

ABSTRACT

GUO, JIYAO. Effect of Chocolate Candy Feed on Growth Performance of Newly Weaned Pigs in a Commercial Farm. (Under the direction of Sung Woo Kim.)

The objective of this research was to determine the effectiveness of Chocolate Candy Feed (CCF, International Ingredient Corp., St. Louis, MO), as an alternative carbohydrate source to lactose for nursery pigs. Weaned pigs (21 d of age, 7.1 ± 0.3 kg, $n = 1,408$) were fed 4 diets (16 pens/treatment and 22 pigs/pen) in phase 1 and 2. Each pig was budgeted to consume 1.8 kg of the experimental diets during phase 1 (approximately 11 d) and 6.8 kg of the experimental diets during phase 2 (approximately 17 d). During phase 3, all pigs were fed a common diet until 49 d postweaning. Treatment diets included PC (20 and 8% lactose in phase 1 and 2, respectively; 0% replacement of lactose with CCF), 15CCF (15% lactose replacement), 30CCF (30% lactose replacement), and 45CCF (45% lactose replacement). Whey permeate was used as the source of lactose. Replacement of lactose by CCF was based on equal amounts of total sugars. Treatment diets were balanced for equal amounts of essential amino acids and energy. Fecal scores were recorded on d 1, 3, and 5. Blood samples were taken at the end of phase 2. Duration of phase 1 tended to linearly decrease ($P = 0.06$) with increasing levels of CCF in diets. During phase 1, ADFI linearly increased ($P < 0.05$) as CCF increased in the diets with no differences in ADG or G:F (gain to feed ratio). Duration of phase 2 was not different ($P > 0.05$) among treatments. During phase 2, ADG linearly decreased ($P < 0.05$) as CCF increased in the diets whereas ADFI and G:F were not affected ($P > 0.05$). No differences ($P > 0.05$) were observed in growth performance during the combined phase 1 and 2 period when treatment diets were fed. Whereas the duration of phase 1 and 2 together linearly decreased ($P < 0.05$) as pigs were fed diets with increasing levels of

CCF. In phase 3, ADFI was linearly reduced ($P < 0.05$) in pigs fed increasing levels of CCF during the previous treatment phases, but no differences ($P < 0.05$) were detected for ADG or G:F. During the overall trial period, ADG, ADFI, and G:F were not different ($P < 0.05$) among treatments indicating no adverse effects of CCF replacing lactose on growth performance or feed conversion of nursery pigs. Serum urea nitrogen was not different among treatments at the end of phase 1 but tended to linearly increase ($P = 0.088$) with increasing CCF at the end of phase 2. During phase 1, there was no difference ($P < 0.05$) in fecal scores among treatments. Mortality rate of pigs was not different among treatments whereas morbidity of pigs tended to linearly decrease ($P = 0.08$) as CCF increased indicating no adverse effects of CCF replacing lactose on health status of nursery pigs. In conclusion, the results showed Chocolate Candy Feed can be used to replace up to 45% of the lactose in nursery diets without negative effects on growth performance, feed conversion or health status.

Effect of Chocolate Candy Feed as an Alternative Carbohydrate Source to the Use of Lactose
on Growth Performance of Newly Weaned Pigs in a Commercial Farm Condition

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CHAPTER 1

LITERATURE REVIEW

Introduction

Newly weaned pigs confront many stressors including changes in the source of nutrients (from milk to solid feed), physical separation from mother, interaction with new pen mates, etc. which can challenge pig growth (Pluske et al., 1997) and nutrient intake (Smith and Lucas, 1956; Leibbrandt and Ewan, 1972; Owsley et al., 1986a). Highly palatable and digestible ingredients help pigs to cope with these stressors upon weaning. Milk-based feedstuffs are more palatable and digestible for nursery pigs compared with cereal-based feedstuffs. As the main carbohydrate source in milk, lactose is the most common energy source in nursery diets. Lactose has been reported to significantly improve weight gain and feed efficiency of nursery pigs (Mahan, 1984; Owsley et al., 1986; Cera et al., 1988; Tokach et al., 1989).

Feed cost makes up to 70% of total cost in swine production. In diets of newly weaned pigs, lactose has been the most important carbohydrate source (Krider et al., 1949). Mahan (2004) reported that supplements of 15 to 20% lactose in pig diets throughout d 7 to 21 postweaning and 10 to 15% lactose throughout d 21 to 35 postweaning maximized growth performance. Therefore swine production has a large need for lactose. Lactose sources mainly come from dairy by-products including dried whey, dried whey permeate and lactose crystal. However, the price of lactose from the year of 2004 to 2007 increased by 3.5 fold from US \$0.44/kg to a high of US \$2.0/kg (Affertsholt-Allen, 2007) but has recently decline to US \$1.1/kg. It was the imbalance between supply and demand that caused the dramatic

increase in lactose price. The market of milk by-products has been increased in recent years. Standardization of milk is a procedure on adjustment of fat and non fat solid of milk to the desired level to meet the legal standards. Standardization of milk powder for protein resulted in a huge demand of lactose, which also caused a worldwide shortage of lactose (Paterson, 2009). Except for the lower production, the dramatic increase in lactose price was also due to the elimination of EU and US stocks of whey products (Affertsholt-Allen, 2007). The increased demand of whey products and increased use of standardization of milk powders may continue increased lactose prices. Therefore pork producers should evaluate replacement ingredients for lactose that may enter into least cost feed formulation.

With the significant increase in the price of whey products, people start to look for the alternative sources to lactose. Single sugars (includes glucose, sucrose and etc.) have been reported as replacement for lactose. Sucrose is as effective as lactose when they are added to nursery diets (Mavromichalis et al., 2001). Adding 45% glucose in initial 14 d nursery diets improved growth performance (Newton and Mahan, 1990). The prices of sucrose and glucose are 52 and 3% cheaper than dried whey permeate, respectively. By-products from food candy industries can also be alternative sources to lactose. Yang et al. (1997) and Naranjo et al. (2010) suggested that partially replacing dried whey with milk chocolate product (MCP, 60% of total sugars, International Ingredient Corp., St. Louis, MO) in diets would not impair the growth performance of nursery pigs. Chocolate Candy Feed (International Ingredient Corp., St. Louis, MO) is also a product from food candy industries which contains 50% total sugars. The price of CCF was about 45% of the whey price and

68% of dried whey permeate price (International Ingredient Cooperation; USDA). Chocolate Candy Feed can be considered as a new alternative carbohydrate source to lactose for economic reasons in nursery pigs.

Weaning Process in Pigs

Natural weaning is a slow process usually happening at 8 to 17 wk of age (Brooks and Tsourgiannis, 2003). In such a long time, piglets have enough time to make the changes from milk to solid diet, to allow for enzyme and immune system adapting to the new substrates and to imitate the feed behavior from their mother. However, in commercial farms, weaning of piglets takes place at 18 to 25 d of age in the US. In the EU, weaning before 28 d of age is prohibited (ECCD, 2001). Generally the wean age is increased up to 28 to 35 d of age in the EU.

Weaning pigs at early age enhances economy efficiency of swine production. The benefits include improving the productivity of the sow (pigs/sow/year), decreasing the disease transmission between sow and piglet, and accelerating the flow of both pigs and sows in farms. (Ten Napel et al., 1995). Main et al. (2004) suggested that weaning at 21.5 d of age would improve wean-to-finish growth performance and decrease the mortality rate compared with the growth performance of pigs weaned at anytime between 21 to 35 d of age. The weaning weight of pigs and feeding program also greatly influence the nursery performance and these effects would carry over to the grow-finish period (Mahan and Lepine, 1991). Thus

it's indispensable to focus on the how to improve the growth potential of nursery pigs and how to reach maximize profit in swine production.

Difference in nutrient content of feed is one of the important stressors for piglets. Milk from mature sows at d 17 of lactation contains approximately 5.8% protein, 7.1% fat and 19.7% total solids (Mateo et al., 2008). A typical nursery diet contains 90% DW and 24% CP (NRC, table 1). Facing differences in dry matter, ingredient type and nutrient compositions of diet, pigs consume little feed during the initial nursery period. Besides, the external stress factors are associated with notable changes in histology and biochemistry of small intestine. It has been reported that there was a reduction in villous height (villous atrophy) and an increase in crypt depth (crypt hyperplasia) after weaning (Homich et al., 1973). Pluske et al. (1997) also found that villous atrophy and crypt hyperplasia decreased digestive and absorptive capacity and resulted in a poor growth performance. The intestinal morphological changes lead to a decline of intestinal functions, reflecting reduced brush-border enzyme activity and absorption ability (Kenworthy and Allen, 1966).

Except for the structural changes, the enzyme change may also be an important factor influencing the absorptive function (Miller et al., 1986). The enzyme activities in gut vary from the birth until pigs are approximate 8 wk of age. Activities of lipase, amylase, trypsin, and chymotrypsin increase steady from birth to 3rd wk of age and increase faster from the 4th to 8th wk of age (Corring et al., 1978). Lactase, an enzyme produced in digestive system of infants, can break down lactose into galactose and glucose. The lactase activity is low at birth, and then the activity starts to decline (Figure 1) after reaching maximal level at 15 d of

age (Ekstrom et al., 1975b). There is a small amount of amylase existing in saliva. Amylase is mainly secreted into the intestinal lumen in the pancreatic juice (Dahlqvist, 1960). Protease is related to hydrolysis of peptide bond. Amylase and protease activities are quite low in activity at birth and then increase with age (Figure 1). The weaning age doesn't influence the pattern of how enzyme activities change (Hartman et al., 1961).

Growth performance and feed intake are quite low during the 1st wk postweaning (Smith and Lucas, 1956; Meade et al., 1965; Owsley et al., 1986). Smith and Lucas (1956) defined the first 10 d postweaning as 'check period'. During the initial 'check period', pigs consume little feed, grow slowly and sometimes scour. After the 'check period' there is a sudden increase in growth performance and feed intake, which is called 'growing period'. Besides, diarrhea also occurs at early weaning. Nabuurs (1998) indicated that nursery pigs at 3 to 5 wk of age changed the flora, the morphology, and the function of the intestine. These changes together may result in diarrhea.

Because the biological and behavioral changes usually result in a post weaning lag phase, a palatable and digestible nutritious diet is needed. Also increase or decrease in feed intake is a good sign to show the health status of pig. Kelly et al. (1990) suggested that nutrients intake in the weaned pigs affected the anatomy, morphology and function of the gut. Shields et al. (1980) also reported the similar result that total activities of protease and amylase increased with enhanced feed consumption of nursery pigs. Here are the nutrient requirements provided by NRC (2012) (Table 1).

Energy Requirement of Nursery Pigs

Nutrient requirements should be expressed in relation to the energy concentration of the diet (ARC, 1981). Unlike energy requirement of grower-finisher pigs, the goal of energy requirement for nursery pigs is to maximize growth performance instead of carcass composition (Dividich and Sève, 2001). Encouraging body fat content and gut development would help nursery pigs to go through the stressful nursery period. Also, it's important to ensure the high growth rate during nursery period and carryover the positive effects to grower-finisher period (Mahan and Lepine, 1991; Mahan, 1993).

Metabolizable energy (ME) requirement includes the requirement for base metabolism, physical activity, and thermoregulation. The average ME requirement for nursery pigs is $470 \text{ kJ ME kg}^{-1} \text{ BW}^{0.75}$ per day, in which 15 to 30% of ME is used for activity (Halter et al., 1980). When pigs are raised indoor, we can ignore the thermoregulation effect on ME. At the same time, maintaining the best ambient temperature could avoid the extra loss of BW in nursery pigs. The energy system of nursery pigs depends on the capacity of digestion, health condition of the gut and feed consumption. Brooks (1999) indicated that most pigs started to eat solid feed within 5 h after weaning but it may take 54 h before the first solid meal for some pigs. Therefore, the ME intake of pig varied. Generally the ME intake increases with age after weaning. Even though, the ME requirement is not met because the value of ME in 1st wk postweaning just reaches 60 to 70% of pre-weaning ME intake of milk (Dividich and Sève, 2001).

The ME intake is also affected by environment and nutrition. Fat and fiber should be limited in nursery diets. The addition of fat in nursery diets results in a decrease in total energy intake (Tokach et al., 1995; McConnell et al., 1982). Same result is also found in nursery pigs fed fiber (McConnell et al., 1982). However, piglets in pre-weaning can utilize high-fat milk to improve growth performance (Jones et al., 1999). The depressive effect of fat and fiber on growth performance is mostly due to the low appetite and low feed intake of nursery pigs. Except for fat and fiber, daily protein intake depends on the energy concentration of the diet. A lysine to energy ratio of 4.1 to 4.2 g apparent digestible lysine/Mcal ME is recommended (Owen et al., 1995; Williams et al., 1997). As age increases, this value may decrease to 3.3 g for 22 kg pig (Smith et al., 1999). In conclusion, insufficient feed intake is the most limiting factor in energy intake, which may impair growth potential. Increase in feed (energy) intake could provide proper nutrient to energy ratios. In this way, highly palatable, digestible ingredients with high net energy concentration are needed to maximize energy intake.

Carbohydrates for Nursery Pigs

Classification of Carbohydrates

Carbohydrates can be classified by the number of sugars into 4 groups:

- Monosaccharides (glucose, fructose, mannose, galactose, etc.)
- Disaccharides (lactose, sucrose, maltose, cellobiose, etc.)

- Oligosaccharides (raffinose, stachyose, verbascose, etc.)
- Polysaccharides (starch, cellulose, hemicelluloses, pectin, etc.)

(Drochner, 1991)

Carbohydrates are the main energy sources for animals. Glucose is absorbed directly into blood during digestion. It also plays an essential role in cell biology as an energy source and a metabolic intermediate. Polysaccharides, as for starch and glycogen, are the storage of energy for animals. Ribose is an important component of coenzymes (e.g., ATP, FAD, and NAD). The deoxyribose is a component of DNA. Carbohydrates and their derivatives play key roles in gene expression, energy metabolism, immune system and etc.

Digestion of Carbohydrates

Considering carbohydrate digestion, simple carbohydrates and starch are mainly digested by intestinal enzyme, but polysaccharides like cellulose, hemicelluloses and pectin are digested by fermentation. Different types of digestion decide the sites of reaction in the gut. A limited breakdown capability of sugars in the stomach has been observed. The digestion in the stomach basically is mainly due to fermentation. The degradation products are volatile fatty acids and lactic acid. The fermentation capacity of stomach flora is depended on the pH level. Simple carbohydrate digestion mainly occurs in the small intestine. Monosaccharides like glucose can be directly absorbed by the small intestine mucosa. At the end of the ileum, the concentration of glucose is extremely low in digesta (Drochner, 1991). For disaccharides digestion, corresponding enzymes are needed to split them into monosaccharides. For example, Lactase breaks down lactose into galactose and glucose. The

level of lactase is very high at 1 wk of age, then the activity of lactase decreases with age because of lacking substrates. Ekstrom et al. (1975) reported that lactase levels of 21 day old piglets were not affected by lactase-containing diet but by breed differences. Maltases can be divided into isomaltase, sucrase, glucoamylase I and glucoamylase II (Dahlquist, 1960). Sucrase breaks down sucrose into fructose and glucose. Except for the age effect, the concentrations of these enzymes depend on the gut-dilatation and feed content, especially starch and sugar content (Kidder and Manners, 1978). The amylase from pancreatic secretion would break down starch. The breakdown-product of starch was maltose, maltotriose and some dextrans (Drochner, 1991).

Glucose

Glucose is also known as dextrose, as a monosaccharide (Figure 2), which is absorbed very quickly in small intestine and then directly, goes into the blood stream. Glucose is rapidly absorbed by intestine mucosa of young pigs, which makes it a very good energy source for young animals (Drochner, 1991). Mahan and Newton (1993) reported that 45% of glucose or lactose added diet increased the weight gain and feed consumption of pigs at 0 to 14 d postweaning compared to a diet with added cornstarch. Glucose can partially replace lactose. Kidder and Manners (1978) and Sambrook (1979) suggested that glucose was as efficient as lactose being a sugar source for pigs less than 7 d old. At d 14 to 28 postweaning, replacing part of lactose in a diet with glucose increases the weight gain (Richert et al., 1996).

Lactose

Lactose enhances growth performance and feed intake. Lactose is a useful carbohydrate source for starter diets (Giesing and Easter, 1985). High level of lactose has been formulated in starter diets as a main carbohydrate for several decades. Tokach et al. (1994) and Kim and Allee (2001) suggested that newly weaned pigs should be able to digest lactose more easily than starch carbohydrates. Turlington et al. (1989) also claimed that lactose helped improve nutrient digestibility by slowing digesta flow rate compared with glucose. Adding corresponding levels of lactose in diets could result in maximum performance of nursery pigs (Mahan et al., 2004). Similarly, Cromwell et al. (2008) indicated the addition of 7.5% lactose in diets of 3 to 4 wk nursery pigs resulted in significant increases in feed intake and growth rate.

Lactose can be converted to lactic acid by lactobacilli bacteria in stomach. Lactic acid is an organic acid maintaining sufficiently low gastric pH, which provides a beneficial environment for intestinal microflora population and causes the optimal enzyme activities. As an organic acid, lactic acid forms in a large proportion in the stomach and small intestine through 9 wk of pig life (Kidder and Manners, 1978). Early weaned pigs may not have enough secretion of hydrochloric acid in stomach (Kidder and Manners., 1978; Manners, 1970). However, the barrier-function of stomach is due to the low pH, which is maintained by lactic acid fermentation in early weaned pigs. Low pH is gradually maintained by increased hydrochloric acid in stomach later. An inverse relation between secretion of hydrochloric acid and production of lactic acid was reported (Cranwell et al., 1976). The pH

of gastric juice only approaches that found in adult pigs (Ph 2.0-3.5) at the age of 3 to 4 wk postweaning. Since lactic acid plays such an important role, study had observed that lactic acid was used to as prophylaxis of post-weaning scours (White et al., 1969).

Lactic acid dissociates in water resulting in ion lactate. Lactate is also a product of glycogen digestion from muscle cell when oxygen supply is inadequate to support pyruvate oxidation and ATP production. Lactate can be carried to the liver where it is oxidized to pyruvate. Pyruvate can then be oxidized via the citric acid cycle (Stryer, 1988; Partanen and Mroz, 1999).

Lactose could increase the absorption and utilization of calcium and phosphorus. Calcium and phosphorus are the minerals required in the greatest amounts in a diet. Calcium and phosphorus are necessary for skeleton development. Research showed that lactose enhanced the absorption of calcium and phosphorus in animals (Robinson et al., 1931; French and Cowgill, 1937; Lengemann et al., 1959; Moser et al., 1980). The site of beneficial action of lactose is in the intestine instead of within the body. The experiment from French and Cowgill (1937) conducted on dogs confirmed that the 'degree of immaturity' played a role in determining the effect of lactose on the utilization of calcium. This result suggested that lactose may have an influence on calcium utilization of nursery pigs. A linear increase in alkaline phosphatase was observed in the rat but no significant difference was observed in serum calcium and phosphorus by Moser et al. (1980). Pig trials showed that alkaline phosphatase was increased when pigs were fed lactose in comparison with those not fed lactose. Lactose decreases the serum calcium of pigs not fed lactose from 0 to 10 wk of

age (Moser, 1980). Except for calcium and phosphorus, the positive effect of lactose can also expand to the absorption of magnesium, strontium, barium and radium (Lengemann, 1959).

Lactose increases protein digestibility. Sewell and West (1965) reported that lactose increased the apparent protein digestibility of soybean meal in nursery pigs. Increasing lactose allows more soybean meal to be used as a replacement for plasma protein (Nessmith et al., 1997). Lactic acid is one product from lactose fermentation. Function of lactic acid not only occurs in reduction of gastric pH, but also appears in stimulatory of energy and utilization of amino acid. Thaela et al. (1998) indicated that lactic acid stimulated pancreatic secretion in piglets after weaning. Pancreatic insufficiency in secretion rates and enzyme concentration has been implicated as a poor digestibility of protein at early age of animals because certain enzymes (protease, trypsin, chymotrypsin, amylase and etc.) exist in pancreatic juice. Thus lactic acid could indirectly increase the proteolytic activity by enhancing the pancreatic secretion.

Sucrose

Both sucrose and lactose are disaccharides (Figure 2). The corresponding enzymes are important to divide the disaccharides into monosaccharides, which can be absorbed directly by mucosa. Sucrase is the enzyme which can catalyze sucrose into fructose and glucose. Pigs fed diets with sucrose showed very poor performance in the first few days after birth (Becker et al., 1954). Piglets fed sucrose at less than 7 d of age cause serious diarrhea, weight loss and high mortality because of deficiency in sucrase (Becker and Terrill, 1954; Aherne et al., 1969). Whereas, pigs can use sucrose effectively after reaching 7 to 10 d of age

(NRC, 1998). The mucosa sucrase activity is able to digest sucrose 7 to 10 d after birth. Therefore, by 2 wk of age pigs produce sufficient sucrase (Bailey et al., 1956; Dahlqvist, 1961; Walker, 1959).

Except for the age effect, sucrase activity is also impacted by the substrate concentration. Manners and Stevens (1972) proved that adding sucrose in baby pig diets increased the specific sucrase (Sucrose- α -glucosidase) activity in mucosa. Similar adaptive mechanisms of intestinal and pancreatic enzyme activities have been investigated in humans and rats (Macarthy et al., 1980). Flores et al. (1986) noticed that for 4 wk nursery pigs, high carbohydrates/low fat diet would result in the increase in activities of sucrase, maltase, and amylase compared with a low carbohydrate/ high fat diet for 7 to 30 d. However, Kelly et al (1990) stated that for specific enzyme activity measurement, the feeding level didn't affect the activity of lactase and sucrase, instead the high intake attributed to an apparent reduction in enzyme activity. Smith et al. (1985) believed that changes in enzyme activity of the villi were due to the reduced distance along the villus and the less mature enterocytes during post weaning period. Furthermore, the activity of sucrase was also affected by the gut-dilatation and diet content of sections of the intestinal tract (Manners and Stevens, 1972).

In post weaning period, pigs can utilize sucrose as effective as lactose and glucose. Jin et al. (1998) reported that when 20% level of corn starch, lactose, glucose, sucrose or dried whey were added in diet, pigs fed sucrose, lactose and dried whey had similar growth performance, gross energy digestibility and DW extraction. Similar result was reported by Becker et al. (1954) that ADG was similar compared pigs fed sucrose and pigs fed glucose

from 7 to 35 d of age. Collectively these results suggest that sucrose can be effectively used in post weaning diets to replace lactose without sacrificing the growth performance of pigs (Jin et al., 1998).

Starch

Starch is generally presented as a mixture of amylose and amylopectin (Figure 3). Amylose is a linear or slightly branched polymer of glucose linked by α -D-(1-4)-glycosidic bond. Amylopectin is also a polymer with a branch of glucopyranoses linked by a chain of amylose units at C-6 position of a glucose residue through an α -D-(1-6)-glycosidic bond (Wiseman et al., 2001).

The series of enzymes which digest starch to D-glucose varies with age and substrate. One enzyme is α -amylase secreted by salivary glands and by the pancreas. The α -amylase from salivary glands is generally considered inactive when it goes through the acidic environment of the stomach. The amylase activity is low at birth and increases with age. Hartma et al. (1961) observed a significant linear regression of amylase level on age. Amylolytic activity linearly increased with age in pigs weaned at 5 wk of age (Hartma et al., 1961). A continuous nutrient supply has been shown to increase the maltase and glucoamylase activities during the first 5 d postweaning (Kelly et al., 1991). McCracken (1984) concluded that amylase activity was related to the previous feeding history (McCracken, 1984; Miller et al., 1986).

According to the digestibility, Total starch (TS) can be divided into degradable starch (RDS), slow-degradable starch (SDS) and resistant starch (RS) by chemical analysis (Table 2).

Englyst et al., 1992). Most starch can be rapidly digested and absorbed as glucose by intestinal mucosa. However, resistant Starch (RS) resists digestion in the small intestine and passes through to the large intestine. Then RS is used by the cecum and colonic microflora, which may influence the microbial groups in the large intestine. Mntagne et al. (2003) observed that adding resistant starch in nursery diets decreased the villous height and crypt depth, which means that the RS decreased the digestive capacity of small intestine. However, RS like potato starch stimulates the formation of short chain fatty acid especial butyrate in large intestine of nursery pigs (Hedemann and Knudsen, 2007). Butyrate is good for the health of large intestine (Sakata, 1987). Collectively, RS has beneficial effects on influencing the microbial fermentation of large intestine but decreasing the digestibility of the small intestine in nursery pigs.

The efficiency of starch utilization varies with grain samples within the same species and grain species. Starch digestibility is affected by amylase/amylopectin ratio, starch granular structure, cell wall components and dietary soluble non-starch polysaccharide (NSP) content (Lee et al., 2010). External factors like methods of process in industry and enzyme activities would further influence the digestibility. With so many various factors, pancreatic enzymes digested starch in different rate, which would result in different speed of glucose release. Many studies have been conducted to assess the degree of change in starch structure. Processing attributed to a large part of the starch degradation (Sauter et al., 1990). The mechanical damage would increase the starch digestibility. Besides, the ratio of starch: protein and starch lipid of the cereal would also influence the change of starch structure.

In conclusion, compared with lactose, glucose and sucrose, starch is more complex in structure. Besides, the environment effects bring in a lot of varies in change of starch structure. The digestion experiment has showed that digesting starch is a simple process in vivo. However, the starch which is an unfamiliar food source for newly weaned pigs may bring in stresses. Pigs at the first few days of weaning reduced the feed consumption (Bayley and Carlson, 1970). The lack of enough feed consumptions may inhibit the release of pancreatic enzymes like amylase (Wiseman et al, 2001). The digestive disorder in intestine and poor palatability of starch would limit the use of cereal starch in nursery diets.

Sources of Lactose

Dried Whey and Dried Whey Permeate

Whey is the most important by-product from cheese and casein manufacture. Whey is also a major lactose source with abundant amount of Ca and other minerals (K, Na, P, Zn, Mg, Fe, etc.). Liquid whey is separated from cheese curd in the cheese manufacture process and then is condensed by either evaporation or evaporation and reverse osmosis (Zadow, 1992; Nessmith et al., 1997). Whey protein concentrate and deproteinized whey (whey permeate) are abstained by process called ultrafiltration. Then whey is generally dried by spray drying or roller drying. Lactose can be removed from crystallized whey and produces the delactosed whey. Dried whey (97.2% DM) contains 72.9% lactose, 11.55% crude protein, 0.8% crude fat, 0.62% calcium and 0.69% of phosphorus with 3,415 kcal/kg of ME (NRC,

2012). Dried whey permeate (98.0% DM) contains 80% lactose, 3.5% crude protein and 0.2% ether extract with 3,153 kcal/ kg of ME (NRC, 2012).

It has been well accepted that the addition of dried whey improved the growth performance of nursery pigs at 3 to 4 wk of age. Cera et al. (1988) conducted a study to compare the performance of nursery pigs at the dietary inclusion of dried whey (0 vs 25%). The result showed that high dried whey in diet resulted in greater weight gain, feed intake and gain to feed ratio during each week of the post-weaning period, the largest relative improvement occurring during wk 1 postweaning. Owsley et al. (1986) also found the similar result. Mahan (1984) further indicated that dried whey improved ADG of nursery pigs by 15%. Some studies reported that the benefits of dried whey were attributed to their high quality of protein (Tokach et al., 1989; Mahan, 1992). The proteins contained β -lactoglobulin, α -lactoalbumin, BSA and immunoglobulin, lactoferrin, lactoperoxidase, lysozyme, casein glycomacropeptide, phosphopeptides, and fat globule membrane proteins (Harper, 2000). Tokach et al (1989) indicated that lactalbumin and lactose, the major component of dried whey, were both responsible for the enhancement of weaned pig growth performance. However, Mahan (1992) suggested that the beneficial response to dried whey may be mainly due to its carbohydrate component which was lactose. In the same concept, the beneficial effects of dried whey permeate are due to the abundant amount of lactose which takes up 80% of dried whey permeate. A number of studies have proved that increasing level of lactose would enhance the growth performance and feed intake (Mahan et al., 2004; Cromwell et al., 2008; Naranjo et al., 2010). The positive response to increasing lactose level

was outstanding at early days postweaning (Cera et al., 1988; Mahan et al., 2004). From d 0 to 14 post weaning, weight gain increased ($P < 0.05$) as lactose increased to 30% (Mahan et al., 2001). In experiment of Cromwell et al. (2008), dried whey permeate was used as a source of lactose, the result showed that the weight gain and feed consumption increased with increasing levels of lactose during wk 3 and 4 postweaning. The additional BW gain was maintained after 5 to 6 wk postweaning. The positive response of lactose was maintained after the level of lactose started to decrease after 4 wk postweaning. Also in total nursery period, ADG of pigs fed dried whey permeate diet increased compared with ADG of pigs fed negative control diet (Naranjo et al., 2010).

Dried Skim Milk

Skim milk is made by removing all the milk fat from the whole milk. Skim milk (94.6% DW) contains 47.8% lactose, 36.8% protein, 1.27% calcium and 1.06% phosphorus with ME at 3730 kcal/kg (NRC, 2012). The main use of dried skim milk is as a palatable protein source in starter diets. The improvement in growth performance is due to both lactose and protein components of dried skim milk. However, as a carbohydrate source (lactose) of nursery pigs, dried skim milk is generally too expensive compared with lactose, whey and whey permeate. It's reported that some processed soybean protein sources could replace dried skim milk as a protein source with similar growth performance for pigs at 3 to 5 wk of age (Dietz et al., 1988; Geurin et al., 1988; Sohn et al., 1994).

Replacement of Lactose

Some experiments have been conducted on evaluating less expensive lactose sources to replace dried whey. It has been proved that crystalline L-lactose, deproteinized whey (whey permeate) can effectively replace dried whey only if the diet contains other balanced and palatable protein sources like spray drying plasmas. Mahan (1992) reported that the positive response of dried whey was mainly due to the lactose fraction. From d 0 to 14 postweaning, total replacement of dried whey (18% of lactose in diet) with deproteinized whey or crystalline lactose not only didn't impair the weight gain and feed consumption, but also enhanced the feed efficiency (Nessmith et al., 1997).

Besides dried whey permeate and crystalline lactose, some products from candy food industries have been used to replace dried whey. Milk chocolate product (MCP) contains 20% of lactose and 60% of sugars. Milk chocolate product could effectively replace 25% of total dried whey (Yang et al., 1997). Yang et al. (1997) reported that the performance of pigs fed diet with 5% of milk chocolate product and diet containing 15% of dried whey had no difference with performance of pigs fed diet with 20% dried whey (14% lactose in diet in total) in 5 wk post weaning period. Naranjo et al. (2010) stated that 100% of replacement of dried whey (20% in diets) in wk 1 postweaning didn't impair the growth performance and feed intake. On the other hand, it seems like milk chocolate product has better palatability than dried whey because pig prefer MCP over dried whey. Yang et al. (1997) reported that pig consumed 65% to 77% of total feed intake came from MCP-containing diet when pigs were provided both MCP and dried whey diet.

In the previous chapter of glucose and sucrose, it has been shown the positive responses of simple sugars on replacing lactose in nursery diets. Richert et al. (1996) reported that partially replacing dietary lactose with glucose increased ADG ($P < 0.1$) at wk 2 and 3 postweaning. Sucrose could effectively replace lactose in nursery diets (Mavromichalis et al., 2001). Jin et al. (1998) also reported that during overall nursery period, pig fed sucrose, lactose or dried whey showed similar growth performance. Except for the growth performance, the gross energy digestibility, nitrogen digestibility and DW excretion also showed the similar results when pigs fed the same treatment diets (Jin et al., 1998). Carbohydrate product, which is the mixture of simple sugars like sucrose, lactose, glucose and oligosaccharides and starch, had been reported to replace lactose. Kim and Allen (2001) stated that carbohydrate by-product (90% total sugars) could replace at least 50% of lactose in phase 1 and 2 starter diets. Naranjo et al. (2010) reported the positive effect of carbohydrate product (40% lactose, 30% sucrose, and 10% glucose) by showing the result that both carbohydrate product and dried whey permeate diets increased ADG and ADFI compared with control diet. In this study, 40% of lactose was replaced by 30% of sucrose and 10% glucose together in diets, no reduction in growth performance was detected (Naranjo et al., 2010).

Some plants contain inulin, which is used as carbohydrate sources in west Europe since the year of 1605. Inulin may improve the growth performance of nursery pigs in the absence of antibiotic in diets. Inulin contains fructo-oligosaccharides, which is possible to substitute lactose partially. High levels of lactose improved growth performance as a possible

replacement for antimicrobial growth promoters and the low level of lactose with addition of inulin had the same benefits (Pierce et al., 2005). In this study, it shows that inulin has the potential to replace lactose partially, especially in EU.

Summary

Palatable and digestible ingredients, especially carbohydrate sources, are really indispensable for nursery pigs. Lactose takes up a large portion in nursery diets. However, the prices of lactose and other milk by products are dramatically high. Previous studies have showed that lactose can be partially and effectively replaced by simple sugars like glucose, sucrose and etc. in nursery diets. In aspect of commercial lactose containing products, previous studies have also showed carbohydrate products and milk chocolate product can replace dried whey or dried whey permeate without impairing growth performance of nursery pigs. Less expensive carbohydrate sources need to be tested in order to reduce the feed cost and improve the economic efficiency of swine production.

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Table.1. Dietary nutrient requirement of starter pigs allowed feed *ad libitum* (90% dry matter)

Body weight, kg	3 to 5	5 to 10	10 to 20
ME content of diet, Mcal/kg	3.3	3.3	3.3
Crude protein, %	26.0	23.7	20.9
Lysine, % ^a	1.3	1.2	1.0
Methionine, % ^a	0.4	0.3	0.3
Threonine, % ^a	0.8	0.7	0.6
Calcium, %	0.9	0.8	0.7
Total phosphorus, %	0.7	0.7	0.6
Copper, mg ^b	6.0	6.0	6.0
Zinc, g ^b	0.1	0.1	0.1

^a % of amino acid was base on true ileal digestibility

^b amount/kg added in diet

Table 2. Classification of starch based on digestibility (Englyst et al., 1992)

Type of starch	Example	Digestion in small intestine
Rapidly digested starch (RDS)	Gelatinized starch (heated)	Rapid, complete
Slowly digested starch (SDS)	Most raw cereals	Slow but complete
Resistant Starch (RS)		
Physically inaccessible starch	Partially milled grain	Resistant
Resistant starch granules	Raw potato	Resistant
Retrograded starch	Overheated/cooked	Resistant

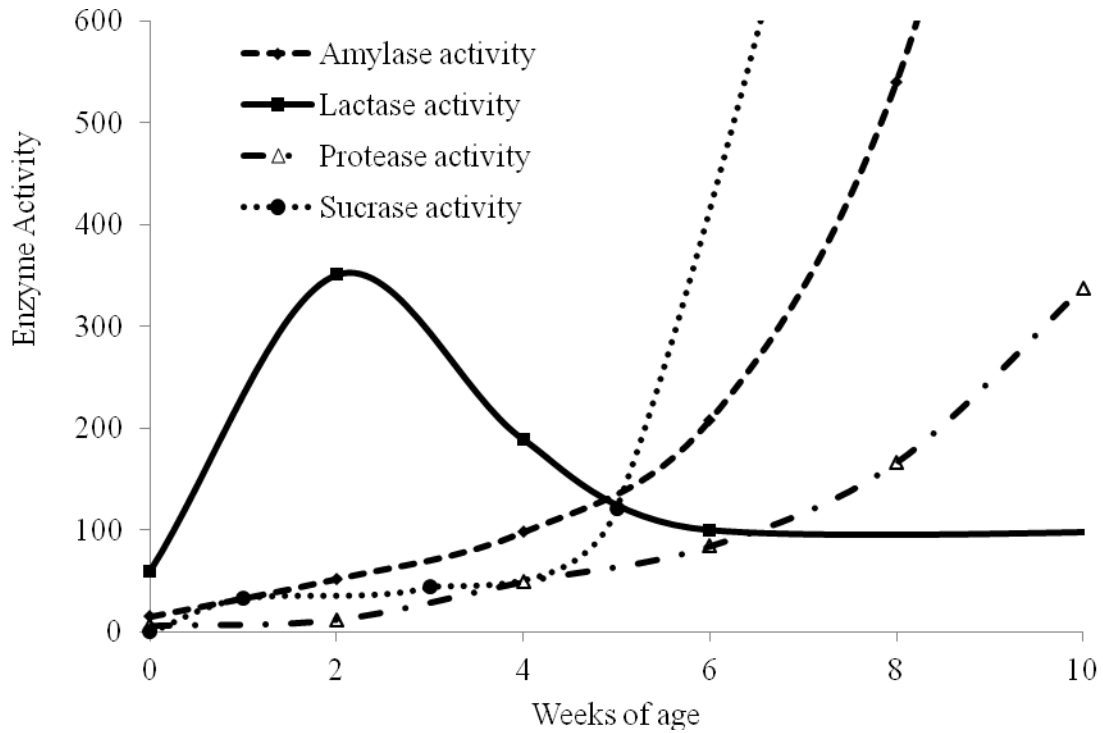
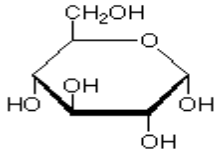
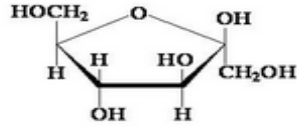


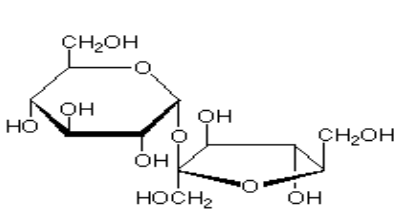
Figure 1. Development of enzyme activity in the young pigs from birth (adapted from Ekstrom et al., 1975; Shields et al., 1980; Adeola and King, 2006). The amylase activity is calculated by grams starch hydrolyzed per minute. The protease activity is calculated by milligram tyrosine equivalents produced per minute. The lactase activity is presented as grams of lactose hydrolyzed per day. Sucrase activity in jejunum is presented as total sucrase/area, $\text{nmol}/(\text{min}\cdot\text{cm}^2)$.



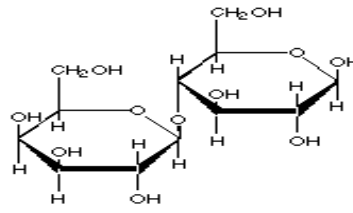
Glucose (Monosaccharide)



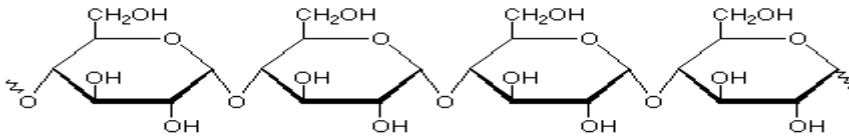
Fructose (Monosaccharide)



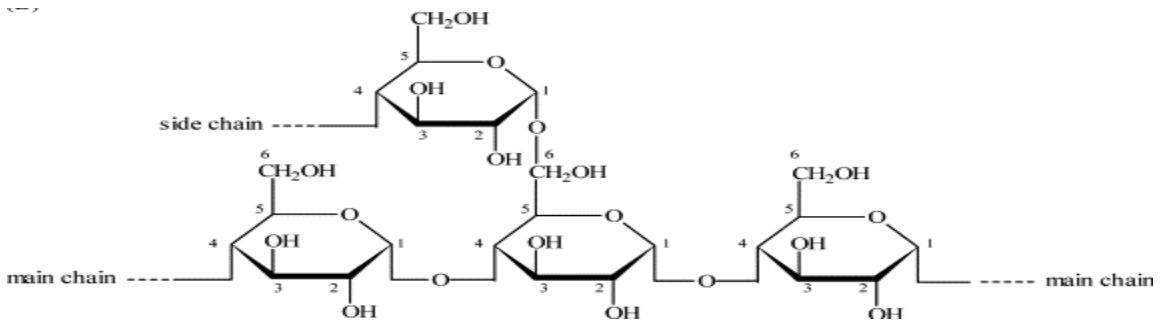
Sucrose (disaccharide)



Lactose (disaccharide)



Amylose Starch (Polysaccharide)



Amylopectin Starch (Polysaccharide)

Figure 2. Structures of the major carbohydrates for pigs (adapted from Brown, 1999)

CHAPTER 2

EFFECT OF CHOCOLATE CANDY FEED AS AN ALTERNATIVE CARBOHYDRATE SOURCE TO THE USE OF LACTOSE ON GROWTH PERFORMANCE OF NEWLY WEANED PIGS IN A COMMERCIAL FARM CONDITION

Effect of Chocolate Candy Feed as an Alternative Carbohydrate Source to the Use of Lactose on Growth Performance of Newly Weaned Pigs in a Commercial Farm Condition

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Abstract

The objectives of this research was to determine the effect of Chocolate Candy Feed, (CCF, International Ingredient Corp., St. Louis, MO), as an alternative carbohydrate source to lactose for nursery pigs. Weaned pigs (21 d of age, 7.1 ± 0.3 kg, $n = 1,408$) were fed 4 diets (16 pens/treatment and 22 pigs/pen) in phase 1 and 2. Each pen of pig was provided 1.8 kg of experimental diets during phase 1 (around 11 d), 6.8 kg of experimental diets during phase 2 (around 17 d). During phase 3, all pigs were fed a common diet until d 49 postweaning . Treatment diets included PC (20 and 8% lactose in phase 1 and 2, respectively; 0% replacement of lactose with CCF), 15CCF (15% lactose replacement), 30CCF (30% lactose replacement) and 45CCF (45% lactose replacement). Whey permeate was used as a source of lactose. Replacements of lactose by CCF were based on equal amounts of total sugars. Treatment diets contained equal amounts of essential amino acids and energy. Fecal scores were recorded on d 1, 3, and 5. Blood samples were taken at the end of phase 2. Duration of phase 1 tended to linearly decrease ($P = 0.063$) with increasing level of CCF in diets. During of phase 1, ADFI linearly increased ($P < 0.05$) as CCF increased in the diets with no

differences in ADG or gain:feed. Duration of phase 2 was not different among treatments. During phase 2, ADG linearly decreased ($P < 0.05$) as CCF increased in the diets whereas ADFI and gain: feed were not affected. No differences were observed in growth performance during the combined phase 1 and 2 period when treatment diets were fed. Whereas the duration of phase 1 and 2 together linearly decreased ($P < 0.05$) as pig were fed diets with increasing levels of CCF. In phase 3, ADFI was linearly reduced ($P < 0.05$) in pigs fed increasing levels of CCF during the previous treatment phases, but no differences were detected for ADG or gain: feed. During the overall trial period, ADG, ADFI, and G:F were not different among treatments indicating no adverse effects of CCF replacing lactose on growth performance of nursery pigs. Serum urea nitrogen was not different among treatments at the end of phase 1 but tended to linearly increase ($P = 0.088$) with increasing CCF at the end of phase 2. During phase 1, there was no difference in fecal scores among treatments. Mortality rate of pigs was not different among treatments whereas morbidity of pigs tended to linearly decrease ($P = 0.083$) as CCF increased indicating no adverse effects of CCF replacing lactose on health status of nursery pigs. In conclusion, Chocolate Candy Feed can be used to replace up to 45% of the lactose in nursery diets without negative effects on growth performance or health status.

Key words: Chocolate Candy Feed, Lactose, Nursery pig

Introduction

Energy is essential for nursery pigs to maximize growth performance. Carbohydrate is the main energy source for newly weaned pigs. Available carbohydrate sources for newly weaned pigs are limited because the intestinal structures of newly weaned pigs are not mature and there are not enough activities of appropriate carbohydrate enzymes. Lactose is the carbohydrate source of milk, which is highly digestible and palatable for nursery pigs. Lactose not only serves as an energy source for nursery pigs but also helps to stimulate the appetite and maintain a healthy gut environment in pigs (Wolter et al., 2003; Cromwell et al., 2008). There was a linear increase in feed efficiency and daily gain as dietary lactose level increased from 12 to 17% during the 1st wk postweaning (Mahan et al., 2004). Up to 7.5% of dietary lactose during 14 to 28 d postweaning resulted in an increase in feed intake and growth performance (Cromwell et al., 2008).

However, because the cost of lactose increased dramatically by 360% from \$0.40/kg in 2002 to \$1.86/kg in 2012 (Gould, 2013), alternative carbohydrate sources have been investigated. Simple carbohydrates, including glucose and sucrose, may partially replace lactose in starter diets. Glucose is a monosaccharide which can be directly absorbed by intestinal mucosa. Kidder and Manners (1978) and Sambrook (1979) suggested that glucose was as efficient as lactose being a sugar source for pigs less than 7 d old. At d 14 to 28 postweaning, replacing part of lactose in a diet with glucose increases the weight gain (Richert et al., 1996). Both sucrose and lactose are disaccharides. Piglets fed sucrose at less than 7 d of age cause serious

diarrhea, weight loss and high mortality because of deficiency in sucrase (Becker and Terrill, 1954; Aherne et al., 1969). Whereas, pigs can use sucrose effectively after reaching 7 to 10 d of age (NRC, 1998). Jin et al. (1998) reported that when 20% level of lactose, sucrose and dried whey were added in diet, pigs had similar growth performance. Kim and Allee (2001) suggested that simple carbohydrates could replace at least 50% of dietary lactose during 0 to 27 d postweaning (14 ± 2 d) in starter diets. Naranjo et al. (2010) also demonstrated that ADG, ADFI and G:F were not different during d 0 to 28 postweaning when dietary lactose was partially replaced by sucrose and glucose. During 10 to 30 postweaning, molasses contains multiple monosaccharides and disaccharides such as glucose, fructose, sucrose, can also substitute lactose without adverse effects on growth performance or nutrient digestibility of pigs, which was weaned at d 19 of age (Mavromichalis et al., 2001).

Chocolate Candy Feed (CCF; International Ingredient Corporation, St. Louis, MO, USA) is a by-product from the food and candy industries containing 50% of sugars including sucrose, glucose, fructose, lactose, etc. The price of CCF would be about 45% of the whey price and 68% of the permeate market. The CCF could be an economic replacement to the use of lactose. Milk chocolate product (MCP) is a by-product similar to CCF containing 20% lactose and 60% of sugars, which have been proved to be an available carbohydrate source for nursery pigs. Sullivan et al. (1992) and Naranjo et al. (2010) demonstrated that milk chocolate can partially or entirely replace the use of DW without adverse effects on growth performance of nursery pigs during d 0 to 35 postweaning. Yang et al. (1997) indicated that pigs strongly preferred MCP over DW. However, no research has been conducted to test the

efficiency of using CCF to replace the use of lactose in nursery diets. If CCF can successfully replace the use of lactose without impairing growth performance and caloric efficiency, overall cost of swine production can be reduced. Therefore, the objective of this study was to evaluate the effect of CCF as an alternative carbohydrate source for lactose on growth performance of newly weaned pigs.

Materials and Methods

Animals and Design

The experiment was conducted in a research farm at Murphy Brown LLC (Rose Hill, NC). A total of 1,408 cross-bred pigs (Smithfield Premium Genetics, Rose Hill, NC) were weaned at 20 ± 1 d of age with 7.1 ± 0.3 kg BW. Immediately after weaning, pigs were randomly allotted to 4 treatments with 16 replicates (16 pens) per treatment using their initial BW as a block. Each phase was planned based in the amount of feed a pig consumes. There were 22 pigs in each pen. Each pig in pens was supposed to consume 1.8 kg of experimental diets during phase 1 (around 11 d), consume 6.8 kg of experimental diets during phase 2 (around 17 d) and fed a common diet during phase 3 (around 21 d). Experiment lasted 49 d for all pigs. Calculated concentrations of SID (standardized ileal digestible) Lys were 1.34, 1.19, and 1.09% for phase 1, 2, and 3, respectively. Concentrations of lactose were 20, 8, and 0% for phase 1, 2, and 3, respectively.

Dried whey permeate (DairyLac80, International Ingredient Corporation, St. Louis, MO) containing 80% of lactose, was used as a source of lactose. For the treatment diets, parts of lactose were replaced by total sugars in CCF during phase 1 and 2. Total sugars (including lactose, sucrose, glucose, fructose, and etc.) content in CCF was 50% (Table 1). Chocolate Candy Feed also contained 96% DM, 10% ether extract, 7% CP, 0.28% Lys, 1.5% crude fiber, 6% ash, 2% Ca, and 0.34% P. Dietary treatments were (1) PC: 0% replacement of lactose with CCF (positive control); (2) 15CCF: 15% replacement of lactose with CCF; (3) 30CCF: 30% replacement of lactose with CCF; and (4) 45CCF: 45% replacement of lactose with CCF. Pigs were fed 4 treatment diets during phase 1 and 2 followed by a common diet during phase 3. Dried whey permeate was replaced by CCF based on the equal amount ratio between lactose in wheat permeate and total sugar in CCF. All diets were formulated to meet or exceed the NRC (2012) nutrient requirements. Feed was mixed and pelleted at the North Carolina State University Feed Mill (Raleigh, NC). Nutrient composition of treatment diets is presented in Table 2 and 3.

Housing and Sampling

All pigs were housed in temperature-controlled nursery rooms. Space allowance was 0.76m²/pig. All pigs were allowed *ad libitum* access to feed and water. Each pen was equipped with 2 nipple drinkers.

Experimental diets were delivered to each feeder provided by the Howema feeding system (Big Dutchman Inc., MI, USA) once a day (0800 h) during phase 1, twice a day (0800 and 1600 h) during phase 2, and 4 times a day (0200, 0800, 1200, and 1600 h) during

phase 3. At the end of each phase, pigs were weighed and feed intake was recorded to calculate ADG, ADFI, and G: F.

Fecal score was measured at d 1, 3, and 5 using a score scaled of 0 to 3 (0 = normal firm stool, 1 = soft stool, 2 = loose stool, 3 = watery stool). Pigs with an average BW in each pen were selected to collect blood sample (10 mL) via the external jugular vein at the end of phase 1 and the same pigs were bled again at the end of phase 2. Blood samples were centrifuged at 3,000 x g for 10 min in 4°C to separate serum and stored in -80°C to measure concentration of serum urea nitrogen using an assay kit (Liquid Urea Nitrogen Assay kit; Canton, MI).

Statistical Analysis

The experiment was planned as a completely randomized block design. Pen was the experimental unit. All data except for fecal score were analyzed by one-way ANOVA using procedure GLM and polynomial contrast of SAS 9.3 (SAS Institute Inc, Cary, NC). Procedure NPAR1WAY (SAS 9.3) was used for fecal score analysis with a Kruskal-Wallis test (Theodorsson-Norheim, 1986). A probability level of $P < 0.05$ was considered significant, whereas probability of $0.05 \leq P < 0.10$ was considered a tendency.

Results

Mortality and Morbidity

No difference was observed in mortality ($P > 0.10$) when pigs were fed diets with increasing levels of CCF in overall nursery period (d 0 to 49). The morbidity during overall

nursery period tended to linearly decrease ($P = 0.08$) when pigs were fed increasing levels of CCF (Table 4). The morbidity of pigs fed 45CCF diet was 48% less than the morbidity of pigs fed PC diet.

Duration of Each Phase

Duration of phase 1 tended to linearly decrease ($P = 0.06$) from 11.3 to 10.4 d as pigs were fed diets with increasing levels of CCF. Duration of phase 2 for pigs was not different among treatments. Duration of phase 1 and 2 together linearly decreased ($P < 0.05$) from 28.4 to 26.7 d as pigs were fed diets with increasing levels of CCF. Phase 3 was ended on d 49 of the study and thus the duration was not related to the treatment effects.

Feed Intake

During phase 1, ADFI linearly increased ($P < 0.05$) from 164 to 178 g/d as pigs were fed diets with increasing levels of CCF. During phase 2, ADFI of pigs was not affected by levels of CCF in the diets. Considering both phase 1 and 2, ADFI was not affected by treatments. During phase 3, ADFI of pigs linearly decreased ($P < 0.05$) from 886 to 828 g/d when pigs were previously fed increasing levels of CCF in diets from phase 1 to 2. No difference ($P > 0.1$) was detected in ADFI during phase 1, 2, and 3 together among treatments.

Weight Gain and Feed Efficiency

Initial body weight did not differ among treatments (Table 4). During phase 1 (around 11 d), ADG of pigs fed CCF containing diets was not different from ADG of pigs fed a PC diet. With increasing levels of CCF in diets, ADG of pigs in phase 2 linearly decreased ($P <$

0.05). No reduction of weight gain was detected during combined periods of phase 1 and 2, as well as during phase 3 with increasing levels of CCF in the diets. Body weight at the end of phase 2 linearly decreased ($P < 0.05$) with increasing levels of CCF in the diets. No difference was observed for BW at the end of phase 1 and at the end of phase 3. The G: F was not affected by treatments at any phase.

Fecal Score and Serum Urea Nitrogen

Serum urea nitrogen (SUN) level tended to linearly increase ($P = 0.09$) from 10.73 to 13.30 mg/dL at the end of phase 2 with increasing levels of CCF in diets. However, no change of SUN level was detected at the end of phase 1 among treatments. Fecal score at d 1, d 3 and d 5 postweaning were not different among treatments, neither (Table 5).

Discussion

The experiment was to evaluate the effect of CCF as a substitute to the use of lactose on performance of nursery pigs. Glucose and lactose are the most effective carbohydrate sources for young pigs (Kidder and Manners, 1978; Sambrook, 1979). However, after reaching 7 to 10 d of age, pigs can utilize fructose and sucrose effectively (NRC, 2012). Sucrose has long been used as energy source in young pigs (Becker et al., 1954a; Brooks, 1972; Veum and Mateo, 1981). The current study showed that increasing levels of CCF in phase 1 diet increased daily feed intake and shortened the duration of phase 1 and 2. This indicates that CCF enhanced feed intake of newly weaned pigs. Others showed similar

results by partial replacement of lactose with other carbohydrate sources. Naranjo et al. (2010) reported that ADG, ADFI and G:F were not different between pigs (21 d of postweaning age, initial BW = 6 kg) fed a diet with a mixed carbohydrate source (CHO) composed of 40% lactose, 30% sucrose, and 10% glucose or a diet with dried whey permeate (DWP, 80% lactose) for 7 d immediately after weaning. At different initial BW (8 kg) and postweaning age (26 d), Naranjo et al. (2010) found that feed consumption of pigs increased when DWP were totally replaced with CHO when fed for 14 d immediately after weaning. Jin et al. (1998) also showed that weight gain and feed consumption of pigs fed diets containing lactose, sucrose, and dried whey were not different during d 0 to 14 postweaning. Similar results were also shown when pigs were fed a carbohydrate by-product including 40% sucrose, 10% lactose, 38.5% oligosaccharides and starch, 1.5% glucose (carbohydrate by-product, International Ingredient Corporation, St. Louis, MO, USA) replacing 50% lactose in the diet without differences in growth performance (Kim and Allee, 2001).

The beneficial effect of CCF in feed consumption may be partially due to the increase in diet palatability. Comparing with dried whey permeate, sucrose, one of sugar components of CCF, increases dietary sweetness (Diaz et al., 1956). At the same time, young pigs prefer diets containing sugars or other sweeteners (Aldinger et al., 1961; Aldinger and Fitzgerald., 1966). Nursery pigs seemed like strongly prefer milk chocolate product (one third whole milk, one third coca, and one third sucrose) over dried whey during d 0 to 14 postweaning (Sullivan et al., 1992; Yang et al, 1997). The reason why pigs prefer milk chocolate product is unclear. But the components of CCF are as similar as components of milk chocolate

product. It makes sense that the feed consumption increased with addition of CCF in diets during phase 1. Furthermore, the shortening duration of phase 1 with increasing level of CCF in diets implied that pigs ate faster when they were fed diets with CCF, which also supported that CCF could enhance the dietary palatability.

Mavromichalis et al. (2001) stated there was no adverse effect on growth performance when replacing lactose with sucrose from d 10 to 30 postweaning. However, in our study increasing level of CCF in diets resulted in poorer growth performance in phase 2 and less BW at d 27 postweaning. Direct comparison between these two results may be not so accurate because 100% replacement of lactose with sucrose was utilized in report of Mavromichalis et al. (2001). However, the experimental results of phase 2 was similar as what Yang et al. (1997) reported that linear reduction was detected in ADG as MCP level was increased from 0 to 15% during phase 2 (wk 2 through 4 postweaning). CCF contains certain amount of glucose. It's reported that compared with lactose, glucose had less effect on improving nutrient digestibility during nursery period (Turlington et al. 1989). Kim and Allee (2001) noticed that feed efficiency of pigs fed the diets with lactose was higher compared with pigs fed carbohydrate by-product, which contained sucrose, lactose, glucose and etc. during 28 d postweaning.

Serum urea nitrogen concentration is directly related to protein intake (Eggum, 1970; Bassily, 1982). Cai et al. (1995) suggested that the decline of blood urea nitrogen was due to low energy intake, so amino acids were oxidized to furnish energy intake which resulted in an increasing accretion of body protein. The higher SUN level of pigs fed CCF containing

diets at the end of phase 2 implied that energy intake of pigs was negatively correlated to the increasing level of CCF from d 11 to 27 postweaning. Since pigs were fed a common diet in phase 3, the decrease of ADFI in phase 3 may be caused by the carryout effect of CCF in phase 2.

The similar growth performance among treatments in phase 1 and 2 together and phase 1, 2 and 3 together agree with some results from previous studies (Kim and Allee, 2001; Naranjo et al., 2010) that ADG, ADFI and G:F were not affected comparing pigs fed DWP containing diets with pigs fed MCP containing diets and carbohydrate by-products during 28 d postweaning. Jin et al. (1998) reported similar results by comparing pigs fed sucrose containing diets and pigs fed dried whey containing diets during 3 wk postweaning. Because the ADFI is calculated by duration of phase, feed intake and No. of pigs in each treatment. If all pigs were fed same amount of feed and the morbidity is same among treatments, shorter duration of pigs fed CCF containing diets during both phase 1 and 2 should induce higher ADFI. However, the morbidity was lower too when pigs were fed CCF in diets. Thus the ADFI among treatments were not different during phase 1 and 2 together.

The results of mortality are in agreement with the early study (Veum and Mateo, 1981) suggesting that sucrose could be utilized by pigs at 7 d of age without mortality. Also, previous studies showed that pigs at 15 to 21 d of age could utilize sucrose without an increase in mortality and with similar performance compared with pigs fed diet with crystal lactose (Mateo and Veum, 1980; Jin et al., 1998). However, pigs at less than 1 wk of age fed diets containing sucrose developed high mortality (Becker and Terrill, 1954; Aherne et al.

1969). The reduced performance of pigs may be related to intestinal enzyme activity. Walker (1959) and Dahlvist (1961) reported that sucrase activity was low at 1 wk of age and increase considerably until 3 to 4 wk of age. Manners and Stevens (1972) reported that pigs reared artificially and fed diets containing sucrose showed higher sucrase activity compared with pigs nursing by sows. Thus, the lower morbidity of pigs fed CCF containing diets may be also due to that addition of sucrose to diet stimulated the production of intestinal sucrase activity.

Chocolate Candy Feed contains 18 mg/kg caffeine and 1,458 mg/kg of theobromine. Caffeine acts as a stimulant drug which can prolong duration of exercise and delay fatigue. The average intake of caffeine in western world per capita per day is 0.3 g (Barone and Roberts, 1996). Greer et al. (1998) suggested that one time ingestion of 5.4 mg/kg caffeine would elicit an ergogenic effect in adult man. Caffeine is associated with an increase in plasma epinephrine concentration (Graham et al., 1994; Greer et al., 1998). Studies in human being (Keijzer et al., 2001) showed an increase of epinephrine in plasma may result in sparing of glycogen in active muscle, declining in insulin sensitivity and increasing in plasma FFA. However, Hulston and Jeukendrup (2008) reported that one time coingestion of 5.3 mg/kg caffeine with carbohydrate didn't influence exogenous carbohydrate oxidation or glucose kinetics when the animals were in a relative stable condition. The direct effect of caffeine on performance of nursery pigs is unknown.

Component of theobromine in chocolate is similar to caffeine and theophylline, whose pharmacological effect is stimulating the central nervous system, stimulating cardiac

muscle, relaxing smooth muscle, and acting on kidney to produce diuresis (Rall, 1990; Yang et al., 1997). Besides, the cocoa beans in chocolate contain flavonoids, which have historically been used as a treatment to diarrhea in children (Maximilian et al., 2005). Even the caffeine and theobomine may stimulate some physiological reactions, the carbohydrate digestion and growth performance of pigs may be not affected. But the direct relation between the components theobomine and flavonoids in CCF and growth performance of nursery pigs is unclear. Further studies on the effects of caffeine, theobomine and flavonoids on growth performance of nursery pigs are needed.

Collectively, the results suggest CCF can replace up to 45% of lactose in phase 1 and 2 diets without impairing growth performance and feed intake of nursery pigs. A by-product, Chocolate Candy Feed, can be an alternative carbohydrate source partially replacing the use of dried whey or dried whey permeate which can also help reducing feed cost benefiting pig production.

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Table 1. Nutrient composition (%) in Chocolate Candy Feed and DairyLac80

Items	CCF ¹	DairyLac80 ²
DM, %	96.00	95.5
Total sugars, %	50.00	80.00
CP, %	7.00	3.50
Ether extract, %	10.00	0.50
Crude fiber, %	1.50	0.00
Ash, %	6.00	10.00
ME (calculated), Mcal/kg	4.03	3.37

¹Chocolate Candy Feed (International Ingredient Corporation, St. Louis, MO)

²Dried whey permeate (International Ingredient Corporation, St. Louis, MO)

Table 2. Composition of experimental diets in phase 1, %

	Treatment ¹			
	PC	15CCF	30CCF	45CCF
Ingredients, %				
Yellow Corn	36.63	35.18	33.58	32.03
DairyLac 80 ²	25.00	21.25	17.50	13.75
Chocolate Candy Feed ³	0.00	6.00	12.00	18.00
SBM, dehulled	25.00	25.00	25.00	25.00
Blood plasma, spray dried	3.00	3.00	3.00	3.00
Fish meal, menhaden	4.00	4.00	4.00	4.00
L-Lys HCl	0.23	0.22	0.21	0.20
DL-Met	0.16	0.15	0.15	0.15
L-Thr	0.11	0.11	0.10	0.10
Poultry fat	3.40	2.60	1.90	1.20
Antibiotics ⁴	0.48	0.48	0.48	0.48
Salt	0.22	0.22	0.22	0.22
Vitamin premix ⁵	0.03	0.03	0.03	0.03
Mineral premix ⁶	0.15	0.15	0.15	0.15
Calcium phosphate (dicalcium)	1.00	1.05	1.15	1.20
Limestone, ground	0.60	0.57	0.54	0.50
Calculated composition:				
DM, %	91.80	91.80	91.90	92.00
ME, Mcal/kg	3.50	3.50	3.50	3.50
Total sugar, %	20.00	20.00	20.00	20.00
Lactose, %	20.00	17.00	14.00	11.00
CP, %	21.00	21.20	21.30	21.50
SID Lys, %	1.34	1.34	1.34	1.34
SID Met + Cys, %	0.78	0.78	0.78	0.78
SID Trp, %	0.24	0.24	0.24	0.24
SID Thr, %	0.85	0.85	0.85	0.85
Ca, %	0.92	0.92	0.93	0.92
Available P, %	0.56	0.56	0.56	0.56
Total P, %	0.83	0.82	0.82	0.82

¹PC = positive control diet, 0% replacement of lactose with CCF; 15CCF = 15% replacement of lactose with CCF; 30CCF = 30% replacement of lactose with CCF and 45CCF = 45% replacement of lactose with CCF.

²DairyLac 80 contains 80% of lactose (International Ingredient Corporation, St. Louis, MO).

³Chocolate Candy Feed contains 50% of sugar (International Ingredient Corporation, St. Louis, MO).

Table 2 is continued

⁴ 2,700 mg/kg of Penchlor100G and 1,578 mg/kg of Denagard10 in each phase 1 diet

⁵ The vitamin premix provided the following per kilogram of complete diet: 6,613.8 IU of vitamin A as vitamin A acetate; 992.0 IU of vitamin D3; 19.8 IU of vitamin E; 2.64 mg of vitamin K as menadione sodium bisulfate; 0.03 mg of vitamin B12; 4.63 mg of riboflavin; 18.52 mg of D-pantothenic acid as calcium pantothenate; 24.96 mg of niacin; 0.07 mg of biotin.

⁶ The trace mineral premix provided the following per kilogram of complete diet: 4.0 mg of Mn as manganous oxide; 165 mg of Fe as ferrous sulfate; 165 mg of Zn as zinc sulfate; 16.5 mg of Cu as copper sulfate; 0.30 mg of I as ethylenediamine dihydroiodide; and 0.30 mg of Se as sodium selenite.

Table 3. Composition of experimental diets in phase 2, %

	Treatment ¹			
	PC	15CCF	30CCF	45CCF
Ingredients, %				
Corn grain	54.28	53.76	53.35	52.83
DairyLac 80 ²	8.00	6.80	5.60	4.40
Chocolate Candy Feed ³	0.00	1.92	3.84	5.76
SBM, dehulled	30.00	30.00	30.00	30.00
Blood plasma, spray dried	1.00	1.00	1.00	1.00
Fish meal, menhaden	2.00	2.00	2.00	2.00
L-Lys HCl	0.12	0.12	0.12	0.12
DL-Met	0.06	0.06	0.05	0.05
L-Thr	0.02	0.02	0.02	0.02
Poultry fat	2.20	2.00	1.70	1.50
Antibiotics ⁴	0.13	0.13	0.13	0.13
Salt	0.22	0.22	0.22	0.22
Vitamin premix ⁵	0.03	0.03	0.03	0.03
Mineral premix ⁶	0.15	0.15	0.15	0.15
Calcium phosphate (dicalcium)	1.15	1.15	1.20	1.20
Limestone, ground	0.65	0.65	0.60	0.60
Calculated composition:				
DM, %	90.41	90.45	90.47	90.50
ME, Mcal/kg	3.44	3.44	3.44	3.44
CP, %	21.23	21.28	21.33	21.38
Total sugar, %	6.40	6.40	6.40	6.40
Lactose, %	6.40	5.44	4.48	3.52
SID Lys, %	1.19	1.19	1.19	1.19
SID Met + Cys, %	0.68	0.68	0.68	0.68
SID Trp, %	0.23	0.23	0.23	0.23
SID Thr, %	0.73	0.74	0.74	0.74
Ca, %	0.81	0.81	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40
Total P, %	0.71	0.70	0.71	0.70

¹PC = positive control diet, 0% replacement of lactose with CCF; 15CCF = 15% replacement of lactose with CCF; 30CCF = 30% replacement of lactose with CCF and 45CCF = 45% replacement of lactose with CCF.

²DairyLac 80 contains 80% of lactose (International Ingredient Corporation, St. Louis, MO).

³Chocolate Candy Feed contained 50% of total sugars (International Ingredient Corporation, St. Louis, MO).

Table 3 is continued

⁴1,127 mg/kg of Mecadox10 in each phase 2 diet

⁵The vitamin premix provided the following per kilogram of complete diet: 6,613.8 IU of vitamin A as vitamin A acetate; 992.0 IU of vitamin D3; 19.8 IU of vitamin E; 2.64 mg of vitamin K as menadione sodium bisulfate; 0.03 mg of vitamin B12; 4.63 mg of riboflavin; 18.52 mg of D-pantothenic acid as calcium pantothenate; 24.96 mg of niacin; 0.07 mg of biotin.

⁶The trace mineral premix provided the following per kilogram of complete diet: 4.0 mg of Mn as manganous oxide; 165 mg of Fe as ferrous sulfate; 165 mg of Zn as zinc sulfate; 16.5 mg of Cu as copper sulfate; 0.30 mg of I as ethylenediamine dihydroiodide; and 0.30 mg of Se as sodium selenite.

Table 4. Effects of lactose replacement on growth performance of nursery pigs¹

	Treatment				SEM	P-value		
	PC	15CCF	30CCF	45CCF		Trt	Linear	Quadr
Mortality, %	3.98	4.26	2.84	2.84	1.350	0.821	0.428	0.917
Morbidity ² , %	7.10	7.39	3.41	3.69	1.800	0.249	0.083	0.990
BW, kg								
Initial BW	7.2	7.2	7.1	7.2	0.100	0.833	0.718	0.541
Phase 1 BW	8.3	8.3	8.3	8.3	0.100	0.986	0.983	0.819
Phase 2 BW	14.3	13.9	13.8	13.5	0.276	0.187	0.036	0.865
Phase 3 BW	26.1	26.1	25.9	25.8	0.263	0.831	0.378	0.877
Duration, d								
Phase 1 ³	11.3	10.8	10.9	10.4	0.310	0.203	0.063	1.000
Phase 2 ³	17.1	17.0	16.5	16.3	0.525	0.686	0.246	0.906
Phase 1+2	28.4	27.8	27.4	26.7	0.513	0.144	0.023	0.903
Phase 3 ⁴	20.6	21.3	21.6	22.3	0.513	0.144	0.023	0.903
Overall	49.0	49.0	49.0	49.0	0.000			
ADG, kg								
Phase 1	0.098	0.105	0.118	0.098	0.009	0.505	0.291	0.359
Phase 2	0.355	0.328	0.337	0.322	0.009	0.103	0.044	0.603
Phase 1+2	0.251	0.241	0.248	0.233	0.008	0.558	0.305	0.922
Phase 3	0.570	0.575	0.561	0.555	0.009	0.410	0.155	0.547
Overall	0.386	0.387	0.385	0.379	0.005	0.840	0.423	0.668
ADFI, kg								
Phase 1	0.164	0.173	0.169	0.178	0.005	0.139	0.049	0.990
Phase 2	0.498	0.464	0.447	0.453	0.028	0.576	0.228	0.480
Phase 1+2	0.338	0.339	0.329	0.339	0.009	0.829	0.864	0.589
Phase 3	0.886	0.880	0.855	0.828	0.015	0.047	0.007	0.511
Overall	0.567	0.570	0.559	0.559	0.011	0.777	0.396	0.558
Gain:feed								
Phase 1	0.595	0.609	0.692	0.545	0.051	0.608	0.629	0.381
Phase 2	0.780	0.722	0.759	0.715	0.038	0.655	0.423	0.909
Phase 1+2	0.761	0.718	0.754	0.689	0.029	0.423	0.284	0.862
Phase 3	0.647	0.656	0.656	0.672	0.013	0.556	0.181	0.810
Overall	0.681	0.679	0.687	0.675	0.009	0.944	0.900	0.850

¹Data are means of 16 pens (22 pigs/pen) and experiment unit was the pen.

²Morbidity includes number of pigs dead and removed due to sickness.

³During phase 1 and phase 2, pigs were fed treatment diets. When each pig in the same pen consumed 1.8 kg of phase 1 diet, diets were changed to phase 2 (6.8 kg/pig).

⁴During phase 3, pigs were fed one common diet until d 49 postweaning.

Table 5. Effects of lactose replacement on serum urea nitrogen, mortality, morbidity and fecal score of nursery pigs

	Treatment				SEM	P-value		
	PC	15CCF	30CCF	45CCF		Trt	Linear	Quadr
Serum urea nitrogen, mg/Dl								
Phase 1	10.10	11.29	11.70	11.63	0.960	0.612	0.241	0.507
Phase 2	10.73	12.99	13.49	13.30	1.029	0.214	0.088	0.255
Fecal score ¹						Kruskal Wallis Test		
D 1	2.81	2.62	2.81	2.69	0.112	0.546		
D 3	2.87	3.00	2.88	2.81	0.079	0.392		
D 5	2.88	2.75	2.88	2.88	0.093	0.705		

¹ Fecal score is measured on d 1, 3, and 5 during phase 1 based on 0 to 3 scale: 0 = normal firm stool; 1 = soft stool; 2 = loose stool; and 3 = watery stool. Observation was made based on an incidence of soft stool, loose stool, or watery stool regardless of amount. As an example, if there was an incidence of soft stool as well as water stool in a pen, fecal score was numbered as 3. As another example, if there were one incidence of watery stool in one pen and more than one incidences of watery stool in another pen, both pens were numbered as 3.