A Thesis

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Effects of Cassava Residue Supplementation on Growth Performance, Nutrient Digestibility, Occurrence of Diarrhea, Fecal Microflora and Blood Profiles in Weaning Pigs

이유자돈 사료 내 카사바 부산물의 첨가가 이유자돈의 성장, 영양소 소화율, 설사빈도, 분내 미생물 균총 및 혈액 성상에 미치는 영향

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지도교수 **김 유 용**

이 논문을 농학석사 학위논문으로 제출함

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Summary

Bio-fuel such as ethanol has been produced globally to supply stable fuel for replacing fossil fuel resources. Corn has been positioned as one of the major feed ingredients used in livestock production, so increase of bio-fuel production caused inflated prices of feed grains. In this situation, developing alternative feed resources is the most effective way to reduce feed costs. This research was conducted to investigate the effects of cassava residue supplementation on growth performance, nutrient digestibility, occurrence of diarrhea, fecal microflora and blood profiles in weaning pigs.

A total of 128 weaning pigs (28 ± 3 old and 7.98 ± 0.83 kg of BW) were allotted into 4 treatments with 8 replicates of 4 piglets per pen in a randomized complete block (RCB) design. The treatments were 1) Control (basal diet) 2) C 5 (replacing corn with cassava residue by 5%) 3) C 10 (replacing corn with cassava residue by 10%) and 4) C 15 (replacing corn with cassava residue by 15%). Three phase feeding programs (phase Ⅰ for 0-2 week, phase Ⅱ for 3-4 week and phase Ⅲ for 5-6 week) were used in this experiment.

In feeding trial, there were no significant difference in BW, ADG, ADFI and G/F ratio among treatments. There was linear response on ADG as dietary cassava residue increased ($P<0.05$) during 3 to 4 week and ADG was the lowest when pigs were fed 15% cassava residue diet. Also, pigs fed increasing cassava residue had decreased ADFI (linear, $P<0.05$) during both the last two weeks and the whole experimental period. In nutrient digestibility, there were linear responses on digestibility of crude protein and crude fat as dietary cassava residue

increased (P<0.01). During the whole experimental period (0 to 6 week), diarrhea incidence was not affected by dietary treatments and the average of diarrhea score was 1.86. In phase Ⅰ, pigs fed 5% of cassava residue showed the lowest occurrence of diarrhea score (P<0.01). During 0 to 2 week, pigs fed 10% or 15% of dietary cassava residue showed higher *E. coli* and *Salmonella* counts compared to those of pigs fed 0% or 5% of cassava residue (P<0.01, P<0.05, respectively). Linear response was observed in IGF-1 concentration as cassava residue supplementation increased during 3 to 4 week (P<0.05).

Based upon this experiment, cassava residue could be supplemented in weaning pig diet by 10% without growth check or detrimental effect.

Key words : Cassava residue, Weaning pig, Growth performance, Nutrient digestibility, Occurrence of diarrhea

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Ⅰ. Literature Review

List of Abbreviation

ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of official analytical chemists
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
DM	Dry matter
DDGS	Distillers dried grains with soluble
DF	Dietary fiber
E. coli	*Escherichia coli*
GMO	Genetically modified organism
G:F	Average daily gain per average daily feed intake
HCN	Hydrogen cyanide
HNL	Hydroxynitrile lyase
IGF-1	Insulin-like growth factor-1
ME	Metabolizable energy
NSP	Non-starch polysaccharides
RS	Resistant starch
SBM	Soybean meal
UDP	Undegradable protein

I. Introduction

Korean livestock industry has been going through a hard time because of Korea - EU (European Union) FTA (Free trade agreement) since 2011 and outbreak of FMD (foot and mouth disease) in late 2011. In order to cope with these crises in swine and feed industries, many researchers have planned further studies to increase animal growth performance and decrease mortality rate of pigs. Besides, they have been searching for means to reduce the feed costs with not only minimally sacrificing animal's productivity but also getting international competitiveness.

Corn, wheat and soybean meal (SBM) are widely used as primary feed ingredients in swine feed industry. However, the price of international major feed ingredients has been increasing since 2006 because of the increasing meat consumption in developing countries such as China, bio-fuel production using feed ingredients in USA and global financial crisis in 2008. In this situation, developing alternative feed resources, instead of conventional ingredients such as corn or SBM, is the most effective way to reduce feed costs.

Alternative feed ingredients such as agri- and agro-byproducts should satisfy the conditions such as adequate production amounts, steady supply and cheap price to substitute for the conventional ingredients. Consequently alternative ingredients such as cassava, palm kernel meal, copra meal, dried distillers grains with soluble (DDGS), guar meal, have been investigated as alternative ingredients in swine

diet.

Cassava is mainly used for human food as a starch source. It is the world's fifth-abundant food crop and is grown mainly in the tropical area. According to prediction, cassava production will increase up to 291 million tones until 2020 (Scott et al., 2000). Based on the sufficient production amounts, cassava has a competitive price compared with other feed ingredients. Cassava is non-GMO (genetically modified organism) feed ingredient and has low contamination possibility by mycotoxin, so it is safer feed grain compared to other feed ingredients (Tewe et al., 2002). Starch in cassava is highly digestible because it composes of 2 parts of amylose and 8 parts of amylopectin. Thanh (1978) reported cassava could be used in swine diet up to 40% for replacing corn. Akoroda (1988) presented using cassava pellet in poultry diet up to 20% did not show any harmful effect on growth performance.

This experiment was conducted to investigate the effects of cassava residue supplementation on growth performance, nutrient digestibility, occurrence of diarrhea, fecal microflora and blood profiles in weaning pigs to utilize cassava as an alternative feed resource instead of corn in swine diet.

II. Literature Review

1. Introduction

1.1. Increase of feed ingredients price

World grain prices have been increasing since 2006 because of global financial crisis and producing bio-fuel for replacing conventional fossil fuels. For example, federal government of US announced the law; Renewable Fuel Standards (RFS) - fuel suppliers should be obliged to use bio-ethanol partly - in 2005. Corn is the major cereal grain not only used in livestock production but also used in producing bio-fuel. Unfortunately, there have been unforeseen climate phenomena globally in 2012, especially in USA there was the worst drought over 56 years. Given that USA is the world's largest producer of corn, high price of corn will maintain for some time. It could be a big burden on Korean livestock industries because over 90% of ingredients are imported from various countries for feed ingredients.

1.2. Necessity of developing alternative feed ingredients

In the feed business, there are several ways for lower animal feed price such as reducing retail margin as well as marketing cost, use cheap ingredients, reduce nutrients contents in diet. However, finding new alternative ingredients is one of effective choice to reduce feed price. There are some limit conditions for using alternative ingredients in animal feed included; first of all, alternative ingredients have to cheaper than corn and SBM. Secondly, ingredients have to contain

adequate nutrients with low anti-nutritional factor, Finally ingredients can be supplied with large amount production and stable supply. A majority of alternative feed ingredients typically contain high level of non-starch polysaccharides (NSP), which are the biggest concerns on their effective use for monogastric animal diets. However, among the alternative ingredients, the potential candidate for animal feed are cassava, copra meal, DDGS, palm kernel meal and so on with their capable to apply to supplement in swine and poultry feed and are cheaper than corn and SBM.

2. Characteristics of cassava

Cassava (Manihot esculenta Crantz), a shrubby tree of the Euphorbiaceous family, is an extensively cultivated plant in many tropical countries (Rubporn, 2006). Cassava is the basic food for more than 700 million people in undeveloped countries (Soccol, 1996; Kato and Souza, 1987; Cereda et al., 1996). Two-hundred eight million tones of cassava are produced annually and Africa is the largest region of cassava production with approximately 60 million tones per year. It can be successfully grown on marginal soils with low rainfall. It is a perennial that can be harvested as required and gives reasonable yields where other crops do not grow well because cassava is one of the most drought-tolerant crops. Also, cassava is a highly productive crop in terms of food calories produced per unit land area per unit of time, significantly higher than other staple crops. Cassava can produce food calories at rates exceeding 250,000 cal/hectare/day compared with 176,000 for rice, 110,000 for wheat, and 200,000 for corn. The mature cassava plant (12 month old) contains 6% of leaves, 44% stem and

50% tubes

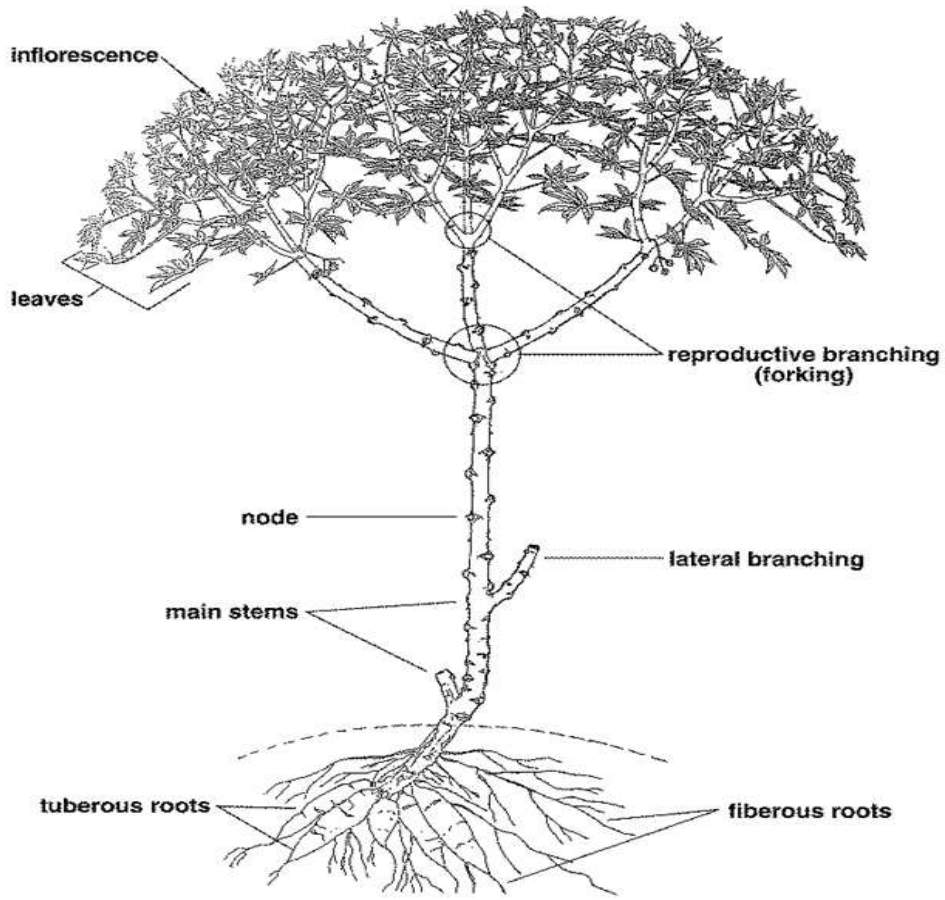

Figure 1. Diagram of a cassava plant

Source: IITA (International Institute of Tropical Agriculture)

2.1. Types and nutritional profile of cassava

Cassava root is used for a carbohydrate source. Its composition shows 60–65 percent moisture, 20–31 percent carbohydrate, 1–2 percent

crude protein (CP) and a comparatively low content of vitamins and minerals. Most of the carbohydrate is present as starch (31% of fresh weight) with smaller amounts of free sugars (less than 1% of fresh weight) in cassava roots (Bradbury and Holloway, 1988). Cassava starch contains 80 percent amylopectin and 20 percent amylose. Cooked cassava starch has a digestibility of over 75 percent. Cassava root, however, is a poor source of protein. Methionine, cysteine and cystine are limiting amino acids in cassava root.

Cassava leaves can also be used as feed, especially to provide undegradable protein (UDP) to ruminants. Unlike the roots, the leaves are a good source of protein, containing 25% CP and producing up to 6 t CP ha^{-1}. The CP content, as a feeding value, decreases as the leaves become older and leaf protein contains a high lysine.

Industrial processing of cassava is done mainly to isolate flour (which generates more solid residues) and starch (which generates more liquid residues) from the tubers. By-products of root processing are 8% peel and 17% pomace. Cassava pomace, also called cassava residue, is a residue after extraction of starch from cassava roots. Cassava residue contains about 50–70% starch on a dry weight basis and 10–20% fibers, which are composed mainly of cellulose and other NSP. The variation in starch content in cassava residue among studies is because most of the processing is done under poorly controlled technological conditions (Pandey et al., 2000).

Cassava residue is low in protein, fat and minerals. It is used for pigs in Southeast Asia, where it is regarded as a valuable feed (Göhl, 1982). In Vietnam (North, Central Coast and South), cassava processing for starch manufacture has been developing rapidly. There are

considerable quantities of by-products which can be used as a feed resource for animals. The quality and appearance of those residues vary with plant age, time after harvest and industrial equipment (Cereda et al., 1996).

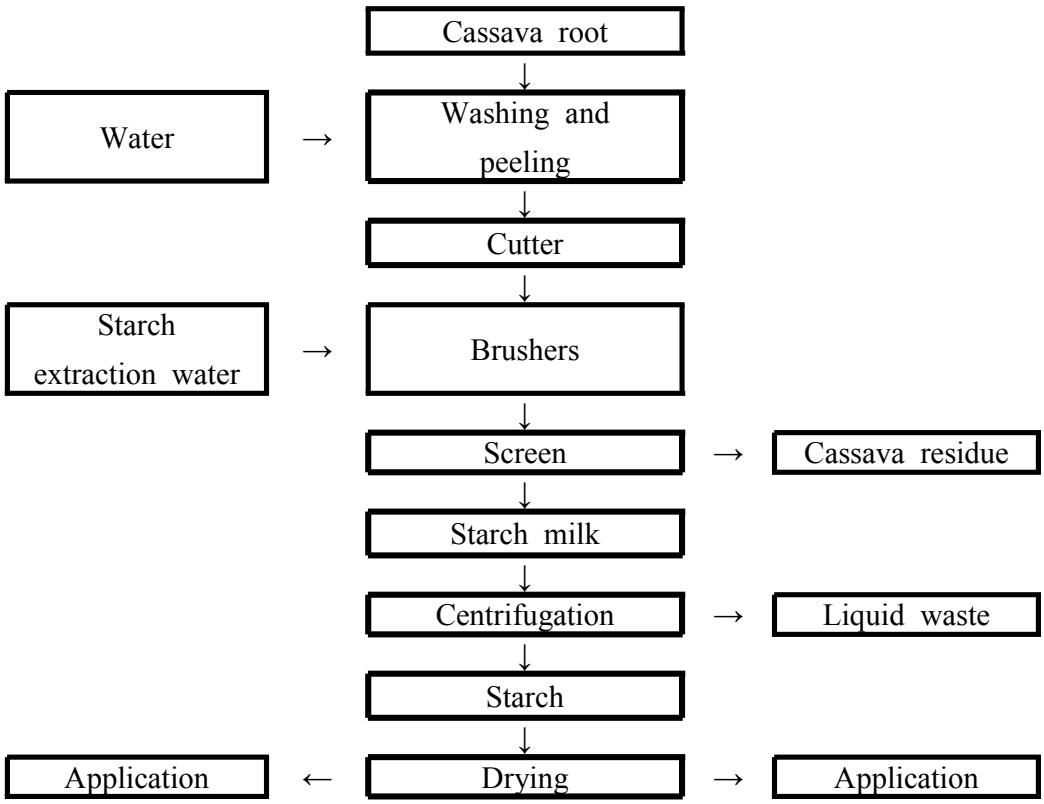

Figure 2. Processing of cassava tubers for isolating starch (Pandey et al., 2000)

Table 1. Percentage nutritional composition of cassava plant

Items	Root	Leaf	Stem	Peel	Residue
Moisture	12.6	nd	nd	70.4	12.2
Crude protein	2.0	24.1	17.2	4.9	2.4
Crude fiber	4.0	26.0	23.5	16.6	15.3
Soluble carbohydrate	75.7	nd	nd	nd	nd
Fat	0.7	5.0	nd	nd	1.4
Ash	5.0	8.0	nd	1.3	6.6
Dry matter	87.4	16.1	nd	29.6	77.9
NFE[a]	nd	39.9	nd	nd	74.3

[a]NFE = nitrogen free extracts
Note: nd = not determined
Sources: Rogers and Milners, 1963; Oyenuga, 1968; Seerley 1972; Devendra, 1977; Khajaren et al, 1977; Montaldo, 1977; Asaolu, 1988; Oguntimein, 1992

Table 2. Mineral contents of cassava plant

Mineral (mg/kg)	Tubers	leaf	Peel	Residue
Calcium	0.02~0.35	1.1~1.4	0.31	0.77
Phosphorus	0.07~0.46	0.25~0.30	0.13	0.06
Magnesium	1.10	nd	0.22	nd
Copper	nd	8.0	nd	4.29
Iron	8~65	450	904	nd
Manganese	18.0	46.0	nd	42.22
Zinc	nd	28.0	nd	11.85

Note: nd = not determined
Source: Chandha, 1961; Barrios and Bressani, 1967; Devendra, 1977; Hutagalucg, 1977.

2.2. Toxin substances and detoxification

Cassava, like other feed grains, also contains anti-nutritional and toxic factors. The cyanogenic glucosides called linamarin which is stored in the vacuoles of the cassava cells (McMahon et al., 1995) are toxin substances. It is hydrolysed to the corresponding ketone (acetone cyanohydrin) and glucose by the endogenous enzyme, linamarase, that

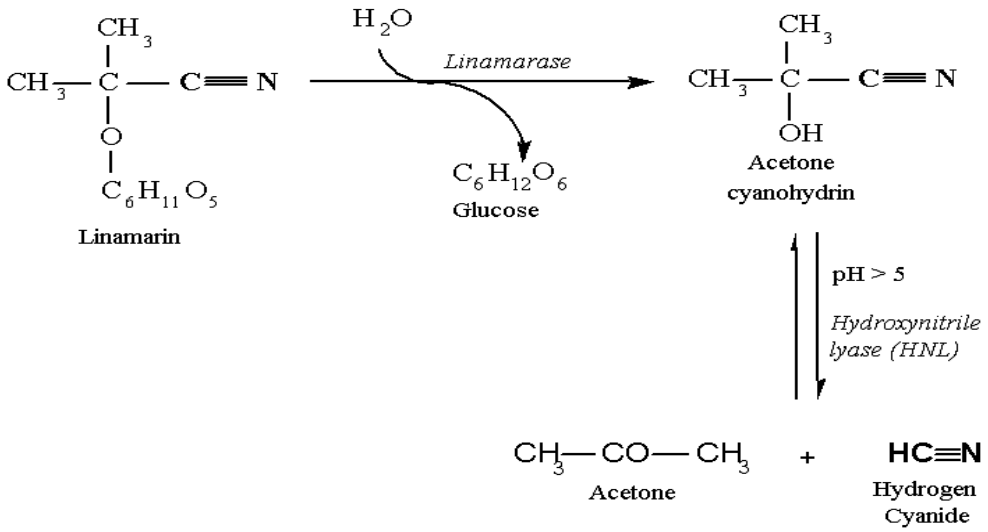

Figure 3. Enzymatic hydrolysis of linamarin

is released when the cells of cassava roots are ruptured (Bruijn, 1973). Acetone cyanohydrin is broken down to hydrogen cyanide (HCN) and acetone by an enzyme hydroxynitrile lyase (HNL), but it has been demonstrated that expression of the HNL gene is mainly in the leaves with little activity in the roots (White et al., 1998).

The presence of HCN in cassava is responsible for chronic toxicity when inadequately processed cassava products are consumed by humans and animals for prolonged period. The concentration of unsafe glycosides varies considerably between varieties and also with climatic and cultural conditions. Selection of cassava species to be grown, therefore, is quite important.

Fresh cassava roots cannot be stored for long because they rot within 3~4 days of harvest. They are bulky with about 70% moisture content, and therefore transportation of the tubers to markets is difficult and expensive. The roots and leaves contain varying amounts of cyanide which is toxic to humans and animals, while the raw cassava roots and uncooked leaves are not palatable. Therefore, cassava must be

processed in order to reduce cyanide content increase the shelf life of the products, facilitate transportation and marketing, reduce cyanide content.

2.2.1. Peeling and grating

Processing cassava roots commences with the peeling of the tubers. The normal range of cyanogen content of cassava tubers falls between 15 and 400 mg HCN/kg fresh weight (Coursey, 1973). The cyanide content is substantially higher in the cassava peel because the concentration of linamarin increases from the center of the tuber outwards (Bruijn, 1973). Removal of the peels therefore reduces the cyanogenic glucoside content considerably. Peeling can be an effective way to reduce the cyanide content by at least 50% in cassava tubers.

Grating process is done after peeling and is applied to whole tubers. Grating of the whole tuber ensures the distribution of the cyanide in the product, and will make the nutrients contained in the peel available for use. In the grated product, the concentration of cyanide depends on the time during which the glucoside and the glucosidase interact in an aqueous medium. Grating provides a greater surface area for fermentation to take place.

2.2.2. Soaking and boiling

Soaking of cassava roots precedes cooking or fermentation. It provides a larger medium for fermentation and allows for extraction of the soluble cyanide into the soaking water. The process removes about 20% of the free cyanide in fresh root chips after 4 hours. A very significant reduction in total cyanide is achieved if the soaking water is

routinely changed over a period of 3.5 days. A variation to the soaking technique known as retting, was described by Ayenor (1985). This process involves prolonged soaking of cassava roots in water to affect the breakdown of tissue and extraction of the starchy mass. A simulation of the technique, followed by sun-drying showed a reduction of cyanide of about 98.6% of the initial content in the roots.

The free cyanide of cassava chips is dramatically lost in boiling water. About 90% of free cyanide is removed within 15 minutes of boiling fresh cassava chips. Cooking destroys the enzyme linamarase at about 72°C thus leaving a considerable portion of the glucoside intact.

2.2.3. Fermentation and ensiling

The importance of fermentation in cassava processing is based on its ability to reduce the cyanogenic glucosides to relatively insignificant levels. It has been known that the higher the retention of starch in grated cassava the better the detoxification process. This could be attributed to the fermentative substrate provided by the starch. Also, the longer the fermentaion process the lower the residual cyanide content. As a preliminary stage, the use of starter cultures recovered from fermentation effluents is being tested to increase the conversion of substrate to product and reduce fermentation time. The process generates heat and mould growth is common.

The ensiling process causes the disintegration of the intact glucoside via marked cell disruption, drop in pH of ensiled medium and intense heat generation. Gomez and Valdivieso (1988) demonstrated that ensiling cassava chips reduced the cyanide content to 36% of the initial value after an ensiling period of 26 weeks.

2.2.4. Drying

Drying is carried out using solar radiation (sun-drying) or driers (electric or fuel) depending on economic viability. The effectiveness of substrate-enzyme interaction will be dependent on the particle size and environmental factors such as ambient temperature, insulation, relative humidity and wind velocity. Hence, proper sun-drying is achieved in between 1.3 days in the dry season and in up to 8 days during the rainy season.

An improvement in sun-drying of cassava roots using inclined tray-drying instead of drying on concrete floors was reported by Gomez et al. (1984). The residual total cyanide content was 10.30% of the fresh sample, with about 60.80% of the cyanide in the dried chips occurring as free cyanide. The comparative advantage of this method could be due to good conductivity of the tray.

3. Dietary fiber

3.1. Definition and classification of dietary fiber

Carbohydrates constitute a diverse nutrient category ranging from sugars easily digested by the monogastric animals in the small intestine to dietary fiber (DF) fermented by microbes in the large intestine. DF is commonly defined as plant polysaccharides and lignin that are resistant to hydrolysis by mamalian digestive secretions (Trowell, 1976). This definition is commonly used for non-ruminant animal, including the pig. DF covers a wide range of carbohydrates known as NSP that cannot be degraded by endogenous enzymes and then reach the colon

almost digested. NSP include pectins, cellulose, hemicelluloses, β -glucans and fructans. Oligosaccharides and resistant starch are also considered in the DF fraction. The hydrolysis of these carbohydrates invariably produces the same pentoses, hexoses, deoxyhexoses and uronic acids (Chesson, 1995). NSP are principally non-α-glucan polysaccharides of the plant cell wall. The physiological properties of NSP and their fermentability are poorly predictable from the monomeric composition and are more related to their solubility, viscosity, physical structure and waterholding capacity (Asp, 1996). Starch is susceptible to hydrolysis by salivary and pancreatic enzymes. However, the hydrolysis is not always complete (Sajilata et al., 2006). A part of the starch, termed " resistant starch " (RS), escapes digestion in the small intestine and reaches the large intestine because of physical inaccessibility (RS1 according to Cummings et al. (1995)), crystalline structure (RS2) or amylose retrogradation after cooking (RS3). Resistant starch is also considered as a DF (Chesson, 1995).

Table 3. Classification of non-digestible carbohydrates

Types of carbohydrate	Constituent monomers	Common sources
Oligosaccharides		
Fructo- and galacto-oligosaccharides	Fructose, galactose, glucose	Soybean meal, peas, rapeseed meal, cereals, milk products
Polysaccharides		
Starch		
Physical inaccessible starch (RS1)	Glucose	Whole or partly milled grains and seeds, legumes
Crystalline resistant granules (RS2)	Glucose	Raw potato, plantain, some legumes, sweet potato, high amylose corn
Retrograded amylose (RS3)	Glucose	Cooled heat-treated starchy products
Non starch polysaccharides (NSP)		
Cell wall NSP		
Cellulose	Glucose	Most feedstuff
Mixed linked β-glucans	Glucose	Barley, rye, oats
Arabinoxylans	Xylose, arabinose	Barley, rye, wheat
Arabinogalactans	Galactose, arabinose	Cereal by-products
Xyloglucans	Glucose, xylose	Cereal flours
Rhamnogalacturans	Uronic acids, rhamnose	Hulls of peas
Galactans	Galactose, arabinose	Soybean meal, beet pulp
Non-cell wall NSP		
Fructans	Fructose	Rye
Mannans	Mannose	Coconut cake, palm cake
Pectins	Uronic acids, rhamnose	Beet pulp
Galactomannans	Galactose, mannose	Guar gum

(Chesson, 1995; Knudsen, 1997; Montagne et al., 2003; Sajilata et al., 2006).

3.2. Physiological effect of dietary fiber on weaning pigs

Feeding fibrous diets results in a number of advantages, such as improved well-being of animals, improvement of gut transit time and reduction of stomach ulcers (Low, 1993). DF that escapes digestion in the upper part of the gastrointestinal tract, is used for bacterial

fermentation in the large intestine. Approximately 90% of the cultivable bacteria in the pig colon are Gram-positive, strict anaerobes belonging to the *Streptococcus*, *Lactobacillus* and *Peptostreptococcus* genus. Oligofructose, galacto-oligosaccharides and lactulose were shown to increase *Lactobacilli* in the large intestine of humans (Macfarlane et al., 2006). In acidic environment, short-chain fatty acids (SCFA) produced by DF fermentation are capable of inhibiting the growth of some intestinal pathogens such as *Escherichia coli* (*E. coli)* and *Salmonella spp*. (Montagne et al., 2003). The presence of DF significantly modifies the microbial equilibrium in the intestines with a positive or detrimental impact on animal health according to he DF source and the physiological status of the pig.

The bulking capacity of DF reduces the transit time in the entire gastro-intestinal tract and the digestibility of the other nutrients of the diet. An increase in fiber content decreases the mean retention time in the small and the large intestines (Wilfart et al., 2007), reducing the time of exposure of the diet to the host's digestive enzymes (Low, 1982). The amount of digesta flow at the terminal ileum is greater in pigs fed diets with high levels of DF than in pigs fed low-fiber diets (Varel et al., 1997). Unlike that in the intestines, the retention time in the stomach can increase in presence of DF, causing earlier satiety due to elongation of the stomach wall (Wenk, 2001).

4. Post-weaning problems in piglets

4.1. Growth check after weaning

Post-weaning stress, disease challenge and inadequate feed intake make a rapid loss of protein synthesis in weaning pigs (Whittemore and Green, 2001). Piglets suffering post-weaning stress showed a shift in the partitioning of dietary nutrients away from skeletal muscle development toward a metabolic response to support the immune system, resulted in muscle protein degradation. In these cases animals may suffer a net loss in weight rather than increase in weight and growth. Also, reduction of voluntary feed intake in the post-weaning period directly affects piglets. Provided that piglets fail to consume sufficient feed, they can not cover their energy requirement for maintenance (Bark et al., 1986). The reduction in live weight gain caused by decreased feed intake after weaning reduces fasting heat production (Koong et al., 1982). Pluske and Williams (1996) presented that changes in gut structure and function purported to be a consequence of physiological stress imposed at weaning are most likely confounded with the low levels of voluntary feed intake seen at this time.

4.2. Occurrence of diarrhea

Piglets after weaning have difficulty in consuming dry feed. They are removed from the sow and offered dry feed and plain water along with other stress factors (Lalles et al., 2007). It causes post-weaning anorexia. Consequently, the integrity of the gastrointestinal tract may be compromised (Pluske et al., 1997). Thus, ensuring a fast start of feeding after weaning is essential to maintain gut function and piglet growth. In general, piglets undergo a diarrhea within 3~10 days after weaning. This is associated with proliferation of *E. coli* in the proximal small

intestine and has been reported as a cause of considerable economic loss on affected swine producers. Bacteria that have been associated with diarrheal diseases after weaning include *E. coli* and *Salmonella* species. Pigs become infected with *Salmonella* after consumption of contaminated protein sources, or exposure to infected feces from rodents or wild birds. Salmonellosis is commonly seen in older weaning pigs, as is infection with the intestinal spirochaetes *Branchyspira hyodysenteriae* (swine dysentery: SD), and *Branchyspira pilosicoli* (porcine intestinal spirochaetosis: PIS), and with the intracellular bacterium *Lawsonia intracellularis* (porcine proliferative enteropathy: PPE). Of all these bacterial diseases, post-weaning colibacillosis, caused by *E. coli*, is the most common and widespread in the immediate post-weaning period.

Ⅲ. Effects of Cassava Residue Supplementation on Growth Performance, Nutrient Digestibility, Occurrence of Diarrhea and Fecal Microflora in Weaning Pigs

Abstract: This experiment was conducted to investigate the effects of supplementation of cassava residue supplementation on growth performance, nutrient digestibility, occurrence of diarrhea, fecal microflora and blood profiles in weaning pigs. A total of 128 crossbred weaning pigs ([Yorkshire × Landrace] × Duroc) with averaging 7.98 ± 0.83 kg of initial body weight were allotted to 4 treatments in a randomized complete block (RCB) design. Each treatment composed of 8 replications with 4 pigs per pen. The treatments were 1) Control (basal diet) 2) C 5 (replacing corn with cassava residue by 5%) 3) C 10 (replacing corn with cassava residue by 10%) and 4) C 15 (replacing corn with cassava residue by 15%). Three phase feeding programs (phase Ⅰ for 0 to 2 week, phase Ⅱ for 3 to 4 week and phase Ⅲ for 5 to 6 week) were used in this experiment. In feeding trial, there were no significant differences in BW, ADG, ADFI and G:F ratio among treatments. During 3 to 4 week, there was linear response on ADG as dietary cassava residue increased ($P<0.05$). Pigs fed

increasing cassava residue had decreased ADFI (linear, $P<0.05$) during 5 to 6 week and the whole experimental period. In nutrient digestibility, there were linear responses on digestibilities of crude protein and crude fat as dietary cassava residue increased ($P<0.01$). The occurrence of diarrhea during 0 to 2 week was decreased when pigs were fed 5% of cassava residue diet compare to that of control diet ($P<0.01$). During 0 to 2 week, pigs fed 10% or 15% of dietary cassava residue showed higher *E. coli* and *Salmonella* counts compared to those of pigs fed 0% or 5% of cassava residue ($P<0.01$, $P<0.05$, respectively). Linear response was observed in IGF-1 concentration as cassava residue supplementation increased during 3 to 4 week ($P<0.05$). Consequently, these results demonstrated that cassava residue as an alternative feed ingredient could be supplemented at 10% level in weaning pig diet without growth retardation.

Key words: Cassava residue, Weaning pigs, Growth performance, Diarrhea, Nutrient digestibility, Occurrence of diarrhea, Fecal microflora

Introduction

Bio-fuel such as ethanol has been produced globally to supply stable fuel for replacing fossil fuel resources. In USA, bio-ethanol production is considerably depended on corn production. However, corn has been also positioned as one of the major feed ingredients used in livestock production, so increase of bio-fuel production caused inflated prices of feed grains. To avoid this problem, searching for non-conventional feed ingredients has increased according to dramatically increasing cost of feed ingredients. Developing alternative feed resources is the most effective way to reduce feed costs.

Cassava is a world's fifth-abundant feed grain and is grown mainly in the tropical zone. It is a non-GMO feed ingredient and has low contamination possibility by mycotoxin, so it is safer feed grain compared to other feed ingredients (Tewe et al., 2002). There is a prediction about cassava production which is going to increase at 291 million tones until 2020 (Scott et al., 2000).

Cassava residue is a by-product after extracting starch from cassava root. It has a competitive price compared with other feed ingredients. The nutritional characteristics of cassava residue are varied and inconsistent caused by differences in the starch extraction methods and processing techniques. Cassava residue can be characterized for low in protein and high in dietary fiber and starch (Ngoc et al., 2012). High fiber contents mean that may cause limitations on weaning pig diet

(Knudsen and Jørgensen, 2001). However, adequate level of dietary fiber affects growth of the positive intestinal microflora or reduction of pathogenic bacteria in gastrointestinal tract (Mateos et al., 2006). Cassava has highly digestible starch because it composes of 2 parts of amylose and 8 parts of amylopectin. It is known that high ratio of amylopectin improved the starch digestibility (Bahnassey and Breene, 1994). Thanh (1978) reported cassava could be used in swine diet up to 40% for replacing corn. Akoroda (1988) observed using cassava pellet in poultry diet up to 20% did not show any harmful effect on growth performance. However, there is still lacking of published data for effects of cassava residue utilization on weaning pig diet.

Therefore, this experiment was conducted to investigate the effects of cassava residue supplementation on growth performance, nutrient digestibility, occurrence of diarrhea, fecal microflora and blood profiles in weaning pig diet to utilize cassava as an alternative feed resource instead of corn in swine diet.

Materials and Methods

Experimental design and diet

A total of 128 crossbred ([Yorkshire × Landrace] × Duroc) pigs with averaging 7.98 ± 0.83 kg of initial body weight were randomly assigned to each treatment based on sex and initial body weight according to randomized complete block (RCB) design in 8 replicates with 4 pigs per pen. Cassava residue contained approximately 12.2% of moisture, 2.4% of CP, 1.4% of fat, 6.6% of crude ash, 47.2% of starch and 15.3% of fiber, respectively. The treatments were designed as a level of cassava residue supplementation. The treatments were 1) Control (basal diet) 2) C 5 (replacing corn with cassava residue by 5%) 3) C 10 (replacing corn with cassava residue by 10%) 4) C 15 (replacing corn with cassava residue by 15%). This experiment was conducted with corn-SBM-barley based diet and three phase feeding programs were used and phase Ⅰ, Ⅱ and Ⅲ diets were provided at intervals of 2 weeks, respectively. Crude protein and lysine contents in phase Ⅰ, Ⅱ and Ⅲ diets are 23.7 and 1.35%, 21.0 and 1.15%, 19 and 1.05%, respectively. All nutrients of experimental diets were met or slightly exceeded the nutrient requirements (NRC, 1998). Formulas and chemical composition of experimental diets were presented in Tables 1, 2 and 3.

Animal management and measurement

Pigs were housed in a half slatted 0.9 × 2.4 m^2 concrete floor equipped with a feeder and a nipple drinker to allow freely access to

feed and water during the whole experimental period. The ambient temperature in the weaning pig's house was kept 31 ℃ during the first 7 days and lowered 1 ℃ every week. Body weight (BW) and feed consumption were recorded at 0, 2, 4 and 6 week to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G/F ratio).

Digestibility trial

Digestibility trial was conducted in completely randomized design (CRD) with 4 replicates to evaluate the nutrient digestibility and nitrogen retention. A total of 16 crossbred barrows with averaging 10.21 ± 0.37 kg body weight were individually allotted to each treatment and housed in an metabolic crate. Total collection method was used for the apparent digestibility. After 5 days of adaptation period, fecal and urine samples were collected for 5 days. To determine the first and last day of fecal collection, 1g of chromium oxide (first day) and ferric oxide (last day) were added in every experimental diet as a selection marker. During the experimental period, water was provided *ad libitum* and all pigs were fed 100g of each experimental diet twice a day. Excreta and urine were collected daily and stored -20 ℃ until analysis. Collected excreta were pooled and dried in an air-forced drying oven at 60 ℃ for 72 h, and ground into 1 mm particles in a Wiley mill for chemical analysis for moisture, protein, fat, and ash contents. Total urine was collected daily in a plastic container containing 50 ml of 4N H_2SO_4 to avoid evaporation of nitrogen, frozen during the 5 days of collection period and pooled

samples for nitrogen retention analysis.

Analysis of diarrhea incidence

During the whole feeding trial period, diarrhea score was recorded once a day (08:00) by counting the pig with diarrhea per pen with the experimental pen. The range of diarrhea score was from 0 (healthy : no pigs with diarrhea) to 4 (severe : all pigs with diarrhea).

Analysis of fecal microflora

Fecal samples were collected every second week from 6 pigs selected randomly through anus-stimulation. Each of the collected fecal samples was weighed by 1 g and diluted with 9 ml of distilled water. After picking up the mixed solution by 1g using pipette, it was diluted with 9 ml of distilled water again. Like this way of dilution, content of each fecal sample was diminished to $1/10^6$ percent of initial diluted solution. Then it was sprayed on microorganism plate (SANITA KUN, LST Korea) with nutrient agar which was made for each microorganism; *E. coli*, *Salmonella* and *Lactobacillus*, respectively. These sprayed samples were then incubated for 24 hours at 35 ℃. After culturing diluted fecal sample, colonies of each microorganism were counted.

Blood sampling

Blood samples were collected from 6 pigs, selected randomly every second week, for blood urea nitrogen (BUN) and insulin-like growth factor (IGF-1) analysis. Collected blood samples were

centrifuged for 15 minutes at 3,000 rpm and 4 ℃. The serum was removed to 1.5 ml plastic tubes and stored at -20 ℃ until analysis.

Chemical analysis

Diets were ground by a Cyclotec 1093 Sample Mill (Foss Tecator, Hillerod, Denmark). Ground diets and feces were analyzed for content of dry matter (DM) (procedure 967.03; AOAC, 1990); ash (procedure 923.03; AOAC, 1990); nitrogen by using the Kjeldahl procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden) and calculating the CP content (Nitrogen × 6.25; procedure 981.10; AOAC, 1990). Nitrogen of urine was determined by the Kjeldahl procedure.

Statistical analysis

The experimental data were analyzed as a completely randomized design using MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). For growth performance and diarrhea incidence, a pen was considered the experimental unit, while individual pig was used as the unit for on apparent total tract digestibility, fecal microflora and blood profiles. The model for MIXED procedures included treatment as a fixed variable and replication as a random variable. Least squares means of treatment groups were compared in a pair-wise manner using PDIFF option of MIXED procedures with Turkey adjustment. The differences were converted to letter groupings using the PDMIX800 macro in SAS (Sazton, 1998). Orthogonal polynomial contrasts were used to determine linear and quadratic response of cassava residue supplementation. The alpha level used for determination of statistical significance was 0.05.

Results and Discussion

Growth performance

Growth performance results for BW, ADG, ADFI and G:F ratio throughout the whole feeding trial period were presented in Table 4. There were no significant differences and no tendency were observed in BW, ADG, ADFI and G:F ratio among treatments during the whole experimental period. With increasing cassava residue level, ADG was declined (linear, $P<0.05$) during 3 to 4 week and was the lowest when pigs were fed 15% cassava residue diet. Also, ADFI was decreased lineally as dietary cassava residue increased ($P<0.05$) during both the last two weeks and the whole experimental period.

Increasing of cassava residue supplementation level in weaning pig diet showed lower growth performance compared control treatment (0% cassava residue) in this experiment. These observations are in agreement with the results from Taksinanan et al. (2010) who presented that a diet containing 10% of cassava residue had negative effects on ADG and FCR compared with a control diet in weaning pigs (ADG: 322 ± 10.4, 267 ± 15.1; FCR (feed conversion ratio): 1.83 ± 0.05, 2.03 ± 0.04, respectively). In another experiment, piglets subjected to diets containing cassava pulp at the level of 0, 5, 10 and 15% had 684.6, 662.7, 659.0 and 653.9 of ADFI, respectively, and ADG were 375.6, 260.1, 361.3 and 353.5, respectively. Based upon these results, Kosoom et al. (2009) reported that cassava residue could be incorporated in weaning pig diets up to 10% without any detrimental effects to piglet performance. Bertol et al. (1999) concluded that

detrimental response in growth performance in growing pigs was observed when 7% of cassava residue supplemented. The possible reason of results above mentioned could be attributed to low palatability due to relatively high ash and dietary fiver contents (6.55% and 15.32%, respectively) in cassava residue.

Nutrient digestibility

Table 5. presented the effects of cassava residue supplementation on nutrient digestibility and nitrogen retention at phase Ⅱ. There was linear response on crude protein digestibility as dietary cassava residue increased ($P<0.01$) and was greater when pigs were fed more than 10% of cassava residue ($P<0.01$). Linear response was observed in crude fat digestibility as cassava residue supplementation was increased in diet ($P<0.01$) but fecal nitrogen was decreased linearly ($P<0.05$). When pigs were fed control diet, crude fat digestibility was decreased ($P<0.01$) and the greater amount of fecal nitrogen was observed ($P<0.05$) compared to those of other treatments. However, there was no significant difference in amount of urinary nitrogen among treatments. A nitrogen retention was lowed when pigs were fed control diet compared with that of 5% cassava residue treatment diet ($P<0.05$).

In general, dietary fiber decreased nutrient digestibility on pig according to their properties. Cassava residue generally contains high level of dietary fiber which has almost same ratio of insoluble and soluble fiber. Insoluble fiber induced the increase the digesta passage rate and fecal volume (Spiller et al., 1986). Whereas soluble fiber resulted in the reduction of nutrient absorption caused by the digesta viscosity (Jenkins et

al., 1978). Moreover, soluble fiber interrupted fat emulsification and lypolysis that imply reduction of fat digestibility (Pasquier, 1996). Therefore, physical properties of dietary fiber that influenced digesta transit time and decreased of nutrient digestibility (Knudsen and Hansen, 1991). However, In this experimental results were conflicted with previous reports. These conflicting observations may be explained by different inclusion level of cassava residue or different composition of ingredients in experimental diet were used. Those may contribute to fecal water holding capacity and interaction with other ingredients.

Occurrence of diarrhea

Data for occurrence of diarrhea was presented in Table 6. During the whole experimental period (0 to 6 week), diarrhea incidence had no significant difference among treatments and the average of diarrhea score was 1.86. In phase Ⅰ, pigs fed 5% of cassava residue treatment had the lowest occurrence of diarrhea score ($P<0.01$). Significantly less occurrence of diarrhea was observed not only in pigs fed 10% of cassava residue diet but also in pigs fed 15% of cassava residue diet compared with that in pigs fed 5% cassava residue during 3 to 4 week ($P<0.05$). In phase Ⅲ, the inclusion level of cassava residue in the diets had positive relationship with diarrhea incidence (linear, $P<0.01$).

Cassava has highly digestible starch because it composes of 2 parts of amylose and 8 parts of amylopectin (Bahnassey and Breene, 1994). High level of amylopectin with starch sources is quickly absorbed than high level of amylose sources (Byrnes et al., 1995). It implies that availability of cassava residue is higher than that of other

starch ingredients. Cassava residue supplementation, however, did not improve the results of diarrhea incidence. This result may be explained by low level of dietary fiber with cassava residue level increased.

Fecal micoflora

Table 7. showed the effects of cassava residue supplementation on fecal microflora. In phase Ⅰ and Ⅲ, there were linear response on *Salmonella* counts as dietary cassava residue increased ($P<0.01$ and $P<0.05$, respectively). Significantly less *Salmonella* counts were observed in pigs fed 0% or 5% of cassava residue diet compared with those in pigs fed 10% or 15% of cassava residue diet in phase Ⅰ ($P<0.05$). In phase Ⅰ and Ⅱ, pigs fed increasing cassava residue had decreased *E. coli* counts (linear, $P<0.01$). Like *Salmonella* counts, significantly less *E. coli* counts were observed in 0% and 5% of cassava residue treatments in phase Ⅰ ($P<0.01$). In phase Ⅱ, pigs fed 15% of cassava residue supplementation diet showed the highest *E. coli* counts ($P<0.01$).

With increasing cassava residue level, *Lactobacillus* counts declined in all phases (linear, $P<0.01$). As cassava residue was added at 10% or 15% of the diets, *Lactobacillus* counts were lower than those of 0% or 5% of cassava residue supplementation in both phase Ⅰ and Ⅱ ($P<0.01$). In phase Ⅲ, pigs fed 15% of cassava residue diet showed the lowest *Lactobacillus* counts ($P<0.01$).

These results indicated that increasing level of cassava residue showed negative effects on proliferation of fecal microflora. Cassava residue contains a high level of ash which relates to the cassava processing. After starch extraction, cassava residue could be dehydrated

by sun-drying processing on the soil and concrete floor (Tewe, 1991). It is natural processing method but often resulted in encouraging the growth of harmful bacteria including *Aspergillus flavus* (pathogenic), *A. fumigatu, A. teirenus, A. flarip, A. niger* and *Penicillium rubrum* (Clerk and Caurie 1968; Oke, 1978). Because of bad microbiological properties in cassava residue, harmful microflora contents were increased as dietary cassava residue increased. This observation indicated that cassava residue needs a quicker drying processing to reduce microbial proliferation and toxic HCN as a feedstuff.

Blood analysis

The blood urea nitrogen (BUN), and insulin like growth factor-1 (IGF-1) concentration were presented in Table 8. In phase Ⅱ, pigs fed increasing cassava residue had decreased BUN concentration (linear, $P<0.01$). Pigs fed 15% of cassava residue diet showed lower BUN concentration than that of other treatments' pigs ($P<0.05$). In phase Ⅰ and Ⅲ there were no significant differences among treatments.

Generally, BUN concentration is good indicator for determination of protein and amino acid utilization by pigs (Eggum, 1970). It was well documented that BUN was directly related to protein intake and inversely to protein quality (Hanh et al., 1995). High level of BUN represented that excessive amino acids were metabolized and circulated in the blood during the excretion. In this experiment, result of BUN concentration was continuous with nutrient digestibility in phase Ⅱ. An improvement of N digestibility might affected BUN concentration of pigs fed 15% cassava residue diet.

IGF-1 is secreted by stimulation of growth hormones which related to growth and differentiation of tissue. It is affected by nutritional status of animal. IGF-1 supplies energy for cell growth and have important roles in regulation of structure and function of cardiovascular system and born growth (Bayes-genis, 2000). In phase Ⅱ, pigs fed 15% of cassava residue numerically showed the lowest IGF-1 concentration. Moreover, linear response was observed in IGF-1 concentration as cassava residue supplementation increased in phase Ⅱ ($P<0.05$). When taking into consideration that pigs fed 15% of cassava residue tended to show the lower BW at 4-week, IGF-1 concentration was found to correlate positively with lower BW of pigs.

Conclusion

In conclusion, cassava residue as an alternative feed ingredient could be supplemented at 10% level in weaning pig diet without growth retardation. In growth performance, there was no significant difference in BW, ADG, ADFI and G:F ratio among treatments during the experimental period. Although linear response was observed in ADFI ($P<0.05$) during 5 to 6 week and the whole experimental period, the result of G:F ratio was similar among treatments. Significantly less *Salmonella* counts were observed in pigs fed 0% and 5% of cassava residue diet compared with those in pigs fed 10% and 15% of cassava residue diet in phase Ⅰ ($P<0.05$). In phase Ⅱ, pigs fed 15% of cassava residue supplementation diet showed the highest *E. coli* counts ($P<0.01$). Diarrhea incidence, however, had no significant difference among treatments. Though there was no significant difference in final BW among treatments, pigs fed 15% cassava residue showed numerically lower BW compared to those of other treatments' pigs. The weight gain of experimental animals is the most important criterion to evaluate nutritional value of a certain ingredient. Consequently, cassava residue could be supplemented at 10% level in weaning pig diet without growth check.

Table 1. Formula and chemical compositions of experimental diets (phase Ⅰ, d 0 to 14); as-fed basis[1]

Ingredients	Cassava residue, %			
	0	**5**	**10**	**15**
Ground corn	23.14	18.14	13.14	8.14
Dehulled SBM (48% CP)	39.09	40.40	41.70	43.01
Barley	17.82	15.07	12.33	9.58
Cassava residue	**0.00**	**5.00**	**10.00**	**15.00**
Soy oil	0.04	1.51	2.98	4.45
Whey powder	2.00	2.00	2.00	2.00
Lactose	12.00	12.00	12.00	12.00
HP 300[2]	3.00	3.00	3.00	3.00
Monocalcium phosphate	1.04	1.09	1.13	1.18
Limestone	0.96	0.90	0.84	0.78
L-Lysine·HCl	0.15	0.13	0.11	0.09
DL-methionine	0.12	0.12	0.13	0.13
Vitamin Mix[3]	0.12	0.12	0.12	0.12
Mineral Mix[4]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
ZnO	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[5]				
ME (kcal/kg)	3,265.06	3,265.05	3,265.02	3,265.00
Crude protein (%)	23.70	23.70	23.70	23.70
Total lysine (%)	1.35	1.35	1.35	1.35
Methionine (%)	0.44	0.44	0.44	0.44
Calcium (%)	0.80	0.80	0.80	0.80
Total phosphorus (%)	0.65	0.65	0.65	0.65

[1] Diets contained 0, 5, 10, 15% cassava residue on an as fed basis and were fed *ad libitum* from d 0 to 14 of the experiment.

[2] HP300 (Hamlet protein, Horsens, Denmark).

[3] Provided the following quantities of vitamins per kg of complete diet: vitamin A, 8,000IU; vitamin D_3, 1,600IU; vitamin E, 32IU; d-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4mg.

[4] Provided the following quantities of minerals per kg of complete diet: Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; Cu·SO_4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[5] Calculated value.

Table 2. Formula and chemical compositions of experimental diets (phase Ⅱ, d 14 to 28); as-fed basis[1]

Ingredients	Cassava residue, %			
	0	**5**	**10**	**15**
Ground corn	26.51	21.51	16.51	11.51
Dehulled SBM (48% CP)	34.08	35.38	36.65	37.98
Barley	26.94	24.19	21.46	18.70
Cassava residue	**0.00**	**5.00**	**10.00**	**15.00**
Soy oil	0.91	2.39	3.86	5.33
Whey powder	1.00	1.00	1.00	1.00
Lactose	8.00	8.00	8.00	8.00
Monocalcium phosphate	1.02	1.07	1.11	1.15
Limestone	0.79	0.73	0.68	0.62
L-Lysine·HCl	0.13	0.11	0.10	0.08
DL-methionine	0.08	0.08	0.09	0.09
Vitamin Mix[3]	0.12	0.12	0.12	0.12
Mineral Mix[4]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[5]				
ME (kcal/kg)	3,265.02	3,265.23	3,265.31	3,265.46
Crude protein (%)	21.00	21.00	21.00	21.00
Total lysine (%)	1.15	1.15	1.15	1.15
Methionine (%)	0.37	0.37	0.37	0.37
Calcium (%)	0.75	0.75	0.75	0.75
Total phosphorus (%)	0.63	0.63	0.63	0.63

[1] Diets contained 0, 5, 10, 15% cassava residue on an as fed basis and were fed *ad libitum* from d 14 to 28 of the experiment.

[2] HP300 (Hamlet protein, Horsens, Denmark).

[3] Provided the following quantities of vitamins per kg of complete diet: vitamin A, 8,000IU; vitamin D_3, 1,600IU; vitamin E, 32IU; d-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4mg.

[4] Provided the following quantities of minerals per kg of complete diet: Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; Cu·SO_4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[5] Calculated value.

Table 3. Formula and chemical compositions of experimental diets (phase Ⅲ, d 21 to 42); as-fed basis[1]

Ingredients	Cassava residue, %			
	0	5	10	15
Ground corn	59.58	54.58	49.58	44.58
Dehulled SBM (48% CP)	29.51	30.81	32.11	33.41
Barley	8.22	5.48	2.73	0.00
Cassava residue	0.00	5.00	10.00	15.00
Soy oil	0.19	1.66	3.13	4.60
Monocalcium phosphate	1.00	1.04	1.09	1.13
Limestone	0.72	0.67	0.61	0.55
L-Lysine·HCl	0.18	0.16	0.14	0.12
DL-methionine	0.06	0.06	0.07	0.07
Vitamin Mix[3]	0.12	0.12	0.12	0.12
Mineral Mix[4]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[5]				
ME (kcal/kg)	3,265.27	3,265.06	3,265.07	3,265.17
Crude protein (%)	19.00	19.00	19.00	19.00
Total lysine (%)	1.05	1.05	1.05	1.05
Methionine (%)	0.34	0.34	0.34	0.34
Calcium (%)	0.70	0.70	0.70	0.70
Total phosphorus (%)	0.60	0.60	0.60	0.60

[1] Diets contained 0, 5, 10, 15% cassava residue on an as fed basis and were fed *ad libitum* from d 28 to 42 of the experiment.

[2] HP300 (Hamlet protein, Horsens, Denmark).

[3] Provided the following quantities of vitamins per kg of complete diet: vitamin A, 8,000IU; vitamin D_3, 1,600IU; vitamin E, 32IU; d-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4mg.

[4] Provided the following quantities of minerals per kg of complete diet: Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; Cu·SO_4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[5] Calculated value.

Table 4. Effects of cassava residue supplementation on growth performance in weaning pigs[1,2]

Items	Cassava residue, %				SEM[3]	*P-value*
	0	5	10	15		
Body weight, kg						
Initial	8.00	7.97	7.97	8.00	-	-
2 week	11.04	11.47	11.02	10.95	0.201	0.421
4 week	18.14	18.08	17.50	16.99	0.286	0.307
6 week	25.72	24.82	24.98	24.01	0.403	0.412
Average daily gain, g						
0~2 wk	218	251	218	211	8.5	0.373
3~4 wk[d]	507	472	463	432	10.9	0.124
5~6 wk	541	482	534	501	14.7	0.507
0~6 wk	422	401	405	381	8.2	0.416
Average daily feed intake, g						
0~2 wk[e]	351	383	363	330	8.4	0.055
3~4 wk	808	769	789	714	13.9	0.135
5~6 wk[d]	1,112	1,035	1,029	984	21.5	0.192
0~6 wk[d]	757	729	727	676	13.1	0.174
Gain:feed ratio						
0~2 wk	0.623	0.655	0.606	0.628	0.0177	0.775
3~4 wk	0.629	0.616	0.586	0.603	0.0099	0.503
5~6 wk	0.490	0.464	0.520	0.512	0.0126	0.496
0~6 wk	0.560	0.552	0.558	0.563	0.0085	0.974

[1] A total of 128 crossbred pigs was fed from average initial body weight 7.98 ± 0.83 kg and the average of final body weight was 24.88 ± 3.72 kg.
[2] Least squares means for eight pens/treatment with four pigs/pen.
[3] Standard error of the means.
[d] Linear supplementation response (P<0.05).
[e] Quadratic supplementation response (P<0.05).

Table 5. Effect of cassava residue supplementation on nutrient digestibility in weaning pigs[1]

Items	Cassava residue, %				SEM[2]	*P-value*
	0	5	10	15		
Nutrient digestibility (%)						
Dry matter	87.25	86.26	87.24	86.69	0.297	0.682
Crude protein[D]	83.17[B]	82.77[B]	85.01[A]	86.24[A]	0.465	0.004
Crude ash	53.71	48.17	59.36	58.74	2.093	0.287
Crude fat[D]	66.67[B]	76.20[A]	82.97[A]	82.60[A]	2.110	0.008
Nitrogen retention (g/d)						
N intake	6.01	6.12	6.07	6.04	-	-
Fecal N[d,e]	1.01[a]	0.95[b]	0.94[b]	0.96[b]	0.009	0.035
Urinary N	1.60	1.48	1.61	1.58	0.031	0.532
N retention[3,e]	3.41[b]	3.69[a]	3.52[ab]	3.50[ab]	0.036	0.049

[1] Least squares means for six pigs/treatment in an individual pen.
[2] Standard error of the means.
[3] N retention = N intake (g) - Fecal N (g) - Urinary N (g).
[A,B] Means with different superscripts within the same row significantly differ (P<0.01).
[a,b] Means with different superscripts within the same row significantly differ (P<0.05).
[D] Linear supplementation response (P<0.01).
[d] Linear supplementation response (P<0.05).
[e] Quadratic supplementation response (P<0.05).

Table 6. Effects of cassava residue supplementation on occurrence of diarrhea in weaning pigs[1]

Items	Cassava residue, %				SEM[2]	*P-value*
	0	5	10	15		
Diarrhea score[3]						
0-2 wk	2.81^{AB}	2.55^{C}	2.84^{A}	2.66^{BC}	0.073	0.007
3-4 wk	1.95^{ab}	2.10^{a}	1.82^{b}	1.88^{b}	0.100	0.010
5-6 wk[D]	0.78^{B}	1.01^{A}	0.79^{B}	1.06^{A}	0.056	<.0001
0-6 wk	1.82	1.87	1.79	1.85	0.073	0.490

[1] A total of 128 crossbred pigs was fed from average initial body weight 7.98 ± 0.83 kg and the average of final body weight was 24.88 ± 3.72 kg.
[2] Standard error of the means.
[3] 0 (healthy : no pigs with diarrhea) ~ 4 (severe : all pigs with diarrhea).
[A,B,C] Means with different superscripts within the same row significantly differ (P<0.01).
[a,b] Means with different superscripts within the same row significantly differ (P<0.05).
[D] Linear supplementation response (P<0.01).

Table 7. Effects of cassava residue supplementation on fecal microflora in weaning pigs[1]

Items	Cassava residue, %				SEM[2]	*P-value*
	0	5	10	15		
Salmonella **(cfu/ml)**						
Initial	4.91	4.91	4.91	4.91	-	-
2 week[D]	3.91[b]	4.14[b]	5.29[a]	5.07[a]	0.190	0.014
4 week	4.00	4.01	4.50	4.25	0.113	0.444
6 week[d]	2.95	3.22	3.58	4.07	0.161	0.110
E. coli **(cfu/ml)**						
Initial	4.64	4.64	4.64	4.64	-	-
2 week[D,E]	4.28[C]	4.60[C]	5.91[A]	5.14[B]	0.191	0.001
4 week[D]	3.85[B]	4.17[B]	4.47[B]	5.85[A]	0.248	0.006
6 week	3.85	4.01	4.15	4.15	0.167	0.795
Lactobacillus **(cfu/ml)**						
Initial	9.10	9.10	9.10	9.10	-	-
2 week[D]	8.23[A]	8.06[A]	6.56[B]	6.93[B]	0.227	0.004
4 week[D,e]	8.10[A]	8.11[A]	6.37[C]	6.87[B]	0.203	0.001
6 week[D]	8.04[A]	7.48[B]	7.13[BC]	6.77[C]	0.142	0.001

[1] Least squares means for six pigs/treatment.

[2] Standard error of the means.

[A,B,C] Means with different superscripts within the same row significantly differ (P<0.01).

[a,b] Means with different superscripts within the same row significantly differ (P<0.05).

[D] Linear supplementation response (P<0.01).

[d] Linear supplementation response (P<0.05).

[E] Quadratic supplementation response (P<0.01).

[e] Quadratic supplementation response (P<0.05).

Table 8. Effect of cassava residue supplementation on blood profiles in weaning pigs[1]

Items	Cassava residue, %				SEM[2]	*P-value*
	0	5	10	15		
Blood urea nitrogen, mg/dl						
Initial	9.40	9.40	9.40	9.40	-	-
2 week	15.32	15.46	16.08	14.24	0.873	0.926
4 week[C]	17.42[a]	16.58[a]	15.96[a]	10.72[b]	0.949	0.026
6 week	13.06	13.60	12.14	11.82	0.347	0.287
Insulin-like growth factor-1, ng/ml						
Initial	60.00	60.00	60.00	60.00	-	-
2 week	105.28	102.14	74.58	94.48	8.626	0.645
4 week[c]	141.60	120.28	115.10	77.60	9.800	0.118
6 week	115.10	108.48	118.22	108.84	5.254	0.897

[1] Least squares means for six pigs/treatment.

[2] Standard error of the means.

[a,b] Least squares means in the same row with different superscripts differ ($P<0.05$).

[C] Linear supplementation response ($P<0.01$).

[c] Linear supplementation response ($P<0.05$).

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Ⅴ. Summary in Korean

본 실험은 이유 자돈 사료 내 카사바 부산물의 첨가가 이유 자돈의 성장 능력, 소화율, 설사 빈도 및 분내 미생물에 미치는 영향을 조사하였다. 총 128두의 28일령 이유자돈 ([Yorkshire × Landrace]×Duroc)을 4처리 8반복 돈방 당 4두씩 공시하였다. 실험돈은 체중과 성별에 따라 난괴법 (Randomized Complete Block (RCB) Design)으로 배치하였다. 처리구는 1) Control (옥수수-대두박 기초사료), 2) C 5 (기초사료 내 옥수수 5%를 카사바 부산물로 대체), 3) C 10 (기초사료 내 옥수수 10%를 카사바 부산물로 대체, 4) C 15 (기초사료 내 옥수수 15%를 카사바 부산물로 대체)로 설정하였다. 실험사료의 급여는 총 6주 동안 2주씩 세 구간 (phase Ⅰ(0-2주), phase Ⅱ(2-4주), phase Ⅲ (4-6주))으로 나누어 급여하였다.

총 6주간의 사양실험 결과에서는 처리구 간에 체중, 일당증체량, 일당사료섭취량 및 사료효율에서 유의적인 차이가 발견되지 않았다. 하지만 3-4주 기간의 일당증체량은 카사바 부산물의 첨가수준에 따라 감소하였다 (linear, $P<0.05$). 일당사료섭취량은 5-6주 기간과 전체 사양 실험 기간 동안 카사바 부산물의 첨가수준에 따라 감소하였다 (linear, $P<0.05$). 영양소 소화율에서는 카사바 부산물의 첨가수준에 따라 조단백질과 조지방의 소화율이 증가하였다 (linear, $P<0.01$). 설사빈도는 0-2주 기간에 카사바 부산물을 5% 첨가한 처리구가 대조구보다 낮은 수치를 보였다 ($P<0.01$). 0-2주 기간의 유해 미생물 분석에서 *E. coli*와 *Salmonella* 수치는 카사바 부산물을 10%이상 첨가한 처리구가 5%를 첨가한 처리구보다 높게 나왔다 ($P<0.01$, $P<0.05$). 혈액분석 결과에서는 3-4주 기간의 유사 인슐린 성장인자-1이 카사바 부산물의 첨가수준에 따라 감소하였다 (linear, $P<0.05$). 본 실험의 결

과를 종합해 본 결과, 카사바 부산물의 자돈 사료 내 적정 첨가수준은 10%인 것으로 생각된다.

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