Nutritional Requirements of Early Weaned Pigs[a] - A Review -

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ABSTRACT : The process of weaning, no matter how carefully managed, results in changes in the gut of the pig that make it more susceptible to digestive upset, diarrhoea and impaired appetite. The objective in developing feeding programs is to recognize these unique needs and facilitate a smooth transition to a dry feed. How well this is accomplished, has a significant impact on future performance. This paper provides a review of recent research on the nutrients required by early weaned pigs and examines what feedstuffs are available to provide those nutrients in a form that can be best utilized by the early weaned piglet. (*Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 6 : 976-987*)

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INTRODUCTION

Off-site segregated early weaning is being used increasingly by the swine industry in North America and to a lesser extent in other areas of the world. By removing the pig from one of its primary sources of infection (the sow), segregated early weaning allows dramatic improvements in the health and performance of growing pigs (Dritz et al., 1996). The degree of improvement varies but improvements in growth rates to market of 5 to 15% are not uncommon. As a consequence, many producers are adopting lactation lengths of 18 days or less and there are now many commercial farms with average lactation lengths of fewer than 14 days.

The adoption of segregated early weaning has precipitated a need to develop feeding strategies for piglets weighing less than 5 kg. For many nutrients, virtually no experiments have been conducted with pigs of this weight range. Currently used estimates of requirements are based largely on extrapolations from work done with heavier piglets. More research is needed if we are to fully exploit the growth potential of the early weaned piglet.

The physiological immaturity of the piglet's digestive system provides a special challenge to nutritionists. The ability to formulate a diet that will economically ease the transition from sow's milk to a nursery diet while maintaining maximum growth rates will have a major impact on the profitability of swine production in the 21st century.

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FACTORS WHICH LIMIT THE PERFORMANCE OF EARLY WEANED PIGS

Some of the principal factors which limit the post-weaning growth potential of early weaned piglets have been summarized by Partridge and Gill (1993) and Cranwell and Moughan (1989) and a modified list is presented in table 1. Any successful feeding program for early weaned piglets must take these factors into account and strategies developed to overcome them.

Table 1. Constraints limiting post weaning growth of early weaned piglets

- Inadequate levels of digestive enzymes
- Reduced absorptive capacity due to changes in villus structure
- Inadequate acid secreting ability
- Removal of beneficial factors present in sow's milk
- Inadequate feed intake
- Inadequate water intake
- Diet antigenicity

Limited secretion of digestive enzymes

The newborn piglet is essentially born with the ability to secrete the digestive enzymes involved in the digestion of milk. Thus, it has a high level of lactase, and sufficient lipase and protease to digest the fats and proteins contained in milk. Levels of other enzymes at 3 weeks of age are often less than 50% of the value at digestive maturity (Jensen et al., 1997; table 2).

Several studies have shown a consistent depression in the levels of pancreatic enzymes in the newly weaned pig compared with the suckling pig (Lindemann et al., 1986; Makkink et al., 1994). As a consequence, any ingredients provided to the early weaned pig must be compatible with its pattern of enzyme secretion and ease of digestion must be given consideration when choosing ingredients for nursery diets.

Table 2. The influence of piglet age on enzyme activity (μ mol substrate hydrolyzed/min)

	Trypsin	Chymotrypsin	Amylase
3 day old pig	14.6	0.94	2,076
7 day old pig	22.0	3.52	14,666
14 day old pig	33.8	4.91	21,916
21 day old pig	32.1	6.99	26,165
28 day old pig	55.6	9.49	65,051
35 day old pig	42.1	3.90	24,730
56 day old pig	515.0	14.30	182,106

Jensen et al. (1997; Pigs were weaned at 28 days of age)

Reduction in absorptive capacity

During the nursing period, the intestinal villi are long and very effective in the digestive and absorption processes. Upon weaning, these villi become sloughed and their surface area is dramatically reduced (table 3). Consequently, diets provided to early weaned pigs must contain feed components that are highly digestible and not antigenic to the intestinal lining of the gut.

Table 3. Villus height and crypt depth along the small intestine of suckling and weaned pigs

	% of Intestine	Suckling Pig	Weaned Pig
Villus height (μ m)	25	550	356
	50	496	354
	75	323	285
Crypt depth (μ m)	25	118	200
	50	130	200
	75	104	185

Pluske et al. (1991)

Reduced acid secreting ability

Another shortcoming of the early weaned pig is its inability to secrete gastric acid (Easter, 1988). There are several consequences of this limited acid secretory ability. Firstly, hydrochloric acid is involved in the activation of pepsinogens and the enzyme pepsin has two pH optima, one at pH 2.0 and another at pH 3.5. Therefore, piglets with an elevated gastric pH are likely to experience a reduction in the efficiency of protein digestion (Easter, 1988). In addition, since gastric pH plays a role in preventing the movement of viable bacteria from the environment into the upper small intestine, the limited acid secretory ability may lead to an increase in digestive upsets (Mayes, 1990).

Because of the limited acid secretory ability of the piglet, a great deal of research has been conducted in which the diet of the weaned piglet has been supplemented with organic acids (Easter, 1988). Most of this research has involved the use of fumaric, lactic, citric or propionic acids supplemented at a level between 0.5-3.0%. A review of the literature indicates that the greatest benefits from acidification seem to occur from 7 to 21 days postweaning (i.e. Transition and Phase II diets) and that the largest improvements occur with simple diets where nutrient digestibility is lowest. Benefits are generally less if diets include significant amounts of milk-based ingredients.

When formulating diets for early weaned pigs, attention must be given to the acid binding properties of ingredients. For example, alkaline mineral mixes, particularly calcium, have very high acid binding properties (Bolduan et al., 1988). As a consequence, high calcium levels in pig starter diets can significantly reduce post-weaning performance (table 4). Since bone mineralization has been found to reach a plateau at 0.8% (Mahan, 1982), restricting the level of calcium inclusion in nursery diets to 0.8% may improve performance.

Table 4. Effect of calcium level on starter pig performance

	Dietary Calcium (%)			
	0.58	0.80	1.01	1.38
Daily gain (kg)	0.64	0.64	0.60	0.55
Feed intake (kg)	0.86	0.91	0.86	0.86
Feed efficiency	1.34	1.44	1.44	1.58

Hardy (1992)

Reduction in immunological protection

The early weaned piglet has still further problems with which to contend and these refer to its immunity or resistance to disease at this time. It is well documented that the pig is born without any protective immunity and receives all of its immunological protection from colostrum largely in the form of IgG. The secretion of this immunoglobulin in milk declines fairly rapidly. The piglet does not normally start to build up its own immunity to prevailing infection until about three weeks of age and the level of immunity builds up rather slowly from this point. As a consequence, weaning of pigs at 10-18 days results in the piglet being weaned at a stage when its immunity is at the lowest level of its life. Therefore, every effort must be made to provide early weaned piglets with the highest possible sanitation level to ensure the least bacterial challenge.

Low feed intakes

In most circumstances, the factor most limiting weanling performance is limited feed intake and more precisely energy intake. Producers who achieve a high level of feed intake are able to realize the best overall performance in the nursery. Feed intake is heavily influenced by diet digestibility (Toplis and Tibble, 1995). Seemingly small reductions in digestibility can have a proportionally large impact on performance by reducing voluntary feed intake (table 5). As a consequence, only feedstuffs with known high digestibility should be utilized in diets fed to early weaned pigs.

Table 5. The effect of diet digestibility on the appetite limit of 10 kg pigs

Diet Digestibility (%)	Volunatry Feed Intake (kg/day)
0.85	0.87
0.80	0.65
0.75	0.52

Toplis and Tibble (1995)

If feed intake is so important during this period, it stands to reason that every effort should be made to stimulate piglets to consume as much feed as possible. For this reason, feed flavours have received attention as a potential means of stimulating intake. Unfortunately, feed flavours tend to be incorporated into swine feeds because of marketing appeal and consumer preference rather than proven efficacy. Presently, very little is known about which specific flavours pigs find attractive and too often flavours are chosen for inclusion in pigs feeds because they are attractive to the human palate rather than to that of the pig.

Very few studies have demonstrated a consistent improvement in feed intake or growth rate as a result of the inclusion of feed flavours in the diet. McLaughlin et al. (1983) compared 129 different feed flavours to determine which specific flavours were preferred by weaner pigs. Five of the flavours that were shown to be most preferred by pigs were used in a feeding trial. However, none of the flavours significantly increased feed intake or growth rate.

Inadequate water intake

The importance of water intake cannot be overstated as a factor affecting the performance of early weaned pigs. Restricted water flow reduced feed intake of pigs aged 3 to 6 weeks by approximately 15% and had a similar effect on growth (table 6). Topplis and Tibble (1994) recommend a minimum of 570 millilitres per minute flow rate in water nipples in the nursery. Type of drinker also has an effect on water consumption and feed intake. Several commercial operations have adopted the use of turkey drinkers as a means of stimulating water intake of early weaned pigs and have observed an increase in growth.

Table 6. Effect of flow rate of water on weaner pig performance (3-6 weeks)

	Water Delivery Rate (mls/minute)			
	175	350	450	700
Time spent drinking (min)	4.46	2.97	2.93	2.32
Water intake (L/day)	0.78	1.04	1.32	1.63
Feed intake (g/day)	303	323	341	347
Daily gain (g/day)	210	235	250	247
Feed efficiency	1.48	1.39	1.37	1.42

Toplis and Tibble (1994)

DIET FORMULATION FOR EARLY WEANED PIGS

Newly weaned pigs, especially those weaned at less than 18 days of age, have a requirement for a diet of high nutrient density, high palatability and high digestibility. Meeting these needs requires very expensive ingredients. Ingredient choice has as big an impact on performance during the weaner period as does the level of nutrients provided.

Carbohydrate sources for early weaned pig diets

A great deal of research in the last decade has emphasized the need for simple carbohydrates such as lactose in the diet of the early weaned pig. More complex carbohydrates such as starch are utilized less efficiently (Mahan and Newton, 1993; Jin et al., 1998; table 7). As a consequence, products such as whey or lactose are widely utilized in diets formulated for early weaned pigs.

Dried whey contains 65 to 75% lactose and about 12% crude protein (NRC, 1998). There is also a whey product available in which some of the lactose has

Table 7. Effect of different carbohydrate sources on the performance of three weeks old pigs (Day 0 to 7)

	Starch	Lactose	Glucose	Sucrose	Dried Whey
Daily gain (g)	241.4	294.0	258.6	291.7	286.0
Daily intake (g)	297.7	329.4	316.0	338.8	333.7
Feed efficiency	1.22	1.11	1.21	1.15	1.16

Jin et al. (1998a)

Table 8. Innovative carbohydrate sources recently tested in early weaned pig diets

Ingredient	Author	Source
Sorghum-Based Distillers Grains	Senne et al., 1997	J. Anim. Sci. 75 (Supp 1):70
Naked Oats	Whitney et al., 1997	J. Anim. Sci. 75 (Supp 1):70
Hard Red Winter Wheat	Rodas et al., 1997	J. Anim. Sci. 75 (Supp 1):15
Potato Chip Scrap	Rahnema et al., 1997	J. Anim. Sci. 75 (Supp 1):59
High Oil Corn	Bergstrom et al., 1997	J. Anim. Sci. 75 (Supp 1):71
Milk Chocolate Product	Yang et al., 1997	J. Anim. Sci. 75: 423-429.
Ground Oat Groats	Rantaner et al., 1995	J. Anim. Sci. 73 (Supp 1):78
Oat Flour	Rantaner et al., 1995	J. Anim. Sci. 73 (Supp 1):78
Extruded Corn	De Luca et al., 1995	J. Anim. Sci. 73 (Supp 1):175
Full Fat Canola Seed	Gipp and Swenson, 1996	J. Anim. Sci. 74 (Supp 1):176
Jerusalem Artichoke	Farnsworth et al., 1995	Anim. Feed. Sci. Tech. 55:153
Galactosyl Lactose	Mathew et al., 1997	J. Anim. Sci. 75:1009-1016

Table 9. Effect of mannanoligosaccharides on starter pig performance

	Control	Spriamycin	Olaquindox	Bio-Mos
Daily gain (g)	359	427	401	329
Feed intake (g)	660	670	689	631
Feed efficiency	1.84	1.57	1.72	1.92
Diarrhea score	12	8	10	13

Li Tong Shou (Ministry of Agricultural Feed Industry Centre, Beijing, China, Unpublished data)

been crystallized and this low lactose whey contains about 17% crude protein. Depending on price, whey is usually included at levels of 15 to 30% in SEW diets (for pigs 2.2 to 5.0 kg), 10 to 20% in Transition diets (for pigs 5.0 to 7.0 kg) and up to 10% in phase II diets (for pigs 7.0 to 11.0 kg; Shurson et al., 1995).

An advantage of using whey in the diet is that in addition to acting as a source of lactose, it provides a high quality protein, predominantly in the form of lactoglobulin. However, since dried whey is high in salt, attention must be paid to the level of supplemental salt utilized in early weaner diets (Shurson et al., 1995).

Lactose (whey permeate, deproteinized whey, edible lactose) can also be used in nursery diets and is often available at a lower price than whey. It is generally recommended that SEW diets (for pigs 2.2 to 5.0 kg) should contain between 18 and 25% lactose, Transition diets (for pigs 5.0 to 7.0 kg) should contain 15 to 20% lactose and phase II diets (for pigs 7.0 to 11.0 kg) may contain up to 10% lactose (Shurson et al., 1995).

In addition to whey and lactose, there has been a considerable amount of research in the past five years conducted to develop alternative carbohydrate sources for use in diets fed to early weaned pigs. Space does not allow a full discussion of all of the recently tested ingredients but a partial list is provided in table 8.

Most recent research with carbohydrates has focused on finding sources of easily digested carbohydrates for use in nursery diets. However, there has been some interest in the study of very complex carbohydrates such as mannanligosaccharides and fructosaccharides which are believed to alter the ability of specific pathogens to colonize the intestinal tract. Russell et al. (1996b) included 0.1 g/day of fructooligosaccharide (an oligosaccharide composed of glucose and two to four fructose units) in the diet of 28 day old weaner pigs and observed improvements in growth and feed efficiency over a two week period. Bunce et al. (1995) reported that inclusion of fructooligosaccharide reduced the incidence of diarrhoea in 7 day old pigs challenged with E. Coli. Galactan (a polymer of D-L galactose) has also been used for this purpose (Mathew et al., 1993). Similarly, Dritz et al. (1995) reported that 0.025% beta-glucan improved growth and survival of weaned pigs challenged with Streptococcus suis infection. The response to these products is not always positive (table 9) and more work is needed to assess their potential to improve weaner pig performance.

Protein sources for early weaned pig diets

In choosing protein sources for use in diets fed to early weaned pigs, consideration should be given to the digestibility of the protein source, its balance of amino acids, its palatability and whether or not the protein source provides any immunological protection to the piglet.

The principal amino acid limiting the performance of early weaned pigs is lysine. Most research has indicated that pigs will respond with higher growth rates and improved feed efficiencies as lysine levels are increased. For example, Owen et al. (1995c) reported that the segregated early weaned pigs required between 1.65 and 1.80% total lysine in the diet (table 10).

Table 10. Lysine requirements of segregated early weaned pigs (0-14 days)

	1.20	1.35	1.50	1.65	1.80	1.95
Daily gain (g)	331	362	382	4.08	394	402
Gain/feed	0.87	0.90	0.93	1.03	1.03	1.03

Owen et al. (1995c)

Other amino acids must be maintained in the proper ratio to lysine to achieve optimal performance. However, there is evidence that the ideal protein balance for early weaned pigs is not the same as that for pigs of heavier weights (table 11). Owen et al. (1995a) reported that a 1.6% lysine diet containing spray dried blood products should contain 0.41 to 0.42% methionine (0.36 to 0.37% apparent digestible). Subsequently, these same authors reported that dietary methionine should be set at 27.5% of dietary lysine to maximize growth of pigs from 0 to 21 days postweaning (Owen et al., 1995b). Bergstrom et al. (1997a) reported that the digestible isoleucine requirement is not greater than 60% of lysine immediately after weaning and that the isoleucine requirement drops rapidly, such that digestible isoleucine requirements are not greater than 50% of lysine for the 10 to 20 kg pig (Bergstrom et al., 1997b).

Table 11. Recommended amino acid pattern for early weaned piglets

	Baker (1997)	NRC (1998)
Lysine	100	100
Isoleucine	60	55
Methionine	30	29
Threonine	65	65
Tryptophan	17	18

One amino acid that is not usually considered essential for pigs but that is getting increased attention in recent research is glutamine. Atrophy of the gut is common in weaned piglets and is often associated with an absence of gut substrates or catabolic stress. This atrophy may be the result of a lack of glutamine because this amino acid is not only the primary respiratory fuel for gut enterocytes but also provides amide nitrogen that may support nucleotide biosynthesis (Windmueller, 1984).

At weaning, exogenous supplies of glutamine generally disappear because sows milk, a major source of glutamine, is no longer available and piglets often fast or eat very small amounts of dry food. Ayondrinde et al. (1995a, b) reported that plasma concentrations of glutamine and glutamate were significantly lower in weaned vs suckling piglets. The decline in plasma glutamine and its breakdown products after weaning indicates that endogenous glutamine sources are incapable of maintaining plasma levels at this time. Thus, glutamine is in short supply in the post weaning period and if it is essential for maintaining the integrity of the enterocytes, the decline in its availability may be associated with the gut atrophy which occurs in newly weaned piglets. Supplementation of milk replacers with glutamine has been shown to increase villus height and reduce crypt depth in weaned pigs (table 12). Glutamine has been proposed as a conditionally essential amino acid for weaned piglets.

Table 12. Effect of adding glutamine to milk replacer on villus height and crypt depth along the small intestine of suckling and weaned pigs

	% of Intestine	Milk Replacer	Milk Replacer+ Glutamine
Villus height (μm)	25	545	596
	50	406	455
	75	291	338
Crypt depth (μm)	25	168	155
	50	165	144
	75	142	125

Pluske et al. (1991)

Protein sources

The high amino acid requirement of the early weaned pig necessitates the feeding of multiple protein sources. Most diets fed to early weaned pigs contain some combination of skim milk, spray dried procine plasma, whey protein concentrate, fish meal, spray dried blood meal, soybean meal, and further processed soy products (soy concentrate or isolate).

The only protein source which is considered essential in the diet of the early weaned pig is spray-dried porcine plasma. Weaver et al. (1995a) summarized 25 experiments in which the effects of adding spray dried porcine plasma to starter pig diets were examined and concluded that on average, daily gain had been improved by 39%, daily feed intake was increased by 32% and feed efficiency was improved by 5.4%.

It has not been firmly established how porcine plasma produces such dramatic improvements in performance but two main hypothesis are available. The first involves spray dried porcine plasma as a source of immunoglobulins. When pigs are weaned at about 3 weeks of age, the maternal immunoglobulins are removed from their diet and this reduction may be responsible for the postweaning growth check commonly observed at weaning. Spray dried porcine plasma contains about 22% immunoglobulins and it has been suggested that it is by providing these immunoglobulins that porcine plasma improves weaner pig performance.

To test the hypothesis that the immunoglobulin fraction is the active component of spray dried porcine plasma, several researchers have separated the porcine plasma into a low molecular weight fraction, an intermediate fraction and a high molecular weight fraction containing most of the immunoglobulins. Diets containing the same amount of each of the three fractions were formulated and the results obtained by feeding the three fractions were compared to spray dried plasma (Pierce et al., 1995; Weaver et al., 1995b). Only the high molecular weight fraction produced any beneficial effect.

If it is the immunoglobulins in plasma that produce the beneficial effect, then other sources of immunoglobulins may be found that can also be used in diets fed to early weaned pigs. Several research groups are currently investigating the potential of immunizing laying hens against specific pathogens which affect pigs. The hens then build up an immunity to the pathogen and deposit the antibody in their eggs. Feeding the egg yolk antibodies to pigs has shown great promise as a means of providing immunological protection (Imberechts et al., 1997; Yokoyama et al., 1992; Zuniga et al., 1997).

Another explanation for the beneficial effects of spray-dried porcine plasma is as a flavour enhancer. One of the most consistently reported responses to feeding spray-dried porcine plasma is an increased feed intake immediately after weaning compared with other protein sources. Ermer et al. (1994) investigated diet preferences when pigs were given the choice of diets containing 20% skim milk powder or 8.5% porcine plasma. Twenty eight of the thirty five pigs on test preferred the diet containing porcine plasma to the diet containing skim milk.

The optimum level of inclusion of spray dried porcine plasma has been investigated in a few studies. Gatnau et al. (1993) concluded that the inclusion of 6% spray dried porcine plasma during the first post weaning period maximized pig performance. However, Kats et al. (1994) fed diets containing 0, 2, 4, 6, 8 or 10% plasma in place of skim milk powder. A linear response to porcine plasma in weight gain and feed intake was observed. A level of 7.5-10% spray dried porcine plasma in diets fed to pigs younger than 28 days is commonly recommended (Shurson et al., 1995).

Porcine plasma is relatively low in the two indispensable amino acids, methionine and isoleucine, so it is important that diets be adjusted to maintain a proper level of these two amino acids. Owen et al. (1995a, b) demonstrated that a positive response was obtained when diets containing porcine plasma are furnished with synthetic methionine.

Porcine plasma contains relatively high levels of sodium and chloride (2.23% and 0.4%, respectively). Therefore, by including 5 to 10% porcine plasma in starter diets, the requirements for these two minerals are usually met. However, Mahan et al. (1996) recently demonstrated that the addition of NaCl to diets containing plasma is beneficial up to a level of at least 0.36% sodium and 0.34% chloride. The current recommendation is to add at least 0.2% NaCl to diets containing spray dried plasma.

Until recently, dried skim milk was also thought to be essential in the diet of the early weaned pig. It provides a high quality protein and also provides a source of lactose to the early weaned pig. However, recent research is showing that skim milk can be replaced with much lower cost protein sources without sacrificing performance (Hansen et al., 1993a). Fish meal is widely utilized as a source of high quality protein (Kim and Easter, 1997) and processed soy products have also shown promise for use in weaner pig diets (Sohn et al., 1994a, b; Li et al., 1991; table 13). In addition, many other products have been tested in the past few years and a partial list of protein sources in given in table 14.

Fat sources for early weaned pigs

Fat sources are commonly added to nursery diets in an attempt to increase their caloric content. However, evidence is mounting that this practise may be counterproductive. Although growth and performance averaged over several weeks after weaning can be improved on high fat diets, a number of studies suggest that the response to fat supplementation during the first week can be very small or even negative (Howard et al., 1990; Mahan, 1991). Utilization of fat is limited by the reduction in pancreatic lipase activity found immediately after weaning. The concentration of lipase in the pancreas and digesta have been reported to fall to about 30 and 60% of preweaning levels (Lindemann et al., 1986) and it may take several days for pancreatic concentrations to recover to a level found in the suckling piglet at weaning.

Despite the poor utilization of fat by the early weaned pig, some fat is generally required to be added to the diet to facilitate pelleting. Diets with high inclusion rates of milk-based ingredients are difficult to pellet and 5-6% fat is often added to

Table 13. Effect of feeding different soy products on starter pig performance (21-28 days)

	Milk	Soybean Meal	Soy Protein Concentrate	Extruded Soy Protein Concentrate	Soy Protein Isolate
Gut Morphology					
Villus height (um)	266	175	207	230	217
Crypt depth (um)	198	222	214	196	189
Anti-soy IgG titre	3.86	6.67	3.83	4.25	2.56
Performance (21-28 days)					
Daily gain (g)	173	127	150	163	-
Daily intake (g)	213	204	232	218	-
Feed efficiency	1.26	1.66	1.55	1.35	-

Li et al. (1991)

Table 14. Innovative protein sources recently tested in early weaned pig diets

Ingredient	Author	Source
Spray-Dried Bovine Plasma	Smith et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):80
Dry Extruded Whole Soybeans	Kid et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):80
Potato Protein	Smith et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):76
Spray-Dried Poultry By-Product	Veum et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):76
Soybean Protein Concentrate	Sohn et al. (1994)	J. Anim. Sci. 72:622-630
Norse LT-94 (herring meal)	Richert et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):75
Spray-Dried Wheat Gluten	Burham et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):171
Spray-Dried Whole Egg	Nessmith et al. (1995)	J. Anim. Sci. 73 (Suppl. 1):171
Spray-Dried Blood Meal	Kats et al. (1994)	J. Anim. Sci. 72:2860-2869
Ultimate Protein 1672	Dvorak et al. (1997)	J. Anim. Sci. 75 (Suppl. 1):59
Avian-Spray-Dried Blood Meal	Dritz et al. (1993)	J. Anim. Sci. 71 (Suppl. 1):57
Enzymatically Digested Protein	Easter et al. (1996)	J. Anim. Sci. 74 (Suppl. 1):53
Spray-Dried Pig Food Cheese	Laughmiller et al. (1996)	J. Anim. Sci. 74 (Suppl. 1):61
Spray-Dried Bovine Globulin	Pierce et al. (1996)	J. Anim. Sci. 74 (Suppl. 1):171
Yellow Peas	Michal et al. (1996)	J. Anim. Sci. 74 (Suppl. 1):195
Turkey Mortality Product	Wood et al. (1996)	J. Anim. Sci. 74 (Suppl. 1):61

lubricate the pellet die. However, care must be taken in choosing the fat to add and only those compatible with the piglets ability to digest lipids should be included. Utilization of fat is enhanced in lipid sources containing a high proportion of short-chain saturated and long chain unsaturated fatty acids compared with fats rich in long chain saturated fatty acids (Cera et al., 1988; Lloyd, 1957; table 15).

Table 15. Effect of chain length on fat digestibility

	3 Week	7 Week
Short Chain (<C14)	86	96
Medium Chain (C14-C18)	70	90
Long Chain (>C18)	37	78

Lloyd et al. (1957)

The digestibility of dietary fat is directly related to the ease with which it can form micelles with bile salts. Short chain fatty acids have a high affinity for micelle formation but can also be absorbed directly into the blood stream following hydrolysis from a triglyceride. Vegetable oils, higher in unsaturated fatty acids have a higher digestibility than animal fat during

Table 16. Coefficient of digestibility of different fats in the weaned piglet

	Corn oil	Lard	Tallow
1 Weeks after weaning	0.79	0.68	0.65
2 Weeks after weaning	0.80	0.72	0.72
3 Weeks after weaning	0.89	0.84	0.82
4 Weeks after weaning	0.89	0.85	0.82

Cera et al. (1988; Pigs weaned at 21 days of age)

Table 17. Effect of fat source on performance of pigs weaned at 21 days

	Coconut	Corn	Soybean	Tallow	Tallow +Lecithin
Daily gain (g)	385	379	382	358	375
Daily intake (g)	483	477	479	462	477
Feed efficiency	1.25	1.25	1.25	1.28	1.27

Jin et al. (1998b)

the first week postweaning. By four weeks, there is little difference between the digestibility of vegetable and animal fat (Cera et al., 1988; table 16). In general, coconut oil, butter fat and lard have been well utilized, soybean and corn oil have given satisfactory results and tallow has given the poorest performance (table 17).

Mineral requirements of early weaned pigs

There has not been a great deal of research examining the mineral needs of the early weaned pig. Current recommendations for the 3, 5, and 7 kg piglet are presented in table 18. One of the most revolutionary areas of recent research interest involving mineral nutrition for early weaned pigs has been the use of pharmacological levels of zinc (table 19). Several studies in the past five years have reported that high levels of zinc (2,000-4,000 ppm of zinc oxide) increases growth rate of early weaned pigs (Smith et al., 1995; Mullen et al., 1995).

The literature on the use of zinc in weaner diets is confusing with response rate dependant on the level of inclusion, the duration and the form of zinc fed. Lemieux et al. (1995) reported that the addition of 3,000 and 6,000 ppm Zn improved growth but 6,000 ppm was no more effective than 3,000 ppm and 12,000 ppm clearly depressed performance. McCully et al. (1995) reported that 3,000 ppm Zn acetate, Zn carbonate, or Zn sulfate did not improve performance although 3,000 ppm ZnO did. The response to zinc appears to be quadratic with experiments examining excessively high levels (<5,000 ppm) indicating negative responses. Differences in zinc availability may explain why some products produce negative effects at lower levels than others. Hahn and Baker (1993) shed some light on this apparent paradox with their finding that daily gain in weaner pigs showed a curve with peak gain occurring at a plasma level of about 2.2 mg/L and dramatically reduced responses on either side. Whether or not plasma zinc levels can be used to evaluate products for their effectiveness in stimulating growth remains to be determined.

Table 18. Mineral needs of early weaned pigs

	3kg	5kg	7kg
Calcium (%)	0.93	0.86	0.82
Phosphorus (%)	0.72	0.68	0.66
Available phosphorus (%)	0.60	0.49	0.43
Sodium (%)	0.31	0.23	0.20
Chlorine (%)	0.32	0.23	0.19
Magnesium (%)	0.04	0.04	0.04
Potassium (%)	0.30	0.29	0.29
Copper (%)	6.32	6.01	5.76
Iodine (%)	0.14	0.14	0.14
Iron (%)	105	100	95
Manganese (%)	4.85	4.03	3.59
Selenium (%)	0.36	0.31	0.28
Zinc (mg/kg)	112	100	93

NRC (1998)

The duration that high zinc is required to be fed has received attention. Carlson et al. (1997) indicated that pigs should be fed pharmacological doses of zinc for at least the first two weeks of the nursery period to increase growth. Mullen et al. (1995) reported a reduction in gain when 4,500 ppm zinc was fed for three weeks in comparison with two.

One particular concern about utilizing high levels of zinc is its impact on the environment. It would be desirable if a beneficial effect could be obtained at lower levels of inclusion. Ward et al. (1996) reported that 250 ppm of zinc as zinc methionine gave equal performance as 2,000 ppm Zn from ZnO. Differences in availability from the two sources are not large enough to explain these results and further work is needed to confirm these findings.

High levels of copper (125 to 250 ppm) are also effective in stimulating growth of early weaned pigs. Cromwell (1991) reported that 250 ppm supplemental

Table 19. The effect of zinc oxide supplementation on starter pig performance (13 to 41 days)

Period	Parameter	Level of ZnO (ppm)				
		165	1000	2000	3000	4000
Day 0 to 14	Daily gain (g)	115	168	177	176	202
	Gain/feed	0.70	0.76	0.77	0.76	0.83
Day 14 to 28	Daily gain (g)	315	328	356	345	325
	Gain/feed	0.53	0.53	0.54	0.54	0.46
Day 0 to 28	Daily gain (g)	237	250	265	260	260
	Gain/feed	0.58	0.59	0.60	0.59	0.56

Smith et al., (1995)

copper improved gain by 24% and feed efficiency by 9% when fed to nursery pigs. The sulfate, carbonate and chloride forms are effective while the oxide and sulphide salts are not. Tribasic copper chloride is as effective as copper sulfate (Cromwell et al., 1995). Recently, interest has been shown in the chelated forms of copper. Coffey et al. (1994) and Apgar et al. (1995) have shown that copper lysine is equally effective as copper sulfate.

Because of the beneficial effects observed from feeding high levels of copper and high levels of zinc, many producers have attempted to feed the two minerals in combination. However, Smith et al. (1997) and Carlson et al. (1995) noted no additive effects between 250 ppm copper and 3,000 ppm zinc.

Vitamin requirements of early weaned pigs

There has not been a great deal of research examining the vitamin needs of the early weaned pig. Current recommendations for the 3, 5, and 7 kg piglet are presented in table 20.

Several recent studies have suggested that National Research Council (1988) levels of one or more of the commonly supplemented B-vitamins (riboflavin, niacin, pantothenic acid and vitamin B_{12}) are inadequate for maximal performance of newly weaned pigs (Stahly et al., 1995; Stahly and Cook, 1996). Subsequent research by Lutz and Stahly (1997) ruled out folic acid as the source of the improvement. However, Wilson et al. (1993) noted no improvement in pig performance from megavitamin supplementation. Clearly, there is a need for further work in this area but it should be noted that the NRC (1998) subcommittee reviewed the current literature and opted not to increase vitamin requirements for starter pigs.

Table 20. Vitamin needs of early weaned pigs

	3 kg	5 kg	7 kg
Vitamin A (IU/kg)	2553	2208	2022
Vitamin D (IU/kg)	241	222	210
Vitamin E (IU/kg)	19	15	14
Vitamin K (mg/kg)	0.50	0.50	0.50
Biotin (mg/kg)	0.08	0.05	0.05
Choline (mg/kg)	0.71	0.56	0.49
Folacin (mg/kg)	0.30	0.30	0.30
Available niacin (mg/kg)	21.7	18.1	16.1
Pantothenic acid (mg/kg)	12.8	11.2	10.4
Riboflavin (mg/kg)	4.30	3.83	3.54
Thiamin (mg/kg)	1.50	1.00	1.00
Vitamin B6 (mg/kg)	2.22	1.83	1.63
Vitamin B12 (mg/kg)	20.6	19.5	18.2

NRC (1998)

CONCLUSION

For a variety of reasons, including the rapidly maturing gastrointestinal tract and the cost of providing an effective diet to the newly weaned piglet, the optimum diet for weaning pigs changes almost weekly. Consequently, a phase feeding program is necessary to balance pig performance and feed costs. Table 21 summarizes many of the conclusions of this paper and can be used as a rough guide in formulating diets for the early weaned pig.

Table 21. Summary of recommended feeding practises for early weaned pigs

	SEW	Transition	Phase II	Phase III
Pig weight range (kg)	2.2-5.0	5.0-7.0	7.0-11.0	11.0-23.0
Duration diet fed	1 Week	1 Week	2 Weeks	3 Weeks
Lysine (%)	1.6-1.8	1.5-1.6	1.35-1.45	1.25-1.35
Digestible lysine (%)	1.4-1.5	1.25-1.35	1.10-1.20	1.05-1.15
Methionine (%)	0.48-0.50	0.42-0.44	0.37-0.40	0.34-0.37
Lactose (%)	18-25	15-20	10	None
Whey (%)	15-30	10-20	10-20	None
Spray dried porcine plasma (%)	6-10	2-3	None	None
Spray dried blood meal	1-2	2-3	0-3	None
Fish meal	3-6	3-5	0-5	None
Soybean meal (%)	10-15	20-30	As Required	As Required
Added fat (%)	5-6	3-5	0-5	None
Additional energy source	Corn/Wheat	Corn/Wheat	Corn/Wheat	Corn/Wheat
Growth promotant	Cu or Zn	Cu or Zn	Cu	Cu
Diet form	Pellet	Pellet	Pellet/Meal	Meal

Adapted from Shurson et al. (1995) and Goodband et al. (1995)

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