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The Low Feed Intake in Newly-weaned Pigs: Problems and Possible Solutions

G. Z. Dong* and J. R. Pluske[1]

College of Animal Science and Technology, Southwest University, Beibei, Chongqing 400716, China

ABSTRACT : The low feed intake immediately after weaning is responsible for villous atrophy and reduced growth rate in newly-weaned pigs. Overcoming this drawback will produce beneficial results for swine producers, and this warrants an understanding of the factors affecting the feed intake in newly-weaned pigs. In fact, a plethora of factors exert influences on feed intake in newly-weaned pigs, and these factors encompass health status, creep feeding, weaning age, mixing of litters, environment, dietary nutrient level and balance, palatability of ingredients, forms of diet presentation, water supply and quality, and stockmanship. Due to the complexity of the factors that affect the feed intake of weaned pigs, a comprehensive approach should be adopted to overcome the low feed intake problem right after weaning. It warrants mention that it is almost impossible to completely restore the feed intake just after weaning to pre-weaning level in terms of energy intake through dietary means which are available for being practiced economically and/or technically in current swine production. However, a refined dietary regime will certainly alleviate the low feed intake problem in the immediate postweaning period. (**Key Words :** Feed Intake, Villous Atrophy, Growth, Weaning, Piglets)

INTRODUCTION

Post-weaning diarrhea and growth check are widespread problems in swine production. A number of factors can result in post-weaning diarrhea and growth check in early-weaned pigs, and these can be categorized as microbiological, environmental and dietary factors. It is suggested that alterations of the small intestinal structure are an important mechanism of post-weaning diarrhea and growth check. Previous studies showed that low feed intake just after weaning can lead to adverse gut morphological and functional changes (see Pluske et al., 1997). Thus, it is extremely important to increase feed intake in newly-weaned pigs in order to reduce post-weaning diarrhea and to improve growth performance. This paper examines the relationship between feed intake and gut architecture as well as growth rate in newly-weaned pigs, analyzes the factors that affect feed intake of newly-weaned pigs, and finally discusses the dietary approaches to increasing feed intake in newly-weaned pigs.

* Corresponding Author: G. Z. Dong. Tel: +86-23-68212799, Fax: +86-23-68212799, E-mail: g.z.dong@tom.com
[1] School of Veterinary and Biomedical Sciences, Murdoch University, Murdoch, WA 6150, Australia.
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EFFECTS OF FEED INTAKE ON GUT MORPHOLOGY AND GROWTH PERFORMANCE IN NEWLY-WEANED PIGS

Adverse changes in intestinal morphology include shortening of the villi, a change in the shape of villi from being finger-like to tongue-shaped, crypt cell hyperplasia, and increased epithelial cell mitosis (Nabuurrs, 1991; van Beers-Schreurs, 1996). The intestinal morphological changes can lead to a decline of intestinal functions, reflecting reduced brush-border enzyme activity and absorption ability (Kenworthy and Allen, 1966; Smith, 1984; Hampson and Kidder, 1986; Miller et al., 1986; Li et al., 1991b; Nabuurrs, 1991; Vente Spreeuwenberg et al., 2003), which then results in diarrhea and poor performance in newly-weaned pigs.

A number of studies have shown a reduction in villous height (villous atrophy) and an increase in crypt depth (crypt hyperplasia) after weaning (Hampson 1986; Miller et al., 1986; Cera et al., 1988; Dunsford et al., 1989; Kelly et al., 1990, 1991a,b; Li et al., 1990, 1991a,b; Nabuurrs et al., 1993a,b; Markkink et al., 1994; van Beers-Schreurs, 1995; Pluske et al., 1996a,b). Many factors are attributable to the alterations of the intestinal structure after weaning (see Pluske et al., 1997). Research in the last two decades has centered on dietary factors, such as feed intake and dietary antigenicity. Early-weaned pigs have low initial feed intake, which was proposed to be a contributing factor to the abruptly-reduced villus height (Cera et al., 1988). It has been reported that a positive relationship exists between feed intake and villous height or villus/crypt ratio (Kelly et al., 1991b; Markkink et al., 1994; Pluske et al., 1996a,b; van Beers-Schreurs, 1996; McCracken et al., 1999; Verdonk et al., 2001a,b; Vente Spreeuwenberg et al., 2003). Therefore, decreased villous heights and villus/crypt ratios may be a direct reflection of decreased feed intake in the immediate post-weaning period. Adverse morphological alterations in the intestine have also been ascribed to local transit hypersensitivity reactions caused by dietary antigens (Miller et al., 1984a, b; Newby et al., 1984; Stokes et al., 1987; Li et al., 1990). However, McCracken et al. (1995, 1999) suggested that the lack of feed intake after the critical first 48 h post-weaning initiated adverse morphological changes, leaving the intestinal lining more penetrable to luminal antigens and eventually resulting in hypersensitivity responses against antigens. According to these authors, lack of intake should be the fundamental cause of the morphological changes.

Beers-Schreurs et al. (1995) weaned pigs at 28 d of age and fed them one of three diets: sow's milk on an *ad libitum* basis, a commercial diet on an *ad libitum* basis, and sow's milk at the same level of energy intake of the commercial diet consumed *ad libitum*. They found that piglets fed the commercial diet and sow's milk at the same level of energy intake had similar smaller villi than pigs fed sow's milk on an *ad libitum* basis. This suggests that reduced feed or energy intake, independent of diet type, is the major factor causing villous atrophy after weaning. Vente Spreeuwenberg and Beynen (2003) reviewed the studies examining the effects of dietary composition involving protein source, specific amino acids, fatty acids, fibers, non-digestible oligosaccharides, growth factors, polyamines and nucleotides on small intestinal integrity in weanling pigs. They concluded that individual feed constituents had only marginal effects on the small intestine of the weaned pigs, and the level of feed intake was the most important determinant of mucosal function and integrity.

In the study of Pluske et al. (1996b), the provision of cow's milk at the maintenance energy level resulted in villous atrophy. However, when weanling pigs were allowed free access to cow' milk (2.5 times the energy maintenance requirement), the pre- and post-weaning villus heights were similar. This suggests that if the feed intake postweaning is maintained, the typical villus atrophy can be avoided. Since there is a linear relationship between feed intake and villous height, and in turn villous height is positively correlated with the rate of empty-body weight gain after weaning (Pluske et al., 1996a,b), better weight gain after weaning can be achieved provided weanling pigs can eat sufficiently just after weaning.

The low feed intake immediately after weaning further affects the nutrient and energy requirements. The weanling pigs' energy requirement for maintenance is not met until day 5 after weaning, and the pre-weaning energy intake level is not attained until the end of the 2nd week post-weaning (Le Dividich and Herpin, 1994). This finding has been confirmed in several studies (van Diemen et al., 1995; Gentry et al., 1997; Moon et al., 1997; Sijben et al., 1997). The average gross energy intake during weeks 1 and 2 is only, respectively, 41% and 82% of the average during weeks 4, 5, and 6 after waning (Bruininx et al., 2001).

Bruininx et al. (2001) summarized several data sets about the energy requirement in weanling pigs, and found that the average ME requirement for maintenance during the first week (461 kJ $kg^{-0.75}$) was higher than that averaged over the subsequent 5 weeks (418 kJ $kg^{-0.75}$). The higher ME requirement for maintenance during the first week may reflect higher activity of the piglet in adapting to new physical and social environments. For example, newly-weaned piglets may expend more energy if they are kept at lower temperatures in the nursery, and fight for formation of a dominance hierarchy after mixing different littermates. Therefore, the higher energy requirement for maintenance and, concurrently, the low feed intake immediately after weaning will affect the growth rate in weanling pigs.

MAJOR FACTORS AFFECTING FEED INTAKE IN NEWLY-WEANED PIGS

Diseases or the immune activation status

Exposure of pigs to pathogens results in release of proinflammatory cytokines which activate the immune system. The activation of the immune system produces an alteration in the metabolic processes (Klasing, 1988; Spurlock, 1997), resulting in suppression of protein synthesis (Jepson et al., 1986) and stimulation of muscle protein degradation (Zamir et al., 1994). Pigs experiencing such immune activation will exhibit poor performance including reduced feed intake. Administration of cytokines (interleukin-1 and tumor necrosis factor) metabolically induced anorexia (Mrosovsky et al., 1989). Kelly et al. (1993) examined the relationship between cytokines and reduced feed intake in sick animals. In contrast, segregated early-weaning or medicated early-weaning pigs exposed to less pathogens eat more and grow faster than traditionally-weaned pigs (Edmonds et al., 1997; Williams et al., 1997a,b,c).

Creep feeding, weaning age, and mixing of different litters after weaning

Creep feeding piglets prior to weaning has been a common practice in pig production. However, the effectiveness of creep feeding is an area open to debate. Bruininx et al. (2002a) demonstrated that creep feeding shortened the time between weaning and the first feed intake, and enhanced feed intake and growth rate during day 0 to 8 after weaning. It is thought that creep feeding predisposes suckling pigs to subsequent stressful weaning through prompting gut adaptations to solid feed. Several studies have confirmed that the provision of solid diets containing complex carbohydrates to suckling pigs stimulates acid and pepsin secretion in the stomach (Cranwell, 1977, 1985; Cranwell and Stuart, 1984) and enhances the activity of some stomach and pancreatic enzymes (Corring et al., 1978; Corring, 1980; de Passillle et al., 1989). Pierzynowski et al. (1990) suggested that changes in pancreatic output of protein and enzymes around weaning were developmental adaptations of the gut to the digestion of the diets, and were more related to the dietary changes rather than the weaning age or weaning *per se*. Therefore, it can be suggested that suckling pigs that eat more solid diets during lactation develop a more advanced digestive tract which helps them more easily cope with a dietary change after weaning.

Weaning imposes nutritional (change from sow's milk to solid feed), psychological (mixing of different litters and loss of the sow), and environmental (moving from farrowing crates to nursery pens) stresses on piglets. As a result, weanling pigs exhibit an acute stress response and poor growth performance including low feed intake. It is recognized that the earlier the weaning age the stronger the weaning stress (Worobec et al., 1999). Therefore, to wean piglets at an older age will alleviate the stress symptoms including the reduced feed intake (Davis et al., 2006).

The impact of mixing different littermates in a nursery pen on feed intake is controversial. Research reports in the literature showed either decreases in growth rate, feed intake and feed:gain ratio (McGlone and Curtis, 1985; Bjork, 1989; Rundgren and Lofquist, 1989) or no effects on the performance (Friend et al., 1983; Gonyou et al., 1986; Blackshaw et al., 1987; McConnell et al., 1987; McGone et al., 1987) after mixing the unacquainted piglets together. However, Pluske and Williams (1996) reported piglets from different litters mixed at weaning consumed more feed than those weaned as entire litters. Their findings suggest that promoting aggression by mixing different littermates together may, in fact, augment feed intake, but may have reduced feeding duration. They proposed two explanations for the findings. Firstly, the reduction in the release of catecholamines by the adrenal gland after the social hierarchy is established following mixing makes the dominant pigs suffer less from stress-induced suppression of feeding (Vergoni et al., 1990) and eat more than the subordinates after weaning. The increase of feed intake in the dominant pigs after mixing may be greater than in those who do not fight at all, and this eventually effects an increase of overall feed intake after weaning. Secondly, as suggested by Baxter (1991), reducing aggression in pens may reduce feed intake because it inadvertently reduces social interaction and social facilitation in feeding. Therefore, the formation of social hierarchy following mixing of weaned pigs may promote feeding behavior and thus increase feed intake.

Environmental factors

There exists an interval between weaning and starting to eat. According to a study by Bruininx et al. (2001), approximately 50% of the weaners started eating within 4 h after weaning, whereas it took about 50 h for 95% of all weaners to start eating. During the first two days, the number of weanling pigs that had not started eating kept declining at daytime, but not at night. In practice, weaned pigs might be housed in dark pens in order to prevent fighting resulting from mixing among litters, and this could lead to a detrimental effect to the feed intake right after weaning. Bruininx et al. (2002b) further studied the effect of lighting periods on feed intake of weanling pigs, and they provided two lighting schedules to weanling pigs: 8 h light vs.16 h darkness and/or 23 h light vs. 1 h darkness. The prolonged photoperiod failed to improve the feed intake during the first week after weaning. However, the feed intake during week 2 and for the total period of the first two weeks was significantly enhanced by the prolonged photoperiod. Glatz (2001) also studied effects of lighting on feed intake and growth rate in weanling pigs. The weanling pigs were provided Triphosphor (TP) lighting to simulate daylight during the day, while at night they were provided Pascal red (PR) lighting to simulate the night-light piglets previously had received from infrared heating lamps. The feed intake in weaners provided TP/PR lighting increased significantly by 31% during the first week after weaning. However, the growth rate and feed conversion were not improved. Glatz (2001) commented that PR lighting stimulated the weaners to eat more because red lighting may encourage more aggressive interactions among pigs. And the increases both in feed intake and in the incidence of aggressive behaviors may account for the failure in the improvement of growth rate and feed conversion.

There is generally a negative relationship between ambient temperature and feed intake. However, since weanling pigs have a higher requirement for temperature, the adverse influence of high temperature on feed intake of weanling pigs rarely occurs in practice with an exception during very hot summer months. The lower critical temperature (LCT) for weanling pigs ranges from 26 to 28°C during the first week after weaning and then decreases to 23 to 24°C during the second week postweaning (Noblet et al., 2001). The relative humidity appears to have no significant influence on the performance of weanling pigs (Noblet et al., 2001).

The space allocation after weaning has an impact on feed intake and growth performance in weanling pigs. Decrease in space allocation results in lower feed intake and weight gain in weanling pigs (Spicer and Aherne, 1987; Kornegay et al., 1993; Kornegay and Notter, 1994; Brumm et al., 2001). A detailed discussion about space allowance and the social group size is available (Brumm and Gonyou, 2001).

Dietary nutrient level and balance

Animals show an innate preference for nutritionally-balanced diets. For an animal in any given physiological status, there is an optimum intake of nutrients and an optimum balance among nutrients (Forbes, 1999). An excess or insufficiency of essential nutrients to some extent generally makes animals eat less. For instance, dietary amino acid imbalance normally leads to marked reductions in both feed intake and growth rate in animals (see D'Mello, 2003). Kyriazakis et al. (1990) reported growing pigs chose to eat more of a diet with a protein:energy ratio closer to the optimal for growth than one with a lower ratio.

Tryptophan is the precursor of serotonin which plays a role in the regulation of feed intake (Henry and Seve, 1993). Meunier-Salaun et al. (1991) have shown that brain serotonin in piglets is linearly related to dietary tryptophan level. A recent study by Koopmans et al. (2006) demonstrated supplemental dietary tryptophan increased hypothalamic serotonergic activity of weanling pigs. It was reported that dietary deficiency in tryptophan significantly decreased feed intake, daily gain and gain/feed ratio of weaning pigs (Seve et al., 1991). Ettle and Roth (2004) also reported piglets showed a clear preference for a higher tryptophan diet when given a choice of feeding between the higher tryptophan diet and a tryptophan-deficient diet. However, in the study of Koopmans et al. (2006), the feed intake after weaning was not affected by dietary tryptophan supplementation although the supplementation improved intestinal morphology.

Palatability of feedstuffs

The freshness and composition of feedstuffs affect dietary palatability. Contamination of feedstuffs with mycotoxins reduces feed intake and weight gain, and furthermore adversely affects the health of pigs (see van Heugten, 2001). For instance, Schell et al. (1993) reported that weanling pigs fed aflatoxin-contaminated diets had markedly lower feed intake and growth rate than pigs fed uncontaminated diets.

The oxidation of fats contained in feedstuffs will produce more free fatty acids and even shorter-chain products such as aldehydes, ketones, alcohols, epoxides, and hydrocarbons. These oxidative products normally have strong or rancid odors which adversely affect dietary palatability (Nelson, 1992).

Some feedstuffs of plant origin contain anti-nutritional factors which may affect palatability. Soybeans, peas, and Phaseoulus beans (such as navy beans, pinto beans, kidney beans, etc.) contain trypsin and chymotrypsin inhibitors and lectins. Heat treatment can greatly reduce the activity of these anti-nutritional factors (see van Heugten, 2001). Diets containing raw soybeans and soybean products (such as soybean meal, SBM) without proper heat treatment are less palatable to weanling pigs. Rapeseed meal and cottonseed meal contain more anti-nutritional factors. The presence of glucosinolates is the major factor limiting the use of rapeseed meal (Bell, 1984; Aherne and Bell, 1990; Thacker, 1990). Cottonseed meal contains gossypol which is toxic to animals (Cunha, 1977; Knabe et al., 1979; Aherne and Kennelly, 1985; Tanksley, 1990). In addition, gossypol can form insoluble complexes with protein and iron, and thus can affect the utilization of protein and iron in pigs (Chiba, 2001). Rapeseed meal and cottonseed meal may cause palatability problems, and rapeseed meal, for instance, is less palatable than SBM (Cunha, 1977).

Weanling pigs also showed different preference for cereals. For example, when different cereals were included in starter diets, the weanling pigs expressed their preference in descending order for oat, corn, low tannin sorghum and high tannin sorghum, and oat significantly stimulated early feed intake in weanling pigs (Reis de Souza et al., 2005). In another study, Mateos et al. (2006) compared the effects of cooked corn and cooked rice on the performance of piglets weaned at 21 days, and found that weanling pigs given cooked rice had higher feed intake and growth rate than piglets given cooked corn, but food conversion ratio was not affected. They concluded that cooked rice was an ingredient of choice for weanling pigs.

Physical form of diets and feeding practice

In practice, weanling pigs are usually provided pelleted diets. It is generally recognized that pellets are more efficacious than meal in decreasing feed wastage rather than stimulating feed intake (Patridge, 1989; Hancock and Behnke, 2001). Therefore, pelleting is important to minimize wastage of expensive weaning diets. Pellets of small size (2.4 mm in diameter) appear to be particularly beneficial for feed intake in weaned pigs, resulting in improved performance over pellets of larger size (3.2 mm in diameter) and crumbs (Patridge, 1989). However, in the studies of Traylor et al. (1996) and Edge et al. (2005), the pellet diameter had no effect on feed intake and growth rate.

Diets containing a large amount of dried skim milk are not easy to pellet and hence will result in hard pellets and reduced feed intake in the initial week post-weaning

(Makkink et al., 1994), since hard pellets are not readily accepted by young pigs (Jensen, 1966; Liptrap and Hogberg, 1991; Patridge and Gill, 1993). When weanling pig diets contain high quality animal protein sources such as whey protein concentrate, fish meal, and spray-dried plasma, pellet processing would be better than extruder or expander processing. The latter would reduce palatability and ileal digestibility of several amino acids, and may, therefore, produce a negative effect on performance in weanling pigs (Ohh et al., 2002).

According to the study of Partridge et al. (1992, cited by Patridge and Gill, 1993), when weaned pigs were provided dry, solid diet in slurry form, they consumed 18% more feed and grew 11% faster than pigs fed the same diet in pellet form during the first week after weaning. Han et al. (2006) have confirmed that liquid feeding results in higher feed intake and weight gain than dry crumble feeding during the first 10 days post-weaning. The improvement in feed intake observed with wet feeding may be behaviorally based on the fact that pigs immediately after weaning do not have to learn new and separate feeding and drinking when wet fed (Patridge and Gill, 1993). Deprez et al. (1987) compared a pelleted diet with the same diet in slurry form and found that pigs fed the slurry had higher villi on day 8 and day 11 after weaning. The villous height may be maintained because the digesta from the slurry is less abrasive and thus causes less shedding of enterocytes. Furthermore, pigs fed the slurry may consume more feed than their counterparts fed the pelleted diet, which may result in higher villi. Although the advantages of wet feeding are obvious, the high cost of automated feeding systems and the high labor requirement of manual systems as well as hygienic problems preclude its widespread use in commercial swine production.

Water supply and quality

The importance of water supply as a factor affecting feed intake and growth rate in pigs cannot be overstated. Pigs habitually drink while eating and eating and drinking times in newly-weaned pigs are positively associated (Dybkjaer et al., 2006). The relationship between feed intake and water consumption in weanling pigs was described by Brooks et al. (1984) as follows: Water intake (L/d) = 0.149+(3.053×kg daily dry feed intake). Clean, fresh and safe water must be available at all times to achieve higher feed intake. The water quality for pigs has been described previously in reviews by Brooks (1994) and Thacker (2001), and will not be reiterated here.

Water is commonly supplied to weanling pigs from nipple drinkers. The availability of water, therefore, depends to a great extent on the delivery rate from drinkers. Barber et al. (1989) reported that enhancing water delivery rate from 0.175 to 0.700 L/min resulted in significant increases of both feed intake and growth rate, but there were no significant differences in feed intake and growth rate between 0.700 L/min and 0.450 L/min water delivery rates. When water is supplied from water bowls with a large reservoir capacity, the water needs of weanling pigs appear to be adequately met (Barber et al., 1989).

The optimum number of weaned pigs per drinker is unclear in the literature. Brumm and Shelton (1986) compared one vs. two nipple drinkers for a pen of 16 weaned pigs, and observed increased variation in growth performance when only one drinker was provided. Ten weaned pigs per drinker space was recommended by MWPS (1991). Therefore, there is a minimum of one drinker per 8-10 weaned pigs.

MAIN DIETARY MEANS TO INCREASE FEED INTAKE IN NEWLY-WEANED PIGS

The factors affecting the feed intake of weaned pigs are many. Thus, a comprehensive approach should be adopted to solve the feed intake problem after weaning. This paper emphasizes the dietary means available in practice to enhance feed intake in newly-weaned pigs. Some promising methods, such as immune suppression of cholecystokinin production in the intestine and use of specific growth factors present in milk or blood, are generally unavailable at present for practical application, and thus are not included in the scope of the present paper. It is worth mentioning that it is almost impossible to raise the feed or energy intake of newly-weaned pigs to the pre-weaning level through dietary means which can be practiced within the current systems of farm management. However, the post-weaning problems involving low feed intake and growth check can surely be alleviated by devising nutritionally-sound dietary regimes.

Good quality ingredients

Weaned pigs are very sensitive to dietary mold growth and rancidity. So, first and foremost, high quality feed ingredients free of mold growth and oxidative rancidity should be used in formulating the weaner's diet. Furthermore, addition of a proper amount of mold inhibitors and antioxidants to the manufactured diet is also necessary to prevent rapid reduction in palatability during storage (Nelson, 1992). Mold inhibitors prevent molds from growing and producing mycotoxins. Antioxidants protect fats in the diet from oxidation, and thus reduce the production of rancidity substances.

Optimum balance among nutrients in the diet

The diet for weaned pigs should be formulated with care to ensure an optimum nutrient balance. Special attention should be given to providing adequate amounts of vitamins, trace minerals and limiting amino acids in the diet. The

Table 1. Effect of dry matter (DM) digestibility on the feed intake of 6 kg piglets

DM digestibility (%)	70	75	80	85	90
Feed intake (g/d)	260	312	390	520	780
Improvement (%)	100	120	150	200	300

importance of tryptophan in improving feed intake of weanling pigs has been described above. Hsia (2005) reported that raising the level of tryptophan from 0.176% to 0.234% in a corn-SBM-meat and bone meal diet increased the feed intake of weanling pigs during the first two weeks after weaning, and synthetic tryptophan could replace part of the spray-dried plasma protein to improve the feed intake of weanling pigs.

Higher digestibility of the diet

The digestibility of diets is a determinant of feed intake in weanling pigs since digestibility is highly correlated with the volume of digesta which in turn exerts an effect on gut filling capacity as well as the appetite. The digestibility of diets, therefore, has a positive relationship with the feed intake. Whittemore (1993) developed an equation to describe this relationship: maximum voluntary feed intake (kg/d) = 0.013W/(1-DM digestibility coefficient), where W represents body weight (kg), and DM represents dry matter. Using this equation, values of the feed intake of 6 kg weanling pigs at different dietary digestibilities were calculated as shown in Table 1. As dietary DM digestibility increases from 70% to 90%, the feed intake triples (Table 1). Consequently, any means which can enhance the dietary digestibility can significantly raise the feed intake level.

Cereals and protein supplements are the major ingredients in practical weaning diets. It is important to increase the carbohydrate and protein digestibility in order to achieve an overall high digestibility of dietary dry matter. Frequently-used methods to improve the carbohydrate digestibility include heat treatment, control of the fiber content, and supplementing with in-feed enzymes. Similarly, heat treatment and addition of acidifiers and in-feed enzymes are the major approaches employed to increase protein digestibility. In the manufacturing of weanling pig diets in practice, in-feed enzymes and acidifiers have been widely-used. A detailed discussion of the effects of in-feed enzymes and acidifiers in weanling pigs is beyond the scope of this paper, and reviews published recently on these aspects are available (Partridge, 2001; Kim et al., 2005).

Palatable feedstuffs

Milk is an excellent food for weanling pigs, although sow's milk is not optimum for maximizing piglet growth (see Pluske and Dong, 1998). Pluske et al. (1996b) fed cow's milk to weanling pigs at 2.5 times the energy requirement for maintenance or on an *ad libitum* basis for the first five days after weaning, and the pigs displayed villous heights equal to or greater than those of the control pigs killed at weaning. However, due to fiscal constraints on pig producers or a compromise between economic concern and the pig's nutritional needs, feeding milk to weanling pigs is not generally feasible in practice. To partially solve this problem, scientists at Kansas State University have introduced high-nutrient-density diets and developed a multi-phase starter program for early-weaned pigs (Goodband et al., 1993, 1995). Of particular interest with this program has been the use of relatively high proportions of lactose-containing products, spray-dried plasma (SDP), spray-dried blood meal (SDBM), and high quality fish meal in the diet for newly-weaned pigs.

Mahan et al. (2004) demonstrated that daily feed intake increased during the initial week post-weaning as dietary lactose levels increased from 0 to 30%. In the study of Nessmith et al. (1997), daily feed intake improved linearly in the first week after weaning when pigs were fed increasing concentrations of lactose up to 40%. Dried whey contains a high level of lactose. When a dried whey-based diet was fed to weanling pigs, feed intake was significantly higher (Stoner et al., 1990; Lepine et al., 1991). Mahan (1992) reported that feed intake, growth rate, N retention, and apparent N digestibility were increased when weanling pigs were fed a corn-SBM-dried whey diet compared with a corn-SBM diet. As dietary dried whey levels increased from 5% to 20%, feed intake increased by 15.4%, and growth rate increased by 36.3% in weanling pigs (Dritz et al., 1993). Early-weaned pigs fed diets containing milk protein (dried skim milk and casein) also displayed higher feed intake, growth rate, digestibility of DM, N and amino acids, and N retention (Wilson and Leibholz, 1981a,b,c,d).

SDP is the most exciting protein source being tested in recent years. A number of studies confirmed that dietary inclusion of SDP stimulates feed intake and growth rate in weanling pigs (See Maxwell and Carter, 2001). One of the important mechanisms of the response involves palatability of SDP (Gatnau et al., 1993). Ermer et al. (1994) reported that pigs offered a choice between a SDP diet and a dried skim milk diet preferred the SDP diet although the two diets had the same levels of lactose, lysine, and methionine. The inclusion of SDP in the diet of newly-weaned pigs enhances feed intake by 33.0%, growth rate by 45.1%, and feed utilization by 9.9% during the first week after weaning (Table 2).

Studies were conducted to compare protein sources of animal and plant origins. Kats et al. (1994) reported that weanling pigs fed diets containing SDBM exhibited greater feed intake and growth rate than pigs fed diets containing fish meal and plant protein sources (soy protein concentrate and extruded soy protein concentrate). Replacement of soy

Table 2. Effects of inclusion of spray dried plasma in complex diets of weanling pigs on feed intake, growth rate and gain/feed ratio during the first week after weaning

References	Inclusion ratio (%)	Weaning age (d)	ADFI		ADG		Gain/feed	
			g	% improvement	g	% improvement	g/kg	% improvement
de Rodas et al. (1995)	0	24	210	-	210	-	970	-
	4	24	270	28.6	280	33.3	1,020	5.2
Grinstend et al. (2000)	0	19	173	-	190	-	1,100	-
	2.5	19	203	17.3	219	15.3	1,080	-1.8
	5.0	19	222	28.3	239	25.8	1,080	-1.8
Grinstend et al. (2000)	0	17	223	-	173	-	770	-
	2.5	17	238	6.7	214	23.7	900	16.9
	5.0	17	267	19.7	243	40.5	910	18.2
Grinstend et al. (2000)	0	12	124	-	99	-	780	-
	2.5	12	143	15.3	120	21.2	830	6.4
	5.0	12	141	13.7	112	13.1	810	3.8
Pierce et al. (2005)	0	21	311	-	141	-	426	-
	8	21	462	48.6	229	62.4	476	11.7
Pierce et al. (2005)	0	21.3	216	-	162	-	730	-
	8	21.3	376	74.1	272	67.9	704	-3.6
Pierce et al. (2005)	0	14.8	178	-	117	-	637	-
	8	14.8	187	5.1	102	-12.8	503	-21.0
Pierce et al. (2005)	0	19.7	209	-	99	-	467	-
	8	19.7	352	68.4	206	108.0	578	23.8
Pierce et al. (2005)	0	19.7	209	-	99	-	467	-
	8	19.7	264	26.3	141	42.4	518	10.9
Pierce et al. (2005)	0	22.5	175	-	87	-	444	-
	8	22.5	287	64.0	183	110.3	625	40.8
Pierce et al. (2005)	0	22.5	175	-	87	-	444	-
	8	22.5	256	46.3	157	80.5	571	28.6
Average				33.0		45.1		9.9

protein with fish meal in the diet of weanling pigs elicited a significant improvement in feed intake and growth rate (Stoner et al., 1990). In a recent study, Yun et al. (2005) fed pigs, weaned at d 17, several sources of protein and found that animal protein sources (whey protein concentrate and fish meal) were more efficacious than plant sources (SBM, fermented soy protein, and rice protein concentrate) in increasing feed intake and growth rate during the first week post-weaning, and animal protein sources showed better gut morphology than plant sources. Among plant protein sources, fermented soy protein and rice protein concentrate had a better effect than SBM on increasing feed intake and growth rate and on improving the gut morphology. Sohn et al. (1994) pointed out the poor palatability was one of the distinct problems with SBM-based diets.

Growth-promoting agents

The growth-stimulating effects of antibiotics and high doses of Cu from copper sulfate or other sources (carbonate, chloride, and some organic complexes) are well established (see Cromwell, 2001). When weanling pigs were fed antibiotics and high dietary Cu (100-250 ppm) from sulfate, enhanced growth rate and feed intake were observed (see Cromwell, 2001). The increased feed intake is attributed to one of the mechanisms concerning the growth promoting effects of antimicrobial agents, especially high dietary Cu (Zhou et al., 1994; Dove, 1995; Coffey and Cromwell, 1995; Davis et al., 2002; Rozeboom et al., 2005).

High dosage of Zn (1,500-3,000 ppm) from ZnO was first used in the late 1980s to control post-weaning diarrhea and to improve the growth performance of weanling pigs (Poulsen, 1989). Subsequent studies further confirmed the effects of pharmacological concentrations of Zn on the performance of weanling pigs even when scouring is not a problem (Poulsen, 1995; Smith et al., 1997; Hill et al., 2000). Hollis et al. (2005) studied the effects of replacing pharmacological levels (2,000 to 2,500 ppm Zn) of dietary ZnO with lower levels (125 to 500 ppm Zn) of organic Zn sources (Zn methionine, Zn polysaccharide complex, Zn proteinate, Zn amino acid complex, and Zn amino acid chelate) in weanling pigs, and found that supplemental Zn at low levels from organic sources was not as efficacious as the pharmacological level of Zn from ZnO for improving the growth performance of weanling pigs. They attributed this to the difference in feed intake. Pigs fed the pharmacological level of Zn from ZnO consumed more feed than those receiving low levels of Zn from the organic sources (Hollis et al., 2005).

Flavors and taste enhancers

In an earlier large-scale growth trial involving 1,219 pigs, McLaughlin et al. (1983) found statistically significant improvements in feed intake and weight gain during the first week after weaning when a cheesy flavor was added to the weaning diets. Other studies have shown feed intake of weaned pigs can sometimes be stimulated by flavors (Cambell, 1976; King, 1979; cited by Forbes, 1995), but not always so (Kornegay et al., 1979; McLaughlin et al., 1983; cited by Forbes, 1995). In a recent study, Torrallarodona et al. (2000) reported that adding flavors combined with a sweetener fraction to weaned pig diets improved feed intake, weight gain, and feed efficiency.

Sugar and molasses can be added to weanling pig diets to increase palatability and feed intake (Cunha, 1979), whereas saccharin produces a “metallic” aftertaste which often results in taste “fatigue” in young pigs (Nelson, 1992). Therefore, saccharin should be modified to eliminate the aftertaste by combining it with flavors such as thaumatin, a natural taste enhancer isolated from the *Thaumacoccus danelli* bush in Africa (Nelson, 1992). Monosodium glutamate (MSG) is also a taste enhancer. When MSG was added to the diet after weaning, feed intake increased by 10% and growth rate by 7%, and there was more effect with lower weight piglets (Gatel and Guion, 1990; cited by Forbs, 1995).

CONCLUSION

The feed intake immediately after weaning is critical in overcoming post-weaning problems. Enhancing feed intake in the newly-weaned pig will prevent villous atrophy, reduce post-weaning diarrhoea and stimulate growth. The factors affecting feed intake after weaning are many, and dietary approaches are available for increasing the feed intake or for lessening the low feed intake problems just after weaning. In practice we need to refine the dietary program to help newly-weaned pigs cope with the low feed intake problem. Meanwhile, the level of sophistication (cost) of feed formulation and the overall acceptance by producers of a refined dietary program must be taken into account.

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