -.6008 + .0448 x	.78
Tryptophan	27	y = -.0113 + .0055 x	.57
Valine	70	y = -.6981 + .0565 x	.64

[a]Rendered Feeds in Swine Feeding, Dr. D.A. Knabe, Texas A & M University, FPRF Directors Digest #273.

▼ **Table 9. Mean nutrient content of apparent ileal digestibility for spray-dried and ring-dried blood meals[a, b]**

Nutrient, %	Content n	Content Mean	Content SD	Digestibility n	Digestibility Mean	Digestibility SD
Crude protein	20	88.0	3.98	10	87	4.1
Arginine	19	3.64	.35	10	90	5.1
Histidine	20	5.39	.52	10	95	2.6
Isoleucine	20	.93	.18	10	67	10.2
Leucine	20	11.16	.67	10	92	2.9
Lysine	20	8.24	.55	10	94	2.1
Methionine	17	1.15	.34	10	84	5.4
Cystine	10	1.12	.11	—	—	—
Phenylalanine	20	6.17	.44	10	92	2.9
Threonine	20	3.93	.50	10	86	3.9
Tryptophan	13	1.12	.30	7	92	5.1
Valine	20	7.76	.64	10	92	2.7

[a]*As fed basis.*
[b]*Rendered Feeds in Swine Feeding, Dr. D.A. Knabe, Texas A & M University, FPRF Directors Digest #273.*

▼ **Table 10. Mean nutrient content of apparent ileal digestibility of protein and amino acids in spray-dried porcine plasma[a, b]**

Nutrient, %	Content Mean	Content SD	Digestibility Mean	Digestibility SD
Crude protein	70.8	5.4	78	7.1
Arginine	4.25	.35	86	6.3
Histidine	2.33	.52	89	2.8
Isoleucine	2.75	.18	83	3.5
Leucine	7.03	.67	83	1.4
Lysine	6.33	.55	86	2.1
Methionine	.68	.34	63	2.1
Cystine	2.36	.09	—	—
Phenylalanine	4.15	.26	85	5.0
Threonine	4.22	.23	80	3.5
Tryptophan	1.29	.21	92	-
Valine	4.77	.14	84	3.5

[a]*As fed basis.*
[b]*Rendered Feeds in Swine Feeding, Dr. D.A. Knabe, Texas A & M University, FPRF Directors Digest #273.*

composition analyses will be near 90 percent in crude protein. Similarly the digestibility of the essential amino acids will be in excess of 90 percent and most approach 95 percent. Blood meal is most often utilized in swine as an ingredient for pig starter diets. The use of blood plasma in first phase nursery diets has replaced a substantial use of blood meal in this phase and has demonstrated superior feed intake qualities, but its substitution in phase two and phase three with all or a portion of blood meal is very common. Spray dried porcine plasma has an

amino acid profile distinctly different from that of blood meal, and its apparent digestibility is lower than that of spray dried blood meal, (Table 9 and Table 10). Blood meal is especially rich in lysine (9.1 percent) which demands a competitive price comparison to synthetic lysine sources. Typically, blood meal will provide twice the lysine content of fishmeal and nearly three times the level in dehulled soybean meal. Its higher relative cost and competitive uses usually restricts its use to specialty swine products and the nursery/starter phases.

Feather Meal

Swine nutritionists often fail to consider the use of feather meal in swine diets. The relatively low levels and lower digestibility of lysine in feather meal, when compared to soybean meal, is namely accountable. Feather meal is a product that also has been associated with significant process improvement and thus nutrient contributions. The mean crude protein content of 85.4 percent, as stated in the 1998 Nutrient Requirements of Swine, is generally understated, especially in those products in which any poultry blood is processed with the feathers. The latter product is generally a browner color and a higher lysine content than pure feather meal. A report by Chiba et.al. found that up to 9 percent feather meal could be used in isolysinis corn-soybean meal diets of the finishing pig without adversely affecting carcass merit, but 3 percent feather meal was the maximum usage rate without reducing performance.[19]

Poultry Meal

Poultry meal is a product that has undergone processing changes. It is an ingredient that commands competition from the pet food industry. The nutritional demands from this industry have lead to the development of low ash poultry meals via special processing and are commonly traded as pet food-grade poultry meals. These meals are generally higher in protein (62–65 percent) with ash levels below 19 percent. Poultry meal based on the more traditional processing and raw material process, yields a product with lower protein and higher ash.

Poultry meal has not generally been an ingredient utilized in swine rations, though the apparent ileal digestibility of its amino acids are higher than for those found in MBM and similar to those reported for soybean meal and fish meal. The competitive utilization from the pet food industry and the internal "buy back" usage by the poultry integraters often lowers its competitive position relative to other ingredients, especially midwest grow-finish swine diets. As an ingredient for swine, considerable attention and success has resulted from the use of poultry meal, and in particular the upper grades, as a nutritional asset for pig nursery and starter diets.

References

[1] FDA-ANPR Document 96N-0135, Statistics, June 13, 1996

[2] Matthews, Danny, Veterinary Laboratories Agency, Surrey, KT15 3NB, United Kingdom; Oral Presentation and Personal Communications, USDA/ARS, BSE Workshop. Rockville MD, March 15, 2001

[3] Sutton, A.L., Purdue University FPRF Final Report 1990

[4] McChesney, D.G., USDA, USAHA Microbiology Subcommittee of Feed Safety Committee, 1994 Annual Meeting.

[5] McChesney, D.G., USAHA, Microbiology Subcommittee, 1995 Annual Meeting Proceedings.

[6] Troutt, Fred, FPRF Project 99A-1 Prevalence of Selected Foodborne Pathogens in Rendered Products.

[7] Pirtle, E.C. Research Virologist, Iowa State University, 1990. "Stability of Pseudorabies Virus (PRV) in Meat and Bone Meal and Intermediate Rendering Products" FPRF Directors Digest #203.

[8] Bellaver, C; Easter, R.A.; Parsons, C; "Prediction Equations for Amino Acid (AA) Digestibility in Meat and Bone Meals (MBM)." July 1997, FPRF Directors Digest #285.

[9] Roush, W.B., 2001 Maryland Nutrition Conference for Feed Manufacturers, May 1-2 in Timonium, MD and "Stochastic Programming has Implications for Precision Feeding" Feedstuffs, July 2, 2001.

[10] Scott et. al. "Protein Evaluation of Porcine Meat and Bone Meal" University of Nebraska 2000 Beef Report.

[11] Knabe, D.A; "Rendered Feeds in Swine Feeding" FPRF Directors Digest #273 January 1996.
[12] NRC. 1998. Nutrient Requirements of Swine (Tenth Revised Edition) National Academy Press, Washington DC.
[13] Traylor, S.L., Doctorate Dissertation, University of Kentucky; "Assessment of Nutrient Bioavailability in Meat and Bone Meal for Pigs and Chicks", 2000; Director, Dr. Gary L Cromwell, Professor of Animal Science
[14] Poe, E.R., Jr. and Harmon, B.D. 1962 "Effect of levels on meat and bone meal scraps on growth rate and feed efficiency of growing-finishing swine." J. Animal Sci. 21:787-790.
[15] Puchal, F.V.; W. Hayes, V.C. Speer, J.D. Jones and D.V. Catron 1962. The free blood plasma amino acids of swine as related to the source of dietary proteins. J.Nutr. 76:11-16.
[16] Evans, D.F., and J. Leibholz. 1979. "Meat meal in the diet of the early weaned pig." Animal Feed Sci. Technol. 4-33-42.
[17] Cromwell, G.L., T.S. Stahly and H.J. Monegue. 1991. Amino acid supplementation of meat meal in lysine-fortified, corn-based diets for growing-finishing pigs. J. Anim. Sci. 69-4898-4906.
[18] Batterham, E.S. 1993. Ileal digestibility and availability values for formulating diets for swine. Proceedings of the 54th Minnesota Nutrition Conference. Page 235-250.
[19] Chiba, L.I., H.W. Ivey, K.A. Cummins and B.E. Gamble. 1996. Hydrolyzed feather meal as a source of amino acids for finisher pigs. Anim. Feed Sci. Tech. ▲

▶ Futuristic aspects of biotech food for livestock and humans

Gary F. Hartnell, PhD, PAS, Dip 1 ACAN
Monsanto Company, St, Louis, Missouri 63167

Summary

Mankind has been genetically engineering (deliberately modifying the genetic material) food since early historical times resulting in more nutritious, higher yielding and more disease-resistant crops. Through the use of gene-modification technology, specific traits can now be incorporated into plants at an accelerated rate to produce a more sustainable, more nutritious food supply and pharmaceuticals to help meet the needs of a rapidly growing population. Benefits of food biotechnology to the consumer include improvement in quantity and quality of food, extended shelf-life, organoleptic quality, health benefits, edible vaccines, and a better environment through reduced herbicide and pesticide use. Livestock producers will benefit through improved profitability; feed utilization; performance; meat, milk, and egg quality; health of livestock and poultry; and less animal waste produced per animal, resulting in less nutrient loss. Biotechnology is a tool that must be utilized if the health, nutrition, and well-being of the future world's population is to be attained.

Introduction

Genetic engineering has been performed for centuries in plants and animals beginning with the selection of seed with desirable traits from superior plants and livestock through breeding programs. These methods have significantly increased productivity, with corn and wheat yields approximately doubling over the past 40–50 years, substantial improvements in milk yield per cow, more efficient use of feed, and leaner pig meat, just to name a few. However, the rate of these gains (which is critically needed to help address the rapidly growing world population) will decrease without continued innovation. The projected doubling of the global population will require at least a doubling of the amount of food that will be needed in the next 40–50 years.

The ability to introduce DNA directly into crop plants enables a selective plant improvement process that promises to continue to enhance agricultural productivity while using more sustainable and environmentally sound approaches. Numerous traits are being evaluated for their potential to: (a) protect plants against insect damage; fungal, viral, or bacterial diseases; (b) provide selectivity to more desirable herbicides for improved weed control; (c) enhance crop yields; (d) increase nutritional quality and health benefits to animals and humans; (e) reduce naturally occurring toxicants or allergens; (f) modify the ripening process and provide superior flavor; (g) use plants as factories to make such products as biodegradable polymers or pharmaceutical products; (h) modify food composition for disease prevention; and many others. While biotechnology provides an important tool to help address many of these challenges, this tool must be effectively integrated with the best current agricultural practices that encompass the most productive and environmentally appropriate technologies around the world.

The development and commercialization of biotech plants has caused a debate in some parts of the world concerning potential risks to food safety and the environment. Potential risks and benefits of the new technology to man and the environment have been previously reviewed (Uzogara, 2000; Hartnell and Fuchs, 2000). Numerous national and international scientific organizations have considered the risks and have concluded that plant biotechnology does not pose any unique risk with respect to other production methods (WHO, 1991; Food and Drug Administration, 1992). This does not imply that there are no risks, simply that the risks are not unique to biotechnology. Hence, the vast

experience in agriculture, food and feed production, and environmental risk assessment provides a scientifically sound basis to assess the risks of genetically modified plants and plant products. This paper will focus on the benefits of genetically altering food for humans and livestock.

Biotech food: Value to humans

Genetically modifying plants for the direct benefit of the consumer is in its infancy. The product concepts and potential benefits appear limitless. The use of biotechnology provides a means to increase food availability to a growing world population as well as providing a healthier, less expensive, more nutritious, better tasting, and safer food with improved shelf-life (Table 1). Indirect benefits include a better environment through reduced applications of pesticides and herbicides and the use of farming methods such as "no till" that result in significantly decreased soil erosion (by 90 percent), reduced fuel use (20–40 percent) and emissions, improved water quality and wildlife habitat, and increased carbon retention in the soil (Hartnell and Fuchs, 2000).

Increased food availability/crop yield and improved environment

The use of B.t. gene in crops (insect protection) results in improved quality, less pesticidal use, improved yields, improved profits, reduced mycotoxins, and an increased number of beneficial insects. Insecticides and associated management practices that have been used traditionally to control insect pests cost approximately $10 billion annually worldwide. Yet 20% to 30% of total crop product is still lost due to insect pests, the equivalent of 1.5 billion tons of food. Insect-protected plants were among the first genetically modified plants to be field tested and marketed because of their importance, the value associated with effective insect control, and the availability of microbial genes with insecticidal activity. Use of these products reduces chemical insecticide use, enhances environmental safety, reduces energy and labor costs, and improves the quality and quantity of the plant product. Recently, Gianessi and Carpenter (1999) described and quantified the insect control benefits on B.t. corn, B.t. cotton, and B.t. potato acreage planted in 1997 and 1998. The increased crop yields (up to 25 percent) from genetically modified plants will have a dramatic impact on the world's food supply.

Cotton growers in the United States who planted insect-protected cotton reduced their chemical insecticide by approximately 300,000 gallons in 1997 (Mackey and Santerre, 2000). These reductions translate to 90 percent, 85 percent, and 85 percent reductions, respectively, in the amount of chemical insecticides used to control the targeted insect pests. This reduction in insecticide use not only benefits the environment but also greatly reduces human exposure.

The use of herbicide-tolerant crops results directly in weed control systems that provide improved seed quality, less herbicide use, improved yields, more efficient use of fertilizers,

▼ Table 1. Potential benefits from application of biotechnology to crops (adapted from Uzogara, 2000)

- Increased food availability
- Improved protein quality
- Improved shelf-life and organoleptic quality of foods
- Improvement in nutritional quality and health benefits
- Improvement in food carbohydrate content
- Manufacture of edible vaccines and drugs
- Improvement in quantity and quality of meat, milk , eggs, and livestock
- Biological defense against diseases, stresses, pests, weeds, herbicides, and viruses
- Increased crop yield
- Bioremediation
- Positive effect on farming/food product
- Protection of the environment
- Genetically modified plants as bio-factories and source of industrial raw materials
- Wealth/job creation

improved profits, and reduced foreign matter in grain. Indirect benefits through the adoption of direct drilling include improved soil quality and conservation, increased carbon retention in the soil, reduced fuel use and emissions, and improved wildlife habitat (Hartnell and Fuchs, 2000).

The use of disease resistance, tolerance to environmental extremes, drought resistance, tolerance to salts and high mineral content, improved nitrogen assimilation in crops are expected to result in improved quality, improved yields, more efficient use of fertilizers, improved profits, and access to land now unusable for crop production. These improvements through biotechnology have the potential to help insure the world against widespread famine.

Disease can have a major economic impact on the food supply. For example, wheat head scab caused by the fungus Fusarium graminearum has caused a loss of over one billion dollars in the northern Great Plains and the eastern U.S. three times in the 90's. As a result of the potential impact of disease on yield, fungal disease resistance is being introduced into corn and wheat. Virus (potato leaf roll virus) and disease control for late blight and Vetricillium are new product improvements for potatoes. Viral resistance, bacterial leaf blight, and fungal disease control for Blast and Sheath Blight are being developed for rice. Viral protection strategies are being evaluated in watermelons, cantaloupes, cucumbers, potatoes, tomatoes, alfalfa, and other crops (Mackey and Santerre, 2000). Virus resistant papayas are already on the market (IFIC, 1999).

Improved nitrogen assimilation will provide value to the grower as well as the environment. The grower will be able to optimize the crop's response to fertilizer, leading to increased yield potential. Plants will have the capacity to more efficiently use the nitrogen applied. In addition, the quality of the crop may be improved through increased protein content in seed and leaves. The environment benefits as a result of decreased nitrogen leaching into the ground water.

There are many environmental situations that limit the ability of the current crops to grow and produce yields of economic value in many areas of the world. Active research programs are in place to develop crops that are cold tolerant, drought tolerant, salt tolerant, can withstand flooding, and tolerant to high aluminum levels, to name a few. Crops with these traits will open up new areas of land that are unusable for crop production today.

Safer food supply

Genetically modified B.t. corn plants have provided significant increases in yield and enhanced grain quality with reduced mycotoxin contamination. Research from Iowa State University and the U.S. Department of Agriculture (USDA) (Munkvold et al. 1997) showed a 96%, 54%, and 64% reduction in the severity of insect damaged ears with the B.t. gene in studies conducted in 1994, 1995, and 1996, respectively. These same researchers (Munkvold et al. 1999) reported a 78% and 87% reduction in mean total fumonisin concentrations (fumonisin B1 + B2 + B3) in kernels where the hybrids were manually infested with neonatal European corn borer larvae in 1996 and 1997, respectively. Epidemiological studies have linked consumption of corn containing high levels of fumonisins with an elevated incidence of esophageal and liver cancer in African subsistence farmers (Marasas et al., 1988). Action levels for fumonisin contamination in grain have been set by two countries, Switzerland (1 ppm) and the United States (3– 4 ppm).

In the future, biotechnology could be used to produce foods with reduced levels or no allergens and reduced levels of toxins such as trypsin inhibitor and lectins.

Improved shelf-life and organoleptic qualities

The Flavr Savr tomato produced by Calgene Corporation was the first genetically engineered crop and whole food approved by the FDA that ripens on the vine with a longer shelf-life by having delayed ripening, softening, and rotting processes. This process leads to superior flavor, color, and texture. Recently, sweet-tasting, seedless peppers and tomatoes have been produced. The slow ripening process (via suppression of cell wall destroying enzyme, polygalacturonase) could also be applied to crops like raspberry, strawberry, and pineapple (Uzogara, 2000).

▼ **Table 2. Potential improvements in the oils of crops through genetic modification.**

Corn	Soybean	Canola (oilseed rape)
1. High oleic	1. High oleic, low saturate 2. High stearate, low polystearate	1. High laurate 2. High oleic, low saturate 3. High stearate, low polystearate 4. High stearate 5. Medium chain fatty acids

Source: Cline et al. (1996)

Improved nutritional quality and health benefits

Considerable efforts are underway to improve the nutritional quality of foods. Most of the current research is focusing on changing the oil composition of crops as shown in Table 2.

High oleic corn and soybean oil contains less saturated fat than conventional oil, making it more stable; thus, it does not require hydrogenation for use in frying or spraying. Hydrogenation creates trans fatty acids which have been associated with adverse serum cholesterol levels. High lauric canola produces an oil composed of about 40% lauric acid. This fatty acid is a key ingredient in soaps, detergents, lubricants, cosmetics confectionery coatings, margarine, and simulated dairy foods. High stearate oil solidifies at room temperature without hydrogenation and would be used for healthier baking, margarine, and confectionery foods and those that cannot use liquid oils. Other valuable traits that are in development include the following: high starch potatoes (low fat chips, and more rigid chips, lower processing inputs)(Cline and Re, 1997); bruise resistance in potatoes; enhanced vitamin content (Vitamin E & C, important antioxidants, Vitamin A); amino acid modifications (improved nutritional value); improved protein content; increased medium chain fatty acids (source of low calorie, quick energy to sport drink market); increased oleic (less saturated fat, more heat stable); enhanced flavors and textures; enhancement of storage; modification of carbohydrates; fiber modifications (colored cotton fibers, stronger, more durable, length); and low linolenic.

Vitamin A and iron-enriched rice species have recently been developed by Ingo Potrykus and his team at the Swiss Federal Institute of Technology in Zurich, Switzerland (Aldridge, 2000). Arrangements with rice breeders for cross-breeding the transgenic species to local varieties are currently being setup in the major rice-growing countries of Asia, Africa, and Latin America. This technology will help address one of the most significant health problems (vitamin A and iron deficiencies) in developing countries where rice is the staple food. The World Health Organization estimates that vitamin A deficiency affects over 250 million children worldwide, causing night blindness and vulnerability to disease (Mackey and Santerre, 2000).

Benefits that can be expected in the near future include reducing levels of natural toxins in plants; providing simpler and faster methods to locate pathogens, toxins and contaminants; and extending the time before spoilage (IFIC, 1999). Table 3 contains products that should soon be on the market.

Edible vaccines and plants as bio-factories

Plants can be genetically modified to produce food enzymes, vitamins, monoclonal antibodies, vaccines, anticancer compounds, antioxidants, plastics, fibers, polyesters, opiates, interferon, human blood proteins, carotenoids or food ingredients like proteins, enzymes, stabilizers, thickeners, emulsifiers, sweeteners, preservatives, colorants, and flavors. In the future, foods will be genetically modified to contain nutraceuticals (such as antioxidants, lycopenes, phyto-chemicals, pharmaceuticals) that have disease-fighting, symptom-reducing, performance-enhancing, and slowing of the aging process capabilities (Uzogara, 2000).

▼ **Table 3. Genetically modified foods expected in the near future.**

- Peas grown to remain sweeter and produce higher crop yields
- Smaller seedless melons for use as single servings
- Bananas, strawberries, cherry tomatoes, and pineapples with delayed ripening qualities
- Peanuts with improved protein balance
- Fungal resistant bananas
- Tomatoes with higher antioxidant (lycopene) content
- Potatoes with higher solids content
- Fruits and vegetables fortified with or containing higher levels of vitamins such as C and E to potentially protect against the risk of cancer and heart disease
- Garlic cloves, producing more allicin, possibly to help lower cholesterol levels
- Soybean oil with oleic acid content increased from 24% to >80%
- Strawberries containing increased levels of ellagic acid, a natural cancer fighting agent
- Peppers, strawberries, raspberries, bananas, sweet potatoes, and melons that are enhanced for better nutrition
- Strawberries with improved freshness, flavor, and texture
- Rice high in beta carotene and iron
- Canola oil high in beta carotene
- Sweet potatoes with improved protein quality

IFIC (1999), Mackey and Santerre (2000)

An exciting use of genetic modification is the use of plants as factories to produce pharmaceuticals at 10 to over 100 times less costly than current fermentation methods (Aldridge, 2000). Plants are being genetically modified to contain genes that instruct the plant to manufacture specific proteins. These proteins may be vaccines, proteins to prevent tooth decay, monoclonal antibodies for targeting specific types of cancer, and antibody-based transport molecules (treat cystic fibrosis), plus others to fight infectious diseases in humans (Langridge, 2000; Potera, 1999). EPIcyte Pharmaceutical (San Diego) is producing human mucosal antibodies in corn for passive immunization (Aldridge, 2000; Yuen, 2000). They are focusing on developing antibodies for herpes infection and, with John Hopkins University, contraception (Aldridge, 2000). University of Illinois researchers are developing genetically modified apples to produce an edible vaccine against a common and sometimes deadly virus, Respiratory Syncytial Virus (Hesman, 2001). Other edible vaccines are being developed in bananas, potatoes, tomatoes, lettuce, rice, wheat, soybeans, and corn (Langridge, 2000). Giddings et al. (2000) in a recent review lists the vaccines, antibodies, and biopharmaceuticals that are being developed through the use of transgenic plants. A partial listing of vaccines produced in plants include those for Hepatitis B, dental caries, autoimmune diabetes, cholera and E. coli diarrhea, rabies, HIV, malaria, influenza, and cancer.

Consumers benefit from a better environment since plants can be used to reduce agricultural inputs and produce the raw materials for the production of fuels and plastics, thus reducing the need for oil. Researchers at John Innes Institute (Norwich, U.K.) are currently investigating the coriander plant which produces petroselenic acid, a compound with great potential as a petro chemical replacement (Aldridge, 2000).

Biotech food: Value to livestock

Attention is turning quickly to value-added traits that directly benefit the livestock producer (Araba, 1997; Owens and Sonderlund, 2000; Sauber, 2000). Efforts are underway to genetically modify plants to enhance protein quality of cereals, increase protein content, modify amino acid composition (emphasis on lysine and

methiorine), modify starch and oil compositions, increase starch content, increase the oil content, reduce protease inhibitors, decrease lectin content in soybeans, reduce indigestible oligosaccharide content (Parsons et al. 2000), increase levels of oligofructans, enhance vitamin content, and produce compounds that result in increased feed efficiency and performance (Bajjalieh, 1996). High oleic acid soybean will provide high-energy concentrations. Grains with oligofructans may reduce the need for antibiotics. The transformation of active components found in botanicals into crops may offer a future substitute for antimicrobials. Holden et al. (1999) summarized three trials that examined the use of garlic, echinacea, and peppermint on growth promotion and meat quality in swine. Garlic has shown antimicrobial, antiviral, and possesses activity against common intestinal roundworms and hookworms. Echinacea is stated to possess antibacterial activity in some cases and immuno-enhancing properties. Peppermint has demonstrated antiviral and antimicrobial activity. The feeding of garlic at 0.5 percent, 2.5 percent, and 5.0 percent of the diet to nursery pigs for five weeks resulted in poorer performance and objectionable odor in the meat as compared to the control. However, in studies with chickens, feeding a 2–4 percent inclusion rate of garlic had a protective effect when chickens were subjected to candidases and feeding 5 percent eliminated the candida infection. Feeding nursery pigs 0.1 percent, 0.5 percent, and 2.0 percent echinacea in the diet or 0.5 percent, 2.5 percent, and 5.0 percent peppermint in the diet resulted in no benefit in performance. Through biotechnology, a more precise selection of specific active agents may help in overcoming the negative, or lack of, effects observed in these studies.

Halpin et al. (1995) reviewed transgenic approaches for manipulating the starch biosynthesis, sucrose accumulation, fructan biosynthesis, and seed oil content in crops. The amount and type of starch is very important for driving rumen fermentation in ruminants and meeting energy needs of monogastrics. Increasing the proportion of oil in corn grain is important in increasing the energy density of the grain. These non-structural carbohydrate components are all important for enhancing value to the livestock producer.

Grains with an increased amino acid content may reduce or eliminate the need for amino acid supplementation. Douglas et al. (2000) evaluated Nutri-Dense® (genetically-modified corn from Exseed Genetics, Decatur, IL) using the precision-fed cecectomized rooster assay. The Nutri-Dense® corn averaged 13.1 percent CP, 0.42 percent lysine, 0.24 percent methionine, and 0.26 percent cystine. The true digestibility coefficients of amino acids were similar (88.6 percent) as compared to conventional corn (88.5 percent). Thus, protein-enhanced corn contained substantially higher amounts of digestible amino acids than conventional corn. Edwards et al. (2000) evaluated soybean meal from conventional and two genetically modified soybeans. The crude protein levels of the soybean meal samples were 52.5 percent, 53.4 percent, 62.7 percent, and 42.7 percent for pilot plant processed conventional, genetically modified, high protein genetically modified, and commercially produced soybean meal, respectively. Digestible lysine, methionine, cystine, threonine, and valine as well as TMEn were higher for the high protein biotech soybean meal as compared to the other meals using the cecectomized cockerel assay. Parsons et al. (1997) also reported similar digestibility of amino acids in properly processed high lysine soybean meal. They indicated the high lysine soybean meal may be more sensitive to overprocessing.

Producers may have the ability to select specific grains or protein sources designed for optimizing performance and profitability of their particular livestock enterprise. White and Higgins (2000) reported an 8 percent increase in wool growth and 7 percent increase in live weight gain in sheep fed modified lupin. Lupin was genetically modified to contain a sunflower gene that produces a protein that is both rich in sulfur amino acids and stable in the sheep's rumen. Dado (1999) reviewed the nutritional value of different corn hybrids (high lysine, high oil, high protein) and their economic value for lactating dairy cows. All specialty corns reduced total feed costs compared to regular corn when the price was the same. High protein corn is the most economical with herd lactation averages of 9520 kg and less, whereas high lysine corn is the most economical for herds with greater than 9520 kg production. Dado (1999) concluded that both ruminally-undegraded lysine and oil will

become more valuable selection criteria as milk production of U.S. herds continues to increase.

Stock (1999) reviewed the effects of nutritional changes in cereal grains from genetic modification in beef feedlot diets. One of the earliest examples of genetic manipulation was the introduction of tannins into grain sorghum hybrids to decrease losses from birds and preharvest mold. The beneficial change, however, resulted in a decreased digestibility of the grain. Efforts continue to improve digestibility without sacrificing grain yield, drought tolerance or heat tolerance. Data on the evaluation of waxy corn, high lysine corn, high oil corn, and other grains in beef feedlot diets is limited. Results to date are variable.

Stilborn (1999) recently examined the future of designer grains for nonruminants. Benefits from feeding high oil corn (HOC) to broilers may include a reduction in abdominal fat and increased breast meat yield when diets contain similar nutrient to energy ratios as the yellow corn control diets. HOC may be used to increase the energy intake of the laying hen during peak production. In swine diets, HOC can be used to either increase dietary energy density or replace yellow dent corn and supplemental fat. Nutritional inputs to consider include high lysine and/or high methionine high oil corn, high lysine, methionine, or protein in corn and soybean meal with high lysine or methionine concentrations. High oleic acid, high oil corn will offer livestock producers the ability to modify the fatty acid profile of lipids deposited in the carcass, resulting in improved processing, storage, and consumer preference properties.

Nutritional value of genetically improved high lysine, high oil corn was evaluated in young pigs (O'Quinn et al. 2000). Researchers reported the lysine in the high lysine, high oil corn was as available as that in the high oil corn based on results of a pig digestibility and performance trial. High lysine, high oil corn offers the potential to reduce the amount of supplemental protein and/or lysine and energy needed in swine diets.

Baumel et al. (1999) evaluated the impact of six corn modifications used in least-cost swine and poultry feed rations. The six corn modifications were: 1) increased protein by 8 percentage points (from 8.7 percent to 16.7 percent dry matter basis); 2) enlarged germ size (from 11.1 percent to 27.1 percent of kernel size); 3) increased starch digestibility by 8 percentage points in poultry diets; 4) doubled methionine content (from 0.207 percent to 0.414 percent dry matter basis); 5) doubled lysine content (from 0.30 percent to 0.60 percent dry matter basis); and 6) doubled available phosphorus (from 0.068 percent to 0.12 percent dry matter basis). Their analysis estimated the impact of each modification on increased corn consumption, changed consumption of traditional ingredients, net value of the modified corns, and range of possible price responses for traditional feed ingredients. Price of the modified corn was the same as the price used for the conventional corn.

The increase in protein percentage had the highest savings per ton of feed ($11.75) and the greatest impact on the consumption of corn and soybean meal. Increasing starch digestibility, followed by increasing germ size, had the next largest effect on cost per ton of feed and the largest impact on feed fat consumption. The small economic impact of available phosphorus would indicate that it would be used when environmental policies dictate.

The per bushel added values of the six modifications in swine and poultry diets are summarized in Table 4. These are gross values since the added costs of providing these modifications were not subtracted from the added values. The added value of each of the six genetic modifications of corn was obtained by dividing the feed savings by the quantity of modified corn used in the feed. Estimates of added value were calculated only for diets in which each modification would likely add value. In swine diets, high protein had the largest benefit with 15.6 cents to 29.4 cents per bushel of corn. Modifying corn to contain high protein, enlarged germ, or high starch digestibility significantly benefited the poultry producer ranging 27.1 cents to 57.4 cents per bushel of corn.

In summary, the estimated least-cost feed ration data by Baumel et al. (1999) show that modified corn with enhanced nutrient content would decrease the cost of swine and poultry diets and decrease the consumption of other major feed ingredients. The greatest value in nutrient modification is increased protein and oil content in swine and poultry diets and increased starch digestibility in poultry rations.

▼ **Table 4. Added values for six genetic modifications of corn in swine and poultry diets, in cents per bushel.**

Modification	Swine		Poultry		
	8-13 lb. Piglets	233-283 lb. Finishers	Broilers	Tom Turkeys	Layers
High protein	29.4	15.6	57.4	45.0	27.1
Enlarged-germ	0.0	10.3	48.0	44.2	36.3
High starch digestibility	—	39.8	33.4	31.1	
High methionine	—	—	7.4	4.1	5.7
High lysine	0.0	5.2	—	—	—
High available phosphorus	1.7	1.7	—	—	—

— Indicates that estimates were not calculated in these diets.
Source: Baumel et al. (1999)

Future developments could include genetically modifying crops to contain compounds that would be absorbed by the animal and deposited in the meat, milk, or eggs to add value such as cancer fighting agents, antioxidants and other agents to extend the shelf-life, natural meat tenderizers, more healthy fatty acid profile, and compounds to prevent disease.

Safer feed supply

One of the current agronomic traits (incorporation of the B.t. gene) has already proven beneficial in the reduction of fumonisin in corn (Munkvold et al. 1999). This trait in itself is very valuable since it helps reduce the incidence of mycotoxicosis in livestock and increase the likelihood of the producer selling this grain. Fumonisin levels greater than 10 ppm in grain can cause death or morbidity in horses and swine (Norred, 1993). Action levels of fumonisin contamination in grain have been set by the United States (5 ppm for horses, 20 ppm for swine, and higher levels for poultry and ruminants). Genetically enhancing the mannanoligosaccharide level in grain also may be beneficial in counteracting the effects of mycotoxins. Recent research has shown the supplementation of the diet with modified mannanoligosaccharide to be beneficial in counteracting the adverse effects of dietary mycotoxins on the immunological status of broiler breeder hens (Afzali and Devegowda, 1999) and significantly improving body weight, feed consumption, and antibody titers in broilers (Raju and Devegowda, 1999).

Plant breeders have made great strides in reducing or eliminating some undesirable constituents of feeds, such as erucic acid and glucosinolates. However, with the use of biotechnology, in conjunction with plant breeding, a greater number of anti-nutritionals can be addressed in a shorter time period. For example, in legumes there are protease inhibitors, tannins, phytohemagglutinins, and cyanogens. Anti-nutritionals in oil seed rape include thioglucosides, also known as glucosinolates, whose degradation products are goitrogenic and heptatoxic, tannins, and sinapine (affects palatability and can result in a fishy taint in eggs of certain strains of laying hens) (Armstrong and Gilbert, 1989). Soybean contains lectin, proteins that bind carbohydrate-containing molecules (Sauber, 2000). Barley grain contains significant amounts of (-1,4 glucan that results in increased viscosity and poor performance in monogastrics. Currently, (-glucanases and xylanases are being added to barley-based diets to overcome this problem for poultry and swine. Fungi and plants are now being bioengineered to produce these specific enzymes. In the future, low (-1,4 glucan barley and/or barley already containing the glucanase and xylanase enzymes in the seed may be bioengineered.

Environmental benefits

Nutritive value of roughages and forages will be enhanced through improved fiber digestibility (Armstrong and Gilbert, 1989). The plant may contain lignin, cellulose, and hemicellulose that are more easily degraded or cellulase,

hemicellulase, and lignase enzymes may be bioengineered into plants or rumen microbes that enhance the utilization of these energy sources. Low lignin corn is already here via plant breeding. The brown mid rib mutant gene was identified and bred into certain lines of corn. This product contains about 40% less lignin than its parental variety. Enzymes could be genetically engineered to convert roughages to substrates now utilizable by monogastrics. Microbes (silage microbial innoculants) could be genetically modified to enhance the fermentation process of forages in silos. Increased digestibility results in reduced waste disposal issues.

Mineral bioavailability will be improved to make more efficient use of the minerals in plants and reduce the contribution to the environment where leaching can occur in streams and lakes. Phosphorus is the main mineral of concern at present. Phosphorus is locked up in the plant as phytate phosphorus. Monogastric animals do not have the necessary enzyme machinery to access the phosphorus, so it ends up in animal waste. The waste is applied to the fields where leaching and run-off can occur. To prevent this problem phytase enzyme is added to poultry and swine feed to unlock this valuable mineral (Stilborn, 1999). Through biotechnology, plants will contain low phytate (high available phosphorus) or phytase activity thus allowing for more efficient use of phosphorus with reduced supplementation of inorganic sources and (Douglas et al., 2000; Stilborn, 1999).

Animal health

Efforts are underway to bioengineer plants to produce proteins that illicit positive health effects in animals. In particular, the chicken interferon gene is being incorporated into corn so a particular protein can be produced in the seed as a vaccine to help combat avian influenza and help keep chickens healthy. The market (estimated $1.7 billion market for chicken vaccines) is high because farmers who raise the world's 18 billion chickens live in fear of the outbreak of virulent avian influenza strains. Recently ProdiGene (College Station, Texas) received a patent covering viral disease vaccines produced in genetically enhanced plants (Feedstuffs, Vol. 71, 1999). The vaccines produced via this technology can be marketed either in edible form, made from parts of the fruit, vegetable, or grain plant, or in injectable form. Hepatitis B in humans and transmissible gastroenteritis virus (TGV) in swine are two diseases being targeted. Clinical trials for the TGV vaccines are underway. Other oral vaccines under development for swine include vaccines against porcine reproductive and respiratory syndrome (PRRS) and diseases like parvovirus (http://agbio.cabweb.org/news/research.htm).

Conclusion

The benefits of genetically modifying plants for humans, livestock, and the environment are far-reaching. Through biotechnology, safer, more nutritious, and healthier foods would be produced to improve the health, nutrition, and well-being of people and livestock worldwide. These innovations will be key in providing a sustainable food supply to feed the increasing world's population.

References cited

Afzali, N.and G. Devegowda. 1999. Ability of modified mannanoligosaccharide to counteract aflatoxicosis in broiler breeder hens. Poultry Sci. 78(Suppl. 1):52.

Aldridge, S. 2000. The Agribiotech Revolution: Effort to focus on the need to feed growing world population. Genetic Engineering News. 20:1,14,16,47.

Araba, M. 1997. Impact of new grain varieties on feed manufacturing. Feed Management. 48(1):11.

Armstrong, D.G. and H.J. Gilbert. 1989. The application of biotechnology for future livestock production. Physiological Aspects of Digestion and Metabolism in Ruminants, Proceedings of the seventh international symposium on ruminant physiology, T. Tsuda, Y. Sasaki and R. Kawashima (Editors), Academic Press, San Diego, CA. P737.

Bajjalieh, N.L. 1996. Added-value grains to have expanded value in feed. Feedstuffs 68:23.

Baumel, C.P., T. Yu, C. Hardy, L.A. Johnson, M.J. McVey and J.L. Sell. 1999. GM corn has impact on feed consumption. Feedstuff 71(40):16, 22-23, 26-28.

Cline, M.N. and D.B. Re. 1997. Plant Biotechnology: A progress report and look ahead. Feedstuffs 69:14.

Cline, M.N., D.B.Re, and G.F. Hartnell. 1996. Today's message is equivalence, tomorrow's may be nutrition. Feedstuffs 68:47.

Dado, R.G. 1999. Nutritional benefits of specialty corn grain hybrids in dairy diets. J. Dairy Sci. 82(Suppl. 2):197 or J. Anim. Sci. 77(Suppl. 2):197.

Douglas, M.W., C.M. Peter, S.D. Boling, C.M. Parsons and D.H. Baker. 2000. Nutritional evaluation of low phytate and high protein corns. Poultry Sci. 79:1586-1591.

Edwards III, H. M., M.W. Douglas, C.M. Parsons and D. H. Baker. 2000. Protein and energy evaluation of soybean meals processed from genetically modified high-protein soybeans. Poultry Sci. 79:525-527.

Feedstuffs, Vol. 71, 1999

Food and Drug Administration. 1992. Statement of Policy: Foods Derived from New Plant Varieties: Notice, Federal Register 57:104; 22984-23005.

Gianessi, L.P. and J.E. Carpenter. 1999. Agricultural Biotechnology: Insect Control Benefits. National Center for Food and Agricultural Policy.

Giddings, G., G. Allison, D. Brooks and A. Carter. 2000. Transgenic plants as factories for biopharmaceuticals. Nature Biotechnology 18:1151-1155.

Halpin, C., G.A. Foxon and P. A. Fentem. 1995. Transgenic plants with improved energy characteristics. Chapter 14 in Biotechnology in Animal Feeds and Animal Feeding. Editors R. John Wallace and A. Chesson. VCH Publishers, New York, p. 279 - 293.

Hartnell, G. F. and R. L Fuchs. 2000. Current and future value of innovative technology in genetically modified crops. Chapter 9 in Concepts of Pig Science 2000, The 2ND Annual Turtle Lake Pig Science Conference, Editors T.P. Lyons & D.J.A. Cole, Nottingham University Press, UK. p. 117-138.

Hesman. T. 2001. Genetic engineering's new goal: food that includes a vaccine. St. Louis Post-Dispatch Vol. 123, No. 190, Monday July 9, 2001, p. A1.

Holden, P.J., J. McKean and E. Franzenburg. 1999. Inclusion of botanicals in swine diets examined. Feedstuffs 71 (26):11-13,23.

IFIC. 1999. Food biotechnology benefits and products. Food Biotechnology, International Food Information Council (IFIC) Foundation. February 1999.

James, C. 2000. Global review of commercialized transgenic crops: 1999. ISAAA Briefs No.21: Preview. ISAAA: Ithaca, NY. http://www.isaaa.org/ briefs/Brief21.htm.

Langridge, W.H.R. 2000. Edible vaccines. Scientific American, September. P 66-71.

Mackey, M.A. and C.R. Santerre. 2000. Biotechnology and our food supply. Nutrition Today 35:120-128.

Marasas, W.F.O., K. Jaskiewicz, F.S. Venter and D.J. van Schalkwyk. 1988. Fusarium moniliforme contamination of maize in oesophageal cancer areas in the Transkei. South Africa Medical Journal 74:110-114.

Munkvold, G.P., R.L. Hellmich and L.G Rice. 1999. Comparison of fumonisin concentrations in kernels of transgenic corn hybrids and nontransgenic hybrids. Plant Dis. 83:130.

Munkvold, G.P., R.L. Hellmich and W.B. Showers. 1997. Reduced Fusarium ear rot and symptomless infection in kernels of corn genetically engineered for European Corn borer resistance. Phytopathology 87:1071.

Norred, W.P. 1993. Fumonisins -mycotoxin produced. Journal of Toxicology and Environmental Health 38:309-328.

O'Quinn, P.R., J.L. Nelssen, R.D. Goodband, D.A. Knabe, J.C. Woodworth, M.D. Tokach and T.T. Lohrmann. 2000. Nutritional value of a genetically improved high-lysine, high-oil corn for young pigs. J. Anim. Sci. 78:2144

Owens, F and S. Soderlund. 2000. Specialty Grains for Ruminants. 61th Minnesota Nutrition Conference & Minnesota Soybean Research and Promotion Council Technical Symposium, September 19-20, 2000, Bloomington, MN. Conference Proceedings p 98-113.2149.

Parsons, C.M. and Y. Zhang. 1997. Digestibility of amino acids in high-lysine soybean meal. Poultry Sci. 76(Suppl. 1):85. (Abstr.).

Parsons, C.M., Y. Zhang, and M. Araba. 2000. Nutritional evaluation of soybean meals varying in oligosaccharide content. Poultry Sci. 79:1127-1131.

Potera, C. 1999. EPIcyte produces antibodies in plants. Genetic Engineering News. February 15, 1999, p 22.

Raju, M.V.L.N. and G. Devegowda. 1999. Influence of modified mannanoligosaccharide on broilers exposed to individual and combined mycotoxicoses of aflatoxin, ochratoxin and T-2 toxin. Poultry Sci. 78 (Suppl. 1):52.

Sauber, T. 2000. Performance of Soybean Meals Produced From Genetically Enhanced Soybeans. 61th Minnesota Nutrition Conference & Minnesota Soybean Research and Promotion Council Technical Symposium, September 19-20, 2000, Bloomington, MN. Conference Proceedings p 44-51.

Stilborn, H.L. 1999. The future of designer grains for nonruminants. 60th Minnesota Nutrition Conference & ZinPro Technical Symposium, September 20-22, 1999 Bloomington, MN. Conference Proceedings p 144.

Stock, R.A. 1999. Nutritional benefits of specialty grain hybrids in beef feedlot diets. J. Dairy Sci. 82(Suppl 2):208 or J. Anim. Sci. 77(Suppl 2):208.

Uzogara, S.G. 2000. The impact of genetic modification of human foods in the 21st century: A review. Biotechnology Advances 18:179-206.

White, C. and T.J. Higgins. 2000. Sheep thriving in GMO feeding trial. CSIRO Media Release. http://www.csiro.au/page.asp?type=mediaRelease&id=prGMLupins.

Web: http://agbio.cabweb.org/news/Research.htm

WHO, 1991. Strategies for Assessing the Safety of Foods Produced by Biotechnology. Report of a Joint FAO/WHO Consultation. World Health Organization, Geneva.

Yuen, M. 2000. Harnessing biotech production power of plants. Genetic Engineering News. 20 (Number 15):62,66,86. ▲