A Thesis
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Different Levels of Palm Kernel Meal Supplementation with ß-mannanase on Growth Performance, Blood Profiles, Pork Quality and Economic Analysis in Growing-finishing Pigs

ß-mannanase를 첨가한 팜박의 수준별 급여가 육성 비육돈의 성장, 혈액 성상, 돈육 품질, 경제성 분석에 미치는 영향

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Summary

International price of swine feed ingredients such as corn and soybean meal (SBM) have increased because of the soaring oil price and increasing bio-fuel (ethanol and bio-diesel) production. Therefore, the importance of agricultural by-products as feed ingredients for swine has grown up due to increasing in the cost of traditional feedstuff. Therefore, present study was conducted to evaluate different levels of palm kernel meal (PKM) supplementation with β-mannanase on growth performance, blood profiles, pork quality and economical analysis in growing-finishing pigs. A total of 120 growing pigs ([Yorkshire × Landrace] × Duroc), average 30.50 ± 3.039 kg body weight, were used in growth trial. Pigs were allotted into each treatment by body weight and sex in 4 replicates with 6 pigs per pen in randomized complete block (RCB) design. Dietary treatments were 5 different levels of palm kernel meal (0, 4, 8, 12 or 16%) in experimental diet. In feeding trial, there was no significant difference in growth performance among the treatments. However, ADFI was increased (linear, $P<0.05$) when pigs were fed high PKM diet during the whole experimental period. In BUN concentration, no differences was observed among treatments. The pork pH and proximate analysis of longissimus muscle (LM) were not affected by dietary treatments. In pork color, a* and b* values were not significant differences among dietary treatments. However, L* value was decreased as PKM level increased. In addition, significant differences were not observed on shear force and water holding capacity (WHC) by dietary PKM with β-mannnanase. Cooking loss was linearly lowered when PKM level increased ($P<0.05$). Interestingly, TBARS value tended to decrease when pigs were fed high PKM treatment diets. This result may be explained by chemical characteristics of PKM due to the fact that PKM contained polysaturated fatty acids rather than polyunsaturated ones although it is plant source. When pigs were fed diets containing PKM with β-mannanase, days to 110kg market weight was reached earlier compared to basal diet and feed cost was also decreased by PKM treatments.

This experiment demonstrated that supplementation PKM with β-mannanase did not show negative responses on carcass characteristic as well as growth performance. And economical profit by PKM treatments was improved because days to market weight and estimated feed cost to market weight were reduced. Consequently PKM can be supplemented up to 16% in growing-finishing pig without detrimental effects on growth and pork quality.

Key words : Palm kernel meal, Mannanase, Growing·finishing pig, Growth performance, Carcass characteristics

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List of Abbreviation

ADG	Average daily gain
ADF	acid detergent fiber
ADFI	Average daily feed intake
BUN	Blood urea nitrogen
BW	Body weight
G:F	Gain to feed
LM	longissimus muscles
NDF	neutral detergent fiber
NSP	non-starch polysaccharide
PKM	Palm kernel meal
SBM	Soybean meal
SFA	Saturated fatty acid
TBARS	2-thiobarbituric acid reactive substances
USFA	Unsaturated fatty acid
WHC	Water holding capacity

I. Introduction

Korean swine industry has been struggled with external situation such as Korea − EU, China, and U.S FTA (Free trade agreement) and incidence of various disease such as FMD (Foot and mouth disease), and PRRS (porcine reproductive and respiratory syndrome). Furthermore, the increasing the bio-fuel demand to produce ethanol caused the high price of corn and soybean meal (SBM). Corn and SBM are the major ingredients in swine diet. In this situation, searching alternative feed resources, instead of conventional ingredients such as corn or SBM, will be the most effective way to enhance the competitiveness in Korea hog industry by reducing feed cost.

Among the alternative feed ingredients, PKM has received a great attention because of their relatively comparable nutritional values and low price compared to corn and SBM. Although PKM is one of useful alternative ingredients in swine feeds because of its extensive availability, adequate nutrients, comparable price and large amount of production, it was not widely used in swine diet of Korea due to color and high contents of anti-nutritional factor, mannan (Sundu and Dingle, 2003; Jang, 2012). It contains a high concentration of non-starch polysaccharide (NSP) and a certain amount of mannan, and therefore, it has been used restrictively for monogastric animals. The NSP has been considered as an ‘anti-nutritional’ factor due to their negative influence on digestion and absorption of nutrients such as starch and protein in the gastrointestinal tract of monogastric animals. Mannan has several negative physiological effects because of its poor digestibility when it is in pig diets. Feeding palm kernel products in swine diets has been studied, but optimum PKM supplementation level in growing-finishing pigs has been varied (Babatunde et al., 1975; Rhule, 1996; O'Doherty and McKeon, 2000). In particular, Rainbird (1984) reported mannan in swine diet decreased the proportion of glucose absorption in the intestine, and then carbohydrate metabolism interrupted with insulin-like growth factor production and insulin secretion (Nune and Malmlof, 1992).

Many studies reported that addition of β-mannanase supplementation to swine diet could break down mannan in PKM and subsequently avaliable carbohydrates would increase, resulted in enhancing growth performance and feed efficiency (Jackson et al., 1999). β-mannanase is one of the carbohydrase that hydrolyze β-1,4 glycosidic linkage of mannan, and it could improve the availability of PKM (Hong, 2009; Kim, 2011). The supplementation of PKM up to 10% with β-mannanase would be used in growing-finishing diets without any negative effects on growth performance (Lee, 2010).

This experiment was conducted to investigate the effects of different levels of PKM supplementation with β-mannanase on growth performance, blood profiles, pork quality and economical analysis in growing-finishing pigs.

II. Literature Review

1. Introduction

1.1 Unstable price of major feed ingredients

Corn and SBM are one of the main feed ingredients for swine feed. Prices for major feed ingredients such as corn and SBM in world market have sharply risen up and unstable for a few years (Figure 1). There are many factor have attributed to the run-up in feed ingredient prices.

1) There is a increasing demand of feed ingredients for livestock production in rapid developing countries. In addition, due to the unbalance between production and demand, it causes the increase of feed cost.
2) Bio-fuel such as ethanol has been produced globally to supply fuel for replacing fossil fuel resources. The united states, EU and other developed countries subsidize farmers to grow cops for biofuel to complement the high international oil price (Mohammad shahidul islam, isas insights, 2008).

Thereby, biofuel production also cause agflation and increase even higher prices for world grain commodities. Recent factors that have further tightened world markets include increased global demand for bio-fuels and animal feed-stuffs for developed countries such as China, Vietnam and India.

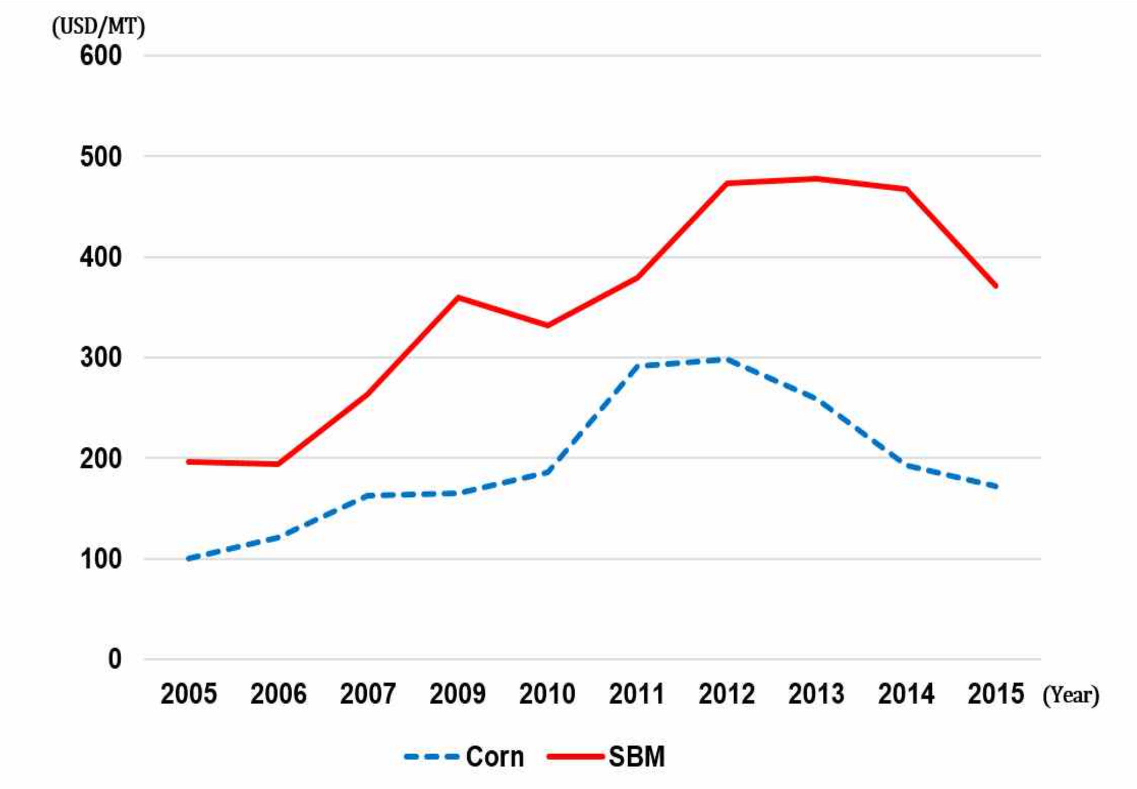

Figure 1. Corn and SBM prices in United state (USDA, 2015)

1.2 Situation of korean swine industry

Korean swine industry has been struggled with external situation such as Korea − EU (European Union), China, U.S (United States) FTA (Free trade agreement) and incidence of disease such as FMD (Foot and mouth disease), and PRRS (Porcine reproductive and respiratory syndrome). With those troubling situations, international grains market also has been very unstable. In particular, alternative feed ingredients are suited for Korean swine industry, because feed cost have the largest portion of production cost of growing-finishing pig and supply of feedstuff depend on import from foreign countries. Table 1 showed component ratio of hog production cost per 100kg live weight for few years.

Therefore, these conditions will be and have been affected to swine industry in korea.

Table 1. Component ratio of hog production cost per 100kg live weight (%).

	2008	2009	2010	2011	2012	2013
Feed	53.6	54.9	53.3	50	52.6	55.5
Live stock	27.1	26.2	26.3	28.3	26.7	23.4
Labor	2.5	2.4	3	2.7	3.2	2.8
Medicine	2.8	2.6	3.1	3.2	2.7	2.6
Excretion disposal	2	1.7	2	1.9	1.8	2.1
Depreciation	2.7	2.9	2.7	2.4	1.1	1.5
Etc	9.3	9.3	9.6	11.5	11.9	12.1

(STATISTICS KOREA)

2. Alternative Feed Ingredients

In Corn and SBM, they are commonly used for pork industry, but the price of these ingredients is unstable and higher than others. Then, feed costs plays a primary role in determining the profit of a swine farm. Because of this, various alternative feed ingredients which are tapioca, barely, wheat, PKM, copra meal and DDGS are used and studied feeding values as ingredients for swine feed. When using those ingredients in monogastric animals, it could have strengths and weaknesses aspects. Therefore, pros and cons about using alternative ingredients must be taken into consideration.

2.1 Qualification of alternative feed ingredients

The qualification of alternative feed ingredients are contents determined based on the cost, nutrient availability, quality of protein, amino acid profile, palatability, presence of anti-nutritional factors, and storage life. A detailed explanation is followed.

1) Cost is one of the most forceful factors to determine when concerning the use of alternative feeds ingredients.

2) Energy or nutrient contents and digestibility are a key issue for evaluation feeding value of the availability in energy and nutrients as a feed ingredient.

3) Palatability is the term used to describe the extent to which a pig likes to eat a feed ingredient or ration. In particular, pig have more taste buds than humans.

4) Anti-nutritional factors are most influential ones in a feed ingredient that interfere with nutrient digestibility and utilization. Alternative feed ingredients commonly contain high level of NSP, that is a limiting factor for their effective use for monogastric animal diets.

Thus, it is restricted to use these ingredients in monogastric animals because of its low nutrient digestibility, poor palatability and anti-nutritional factors.

2.2 Types of alternative ingredients

There are many suitable alternatives that fill up with nutritional requirements while reducing the cost of the diet.

1) Copra meal

Copra meal or coconut meal is produced from the ripe fruit of the coconut palm *(Cocos nucifera)* in tropical area. It contains approximately 60%

carbohydrate, 15 to 25% of protein, low levels of lysine and methionine (Lachance and Moliana, 1974; Sundu et al., 2009). There are two type of oil extraction process, one is solvent-extracted and the other is expeller pressed. Solvent-extracted is more effective method for protein content than expeller pressed coconut meal (Throne et al., 1989). When the copra meal was used as swine feeds, there was limit to use copra meal in monogastric animal, because they do not degrade NSPs, have high fiber and low palatability. The NSPs in copra are mostly composed of galactomannan (61%), mannan (26%) and cellulose (13%). Although it is hard to digest nutrient in the feed, recent research reported that supplementation of mannanse in copra meal diet could increase a growth performance (Hong et al. 2009; Kim et al. 2011).

2) Rapeseed meal

Rapeseed meal (RSM) is by-product after rapeseed is processed and the oil removed that can be used as feed for livestock. Rutkowski (1971) demonstrated that RSM is not common as a protein source for livestock, and it is used mostly in ruminant feeding. Even though RSM contains approximately 35 to 40% of protein (Mawson et al., 1993) and balanced amino acids (Sarwar et al., 1975; NRC, 1998), it is hard to use for swine diet, because of anti-nutritional factors such as glucosinolates and erucic acid (Mawson et al., 1993). Previous studies reported supplementation of RSM in swine diet has a cost effectiveness (Canola council of Cananda, 2014; The solvent extractor’s association of India, 2014; Choi et al., 2014)

3) Palm kernel meal

Palm kerenel meal (PKM) is a by-product of oil extraction of oil palm

(Elaeis guineensis Jacq.). It is main co-product of the palm kernel oil extraction process. Pickard (2005) reported PKM is a highly fibrous and medium grade protein feed. Hence, most of it is suited for ruminant or rabbit feeding. FAO (2012) notified the most of the PKM production goes to animal feeding.

PKM generally contain 17 to 21% protein, 10 to 17% crude fibre, 4 to 5 % ash and 0.7 to 0.9% of ether extract depending on the efficiency of oil extraction from the kernel (Nwokolo et al., 1976). It has comparable energy level (ME), protein with corn and SBM and aflatoxin free. However, it is high fiber, gritty and lowly palatable but rich in methionine and cystine while being deficient in lysine.

Supplementation of PKM in pig diets tend to decrease growth performance, which can be attributed to the high NSP content, to the low palatability of the meal and to its low amino acids and energy digestibilities (Kim et al., 2001). But, adding β-mannnanase in PKM diet can be improved the availability and growth rate in pig. (Kim et al., 2011). Futhermore, Gohl (1982) studied that PKM tends to produce firm pork of good quality.

3. Palm Kernel Meal

3.1. Trend of palm kernel meal

Palm kernel products are by-products from the kernels of the oil palm fruit *(Elaeis guineensis)* and are after the fruits have been deoiled. There are three-methods of extraction of palm kernel products, those are mechanical pressing, solvent extraction, and combination of 2 methods to extract oil.

PKM generally refers to the product obtained after solvent extraction of palm oil from the oil palm, whereas palm kernel expellers by mechanical extraction. Solvent extraction is more efficient than mechanical pressing in removing oil from the palm kernels. Indonesia is the world's largest producer of PKM (Figure 3) and annual growth rate of 7.07%.

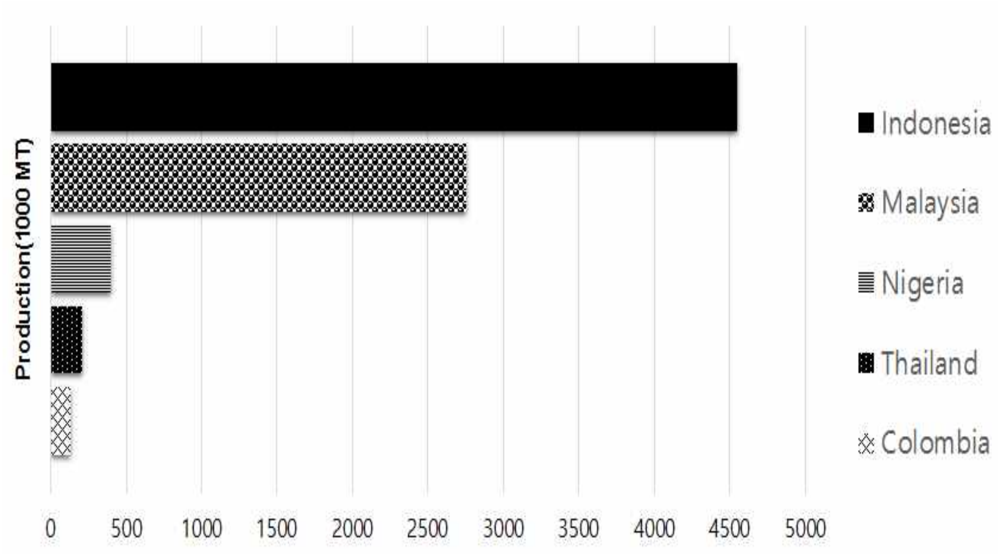

Figure 3. Palm kernel meal production by country in 1000MT (USDA, 2014)

PKM are found in large quantities in a number of tropical countries and are available at competitive prices (Table 3). While corn is the dominant grain source for pigs in most region in the U.S., PKM's low price and comparable protein concentration can make it more attractive than corn and SBM, particularly in PKM-producing areas or in areas where corn in scarce. Korea is the world's third biggest PKM importer and imports also increasing every year (Figure 4).

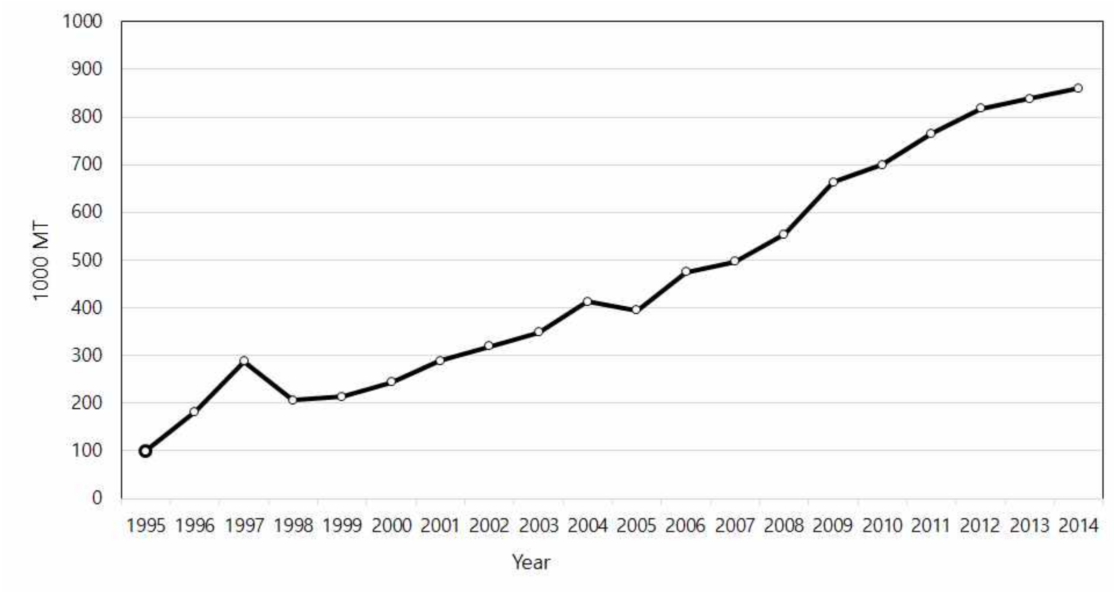

Figure 4. Korea of Palm Kernel meal imports by year. (USDA, 2014)

Table 2. The price of some protein supplements. (USD/MT) (KFIA, 2015)

Item	Country of origin	2014				2015				
		3	6	9	12	1	2	3	4	5
PKM	Indonesia	195	193	182	129	120	121	182	123	117
	Malaysia	195	200	180	143	144	132	124	126	127
CM	Philippine	282	255	238	186	178	180	182	184	198
	Indonesia	282	262	238	206	179	179	175	188	198
SBM	Brazil	539	549	553	527	539	497	458	452	458

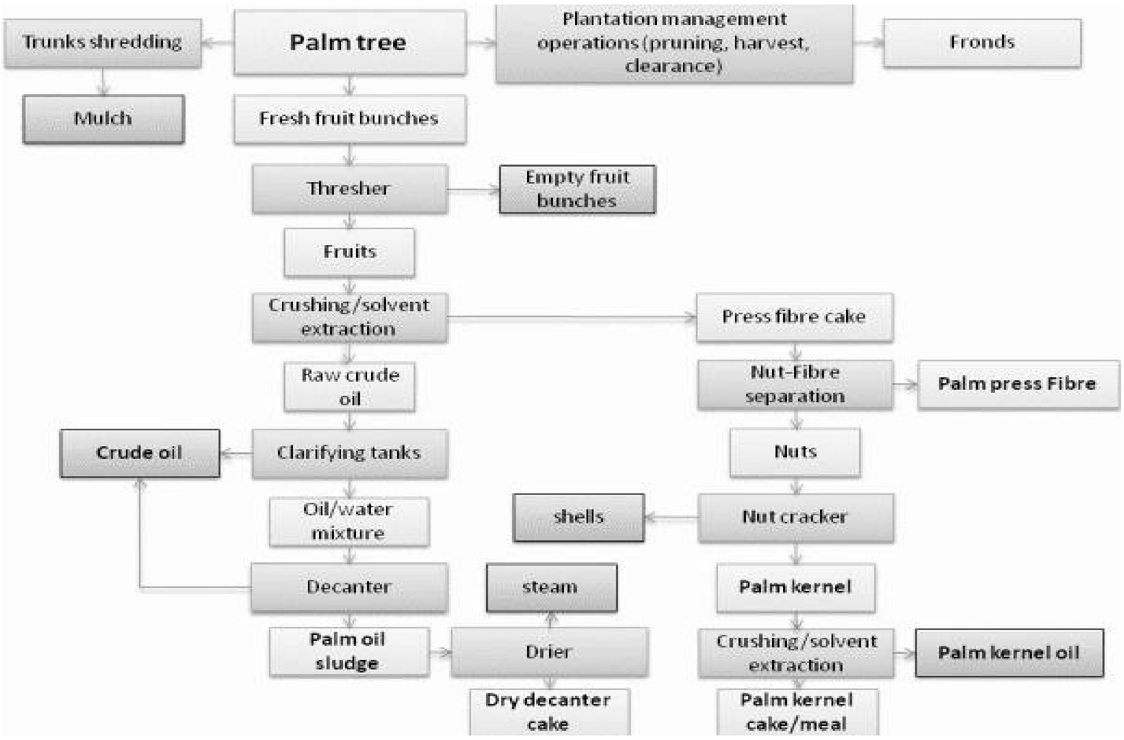

Figure 5. Flow chart for PKM processing (Valérie Heuzé / AFZ)

3.2. Nutrients in PKM

PKM contains greater concentrations of acid detergent fiber (ADF) and neutral detergent fiber (NDF) than others. PKM also has higher contentof crude protein than corn and lower concentration of crude protein than SBM and CM (Table 2).

PKM has lower concentration of digestible (DE), metabolizable (ME), and net (NE) energy, compared with others (Table 4). PKM contains 73 to 75 % of the energy component to corn when fed to pigs. The presence of variable amounts of non-starch polysaccharide (NSP) in PKM may be responsible for the lower concentration of energy in PKM than in corn. Nwokolo et al. (1976) reported that PKM has 8-10% oil and 17 to 21% crude protein, 10 to 17% crude fibre, 4 to 5% ash and 0.7 to 0.9% of ether extract depending on the efficiency of oil extraction from the kernel and is evaluated a safe protein source for animal feed especially ruminants and rabbits. Apart from PKM are free from aflatoxin B1, there are varying in its nutrient content, depending upon the oil extraction process, the species of the palm nut and the amount of shell content remaining in the meal (O'Mara et al., 1999)

Table 3. Nutrient composition of ingredients in pig feed.

Item, %	Corn	SBM	PKM	CM
Dry matter	86.3	89	92.6	92
Crude protein	8.01	43.8	16.9	21.9
Ether extract	3.78	1.5	6.74	3
NDF	8.68	13.3	68.3	51.3
ADF	2.41	9.4	37.8	25.5

(NRC 2012, Sauvant et al., 2004)

Table 4. Digestible energy and ME in PKM, CM , Corn and SBM. (Sulabo et al., 2013)

	Ingredient			
Item	**PKM**	**CM**	**Corn**	**SBM**
As-fed basis				
DE, kcal/kg	2,669	3,430	3,579	3,753
ME, kcal/kg	2,542	3,248	3,488	3,566
DM basis				
DE, kcal/kg	2,905	3,692	4,021	4,275
ME, kcal/kg	2,766	3,496	3,919	4,062

Table 5. Analyzed amino acid composition of ingredients (as-fed basis)

Item	Ingredient[1] PKM	CM	SBM
Indispensanle AA, %			
Arg	1.36	2.08	3.34
His	0.17	0.35	1.16
Ile	0.41	0.66	2.15
Leu	0.71	1.2	3.51
Lys	0.36	0.42	2.91
Met	0.22	0.217	0.66
Phe	0.47	0.79	2.3
Thr	0.33	0.55	1.73
Trp	0.05	0.15	0.62
Val	0.57	0.97	2.27
Dispensable AA, %			
Ala	0.46	0.85	2.02
Asp	0.89	1.5	5.22
Cys	0.17	0.28	0.66
Glu	2.02	3.34	8.02
Gly	0.53	0.82	1.92
Pro	0.36	0.6	2.6
Ser	0.44	0.71	2.01
Tyr	0.29	0.41	1.63

[1]PKM=Palm kernel meal ; CM = Copra meal ; SBM = Soy bean meal

(Sulabo et al., 2013)

3.3. Performance of pigs fed PKM

PKM has been widely used in ruminant diet (Moss and Givens, 1994; Umunna et al., 1994; Chandrasekariah et al., 2001) and rabbit diets (Aduka et al 1988).

PKM is generally considered to be an energy and protein source, because it supplies both of them (Boateng et al., 2008). When feed to swine, it could replace corn and SBM. The inclusion of PKM in swine diet has been studied for a long period, but the results have been variable. Especially, optimum inclusion level is uncertain, it considered high fiber content and due to the maillard reactions occurring during processing, energy digestibility of PKM is lower than 50%, resulting in the ME content for growing pigs being very low (7.8 MJ/kg DM vs. 16 MJ/kg DM for the maize grain). For weaning piglets and lactating sows, in which energy intake is the main limiting factor for optimal performance, the inclusion of PKM is not recommended because of its low palatability and its high dietary fibre content. However, high levels of PKM (30-40%) can be fed without negative effects on reproductive performance in pregnant sow. Kim et al. (2001) studied the use of PKM to replace SBM decreased growth performance. With no detrimental effect on carcass characteristics. When application of an enzyme was supplied to PKM diet, it could improve the energy value. Ao et al. (2011) demonstrated energy value can be improved by the application of an enzyme complex to the diet that facilitates the breakdown of non-starch polysaccharide in finishing pigs. Park (2010) concluded that PKM supplementation showed decreased of ADG and G:F ratio in early finishing period compared with corn-SBM based diet. Lee (2010) reported the inclusion of PKM up to 10% with 0.1% β-mannanase could be used without any detrimental effects on growth performance in growing-finishing diets.

Thus, performance of pigs fed PKM with β-mannanase diets is expected to be similar to that of pigs fed corn-based diets. PKM can replace corn or SBM in dites for growing finishing pig could be replaced PKM up to 5% (Park, 2010), and β-mannanse supplementation could increased inclusion level of PKM in swine diet (Lee, 2010).

3.4. Consideration in use of PKM as feedstuff

Some properties of PKM were a limitation in swine diet. Those are high content of fiber, low palatability, and lack of essential amino acids as well as a presence anti-nutritional properties such as mannan, galactomannan, xylan and arabinoxylan (Sundu and Dingle, 2003; Lee, 2010; Jang et al., 2012).

PKM has mannan and galactomannan, known as anti-nutritional factors in monogastric animal which has no endogenous enzymes to degrade these NSPs. The NSPs in PKM consisted of 78% pure mannan, 3% arabinoxylans and 3% glucoronoxylans. The β-mannan contents in PKM is 30~35% of DM (Sundu and Dingle, 2003). Kim et al. (2001) studied the inclusion of PKM in pig diets tends to decrease growth performance, which can be attributed to the high non-starch polysaccharides content, to the low palatability of the meal and to its low amino acids and energy digestibilities. PKM had the variation of nutrients, derived from different region, extraction methods and there by lipid contents. Many research was studied about PKM. The gross energy (GE) varied from 4,600 to 5,000 kcal/kg in PKM. Carbohydrate and lipid contents were 48% and 5 to 8% in PKM, respectively (Pickard, 2005; Boateng et al., 2008; Amaefule et al., 2009; Sundu et al., 2009). Crude protein contents are also varied in 15 to 19% of PKM, and lack in several essential amino acids. PKM had highly in dietary fiber. Dietary fiber which defined as “the plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzymes” (Jenkins, 1976). In general, dietary fiber can not digest in small intestine but, can digest prominently in the large intestine. When supplementation NSPs in swine diet, commensal microbes which presented in the cecum and colon led to produce short chain fatty acids, metabolites, gases and microbial biomass. Manipulating of NSP in PKM is helpful to use PKM for animal feeds.

Ⅲ. Different Levels of Palm Kernel Meal Supplementation with ß-mannanase on Growth Performance, Blood Profiles, Pork Quality and Economic Analysis in Growing-finishing Pigs

Abstract: This experiment was conducted to evaluate different levels of palm kernel meal with ß-mannanase supplementation on growth performance, blood profiles, pork quality and economic analysis in growing-finishing pigs. A total of 120 growing pigs ([Yorkshire × Landrace] × Duroc), average 30.50 ± 3.039 kg body weight were used in feeding trial. Pigs were allotted into each treatment by body weight and sex in 4 replicates with 6 pigs per pen in randomized complete block (RCB) design. The treatments were different levels of palm kernel meal (0, 4, 8, 12 or 16%) in experimental diet. In feeding trial, there were no significant differences in growth performance and BUN concentration among dietary treatments. However, ADFI was increased linearly when pigs were fed high PKM diet during the whole experimental period (P<0.05). The pork pH and proximate analysis of longissimus muscle were not affected by dietary treatments. In pork color, a* and b* values, were not significantly different among dietary treatments.

However, L* value was decreased as PKM level increased. In addition, significant differences were not observed on shear force and water holding capacity (WHC) by dietary PKM with β-mannnanase supplementation. Cooking loss was linearly higher when PKM level increased ($P<0.05$). In fatty acid composition, C16:0, SFA were increased and USFA, USFA/SFA ratio were linearly decreased as pigs were fed higher PKM treatment diets ($P<0.05$). The value of TBARS tended to decrease when pigs were fed high PKM treatment diets. When pigs were fed diets containing PKM with β -mannanase, days to market weight was reached earlier compared to control diet and cost of feed per weight gain was also decreased by PKM treatments. This experiment demonstrated that supplementation of PKM with β -mannanase did not show negative responses on carcass characteristic as well as growth performance. Also, PKM treatment improved the economical profit by days to market weight and feed cost. Consequently PKM can be included up to 16% in diet for growing-finishing pig without detrimental effects on growth performance and pork quality.

Keywords : Palm kernel meal, β-mannanase, Growing·finishing pig,
Growth performance, Carcass characteristics

Introduction

International price of swine feed ingredients such as corn and soybean meal (SBM) has increased due to increasing bio-fuel (ethanol and bio-diesel) production. Therefore, the importance of agricultural by-products as feed ingredients for swine has grown up because of increasing in the cost of traditional feedstuff (Wachenheim et al., 2006).

Palm kernel meal (PKM) is one of the most useful alternative ingredients in swine feeds because of its extensive availability, adequate nutrients, comparable price and large amount of production (Onifade and Babatunde, 1998; Perez et al., 2000; Sundu et al., 2006; Sumathi et al., 2008). As an feed ingredient, PKM has been examined widely for diverse monogastric animals including swine, poultry, and rabbits (Onifade and Babatunde, 1998; Perez et al., 2000; Okoye et al., 2006; Fatufe et al., 2007). However, PKM has some limitation for supplying to swine such as a low palatability, high content of fiber, and lack of essential amino acids as well as anti-nutritional properties (Sundu and Dingle, 2003; Jang, 2012). In particular, Rainbird (1984) reported mannan in swine diet decreased in proportion of glucose absorption in the intestine, then carbohydrate metabolism interrupted with insulin-like growth factor production and insulin secretion (Nune and Malmlof, 1992). Providing of PKM in swine diets has been studied, but optimum PKM supplementation level in growing-finishing pigs have been variable (Babatunde et al., 1975; O'Doherty and McKeon, 2000).

Many studies reported that addition of mannanase into diet could enhance the growth performance and feed efficiency of pigs (Dingle, 1997;

Jackson et al., 1999). It is well known that β-mannanase is one of the carbohydrase that hydrolyze β-1,4 glycosidic linkage of mannan, and it could improve the availability of PKM (Hong, 2009; Kim, 2011). The supplementation of PKM up to 10% with β-mannanase would be used without any negative effect on growth performance in growing-finishing pigs (Lee, 2009).

Therefore, the present study was conducted to evaluate different levels of PKM supplementation with β-mannanase on growth performance, blood profiles, pork quality and economical analysis in growing-finishing pigs.

Materials and Methods

Experimental design and diet

A total of 120 crossbred pigs ([Yorkshire × Landrace] × Duroc), with an average body weight of 30.50 ± 3.039 kg, were used in experiment at Seoul National University experimental farm in Muan-gun, Jeollanam-do. Pigs were allotted into each treatment by body weight and sex in 4 replicates with 6 pigs per pen in a randomized complete block (RCB) design. The treatments were different levels of PKM (0, 4, 8, 12 or 16%) in each treatment diet. Experimental diet were formulated for 4 phases, including early growing (0~3 weeks), late growing (4~6 weeks), early finishing (7~9 weeks) and late finishing period (10~12 weeks), respectively. All nutrients were met or exceeded the requirement of NRC (1998). The formula and chemical compositions of experimental diets were presented in Tables 1, 2, 3 and 4.

Animal management and measurement

Pigs were reared in growing-finishing facilities for 12 weeks. Animals were fed diet and water *ad libitum* during the whole experimental period. Body weight and feed consumption were recorded at 0, 3, 6, 9 and 12 weeks to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F ratio).

Blood sampling

Blood samples were taken from anterior vena cava of 6 pigs per treatment for measuring blood urea nitrogen (BUN) after 3 hours of fasting. Collected blood samples were centrifuged for 15 min by 3,000 rpm at 4°C

(Eppendorf centrifuge 5810R, Germany). Then, sera samples were aspirated by pipette and stored at –20°C for further analysis. Total BUN concentration was analyzed using blood analyzer (Ciba-Corning model, Express Plus Ciba Corning Diagnostics Co. USA).

Carcass traits

Four pigs from each treatment were slaughtered for the carcass analysis at the end of experiment. *Longissimus muscles* (LM) were used from nearby 10th rib on right side of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time. The time to measured pH and pork color were in intial time, 3, 6, 12 and 24 h. The pH was measured using a pH meter (Model, Themo Orion, U.S.A) and pork color was measured by CIE color L*, a* and b* value using a CR300 (Minolta Camera Co., Japan). Proximate analysis of pork samples were conducted by the method of AOAC (1995).

Pork quality

Water holding capacity (WHC) of pork was measured by centrifuge method. Samples of LM were ground and sampled in filter tube, then heated in water bath at 80℃ for 20 min and centrifuged for 10 min at 2,000 rpm and 10℃ (Eppendorf centrifuge 5810R, Germany). After recording WHC, LM was packed with polyethylene bag and heated in water bath until core temperature reached 72℃ and weighed before and after cooking to calculate the cooking loss. After heating, samples were chopped (0.5 inch in diameter) parallel to muscle fiber and the cores were used to measure the shear force using as alter (Warner Bratzler Shear, USA).

TBARS Assay

The extent of lipid oxidation was measured using the 2-thiobarbituric acid reactive substances (TBARS) method described by Ahn et al. (1999) with a few modifications (Ahn et al., 1999). Twelve milliliters of deionized distilled water (DDW) was added to the longissimus muscles fillet samples (3 g), and homogenized with 50 ml of butylated hydroxyanisol 7.2% (Sigmae-Aldrich, Saint Louis,MO, USA) for 15 sec. The homogenated pork sample (1 ml) was transferred to disposable test tube and then 1 ml of 2-thiobarbituric acid (Sigmae-Aldrich, Saint Louis, MO, USA) and trichloroacetic acid mixture (20 mM TBA in 15% trichloroacetic acid) solution were added. The mixture was mixed with vortex and incubated in a boiling water bath for 15 min. The sample was then cooled in cold water for 10 min, and centrifuged for 15 min at 2,500g and 4°C. The absorbance was measured at 532 nm using a UV-240 spectrophotometer (Shimadzu Co., Kyoto, Japan), and lipid oxidation was expressed as mg of malonaldehyde/kg meat.

Fatty acid composition

Lipids in the pork sample (10 g) were extracted with 100 mL of chloroform/methanol (2:1, v/v) according to the procedure of Folch et al. (1957). After adding 0.9% NaCl solution, samples were mixed throughly. After phase separation, the upper layer was removed and the remaining organic layer was dried under nitrogen flow. Extracted lipids were mixed with 2 mL of BF3-methanol (14%,w/w) before being heated in a water bath (85°C) for 10 h. After cooling, hexane (2 mL) and DW (5 mL) were added and centrifuged at 3,100 rpm for 10 min (HM-150IV, Hanil Co. Ltd., Korea).

Then, the top hexane layer containing fatty acid methyl esters (FAME) was transferred to vial, followed by separation on a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA). A split inlet (split ratio, 50:1) was used to inject the samples into a capillary column (SPTM2560 Capillarycolumn; 100 m × 0.25 mm × 0.20 μm film thickness) and ramped oven temperature was used (100°C for 5 min, increased to 240°C at 4°C/min and maintained for 20 min). The inlet temperature was 225°C and N_2 was used as the carrier gas at a constant flow rate of 20 mL/min.

Economical analysis

All of the experimental pigs were lived in the same environmental condition. Economical efficiency was calculated by feed cost and feed efficiency (G:F ratio). The total feed cost per body weight gain (kg) was calculated using total feed intake and feed price. Estimated feed cost was calculated as follows;

Estimated feed cost (Won) =

$$\text{Total feed cost} + \frac{\text{Finishing period feed cost}}{\text{Finishing period weight gain}} \times (110\text{kg} - \text{Final BW})$$

(during 9~12 weeks)

The days to market weight (110 kg) was estimated from the body weight at the end of feeding trial and ADG of pigs during 9~12 weeks.

Statistical analysis

The experimental data was analyzed as a randomized complete block design using the General Linear Model (GLM) procedure of SAS. For data on growth performance, a pen was considered as an experimental unit, while individual pig was used as an unit for data on blood profile, pork quality, carcass traits and economical efficiency. Linear and quadratic effects for equally spaced treatments were assessed by measurement of orthogonal polynomial contrast. The differences were declared significant at $P < 0.05$ or highly significant at $P<0.01$ and the determination of tendency for all analysis was $0.05<P<0.10$.

Results and Discussion

Growth performance

The effect of PKM levels with β-mannanase supplementation on growth performance is presented in Table 5. During the whole experimental period, there were no significant difference in body weight (BW), average daily gain (ADG), and gain to feed ratio (G:F ratio) among treatments. As the dietary PKM levels increased, ADFI was increased (linear, $P<0.05$). When pigs were fed high PKM treatment diet, G:F ratio tended to decrease during 0 to 6 week (linear, $P=0.09$).

Supplementation of PKM level in swine diet have been studied for a few years. Park (2009) demonstrated that 10% of PKM could replace corn-SBM based diet without β-mannanase supplementation. Lee (2009) reported that the use of PKM up to 10% with 0.10% of β-mannanase (800 IU) supplementation based on corn-SBM did not show any negative effect on growth performance in growing-finishing pig. In this study, up to 16 % inclusion of PKM with 0.1% β-mannanase supplementation had no significant differences on BW, ADG, G:F ratio among treatments as previous study. Although high level of mannan in swine diet interfered with the insulin secretion and influenced negatively on gastric emptying (Nune and Malmlof, 1992), addition of 0.1% β-mannanase is able to digest mannan in PKM in GI tract of growing-finishing pigs.

In monogastric animal, PKM has a low palatability in previous study (Gohl, 1981). This result, however, demonstrated that palatability of PKM did not influence on feed intake of growing-finishing pigs although dietary PKM level increased. Ravindran et al. (1984) reported the energy digestibility values in the diets were correlated with the NDF concentration as negatively. Thus, low energy digestibility value could influence on ADFI subsequently high NDF value in PKM caused an increment in feed intake of growing -finishing pigs.

Based on present study, no adverse effect in growth performance was observed by PKM 16% treatment during the whole experimental period. This result suggested that corn and SBM could be replaced by PKM up to 16% in diet of growing-finishing pigs.

Blood profiles

The effect of PKM with β-mannanase supplementation on blood urea nitrogen (BUN) was shown in Table 6. During the whole experimental period, BUN showed the normal levels (9.8~17.2) regardless of PKM supplementation level and no significant differences were observed among treatments. Munchow and Bergner (1968) reported that negative correlation between the biological value of feed and BUN concentration was observed in rats and pigs. Excessive consumption of protein decreased the availability of protein and increased the excretion of the nitrogen as urea form (Han et al., 2001). Thus, increasing BUN concentration demonstrated that excessive amino acids are ineffectively circulated and metabolized in the blood before excretion (Jeong et al., 2010). The present study demonstrated that the PKM 16% supplementation instead of corn and SBM has no detrimental effects on protein or amino acid availability. Moreover, this result is partially in agreement with Kim et al. (2011), who observed that BUN concentration was not affected by more than 10% supplementation of PKM with β-mannanase in diets of growing-finishing pigs.

Consequently, supplementation of PKM with β-mannanase was not shown any detrimental effect on blood urea nitrogen concentration.

Carcass traits

The effect of dietary PKM with β-mannnanase supplementation on carcass traits was presented Table 7. In the current study, there were no significant difference in moisture, crude protein, crude fat and crude ash of LM. These results were in agreement with the observation of Kim (2011) which demonstrated that feeding of PKM with β-mannanase did not influence on the chemical composition of LM.

In physiochemical property, any significant difference was not observed by inclusion of PKM with β-mannanase on cooking loss, shear force and WHC among treatments. However, cooking loss was linearly decreased as level of PKM was increased in diet (P<0.05). In WHC, PKM 4% treatment showed quadratic response (P<0.01) and it tended to increase linearly (P= 0.09) as level of PKM was increased in diet. Hamm (1986) reported that cooking loss can be an indirect index of WHC when it was increased. Maribo et al. (1998) reported WHC was a crucial factor of pork quality and high WHC is an index of high quality of pork (Lucy, 1972). Based on the result of the current study, supplementation of PKM with β-mannanase supplementation positively influenced on pork quality.

Pork quality

The effect of PKM with β-mannnanase supplementation on pork color (CIE-value) of LM. No significant differences were observed in a* and b* value at 0, 3, 6, 12, 24h after slaughter when pigs were fed different levels of PKM (Table 8). In L* value, there was significant difference at 3, 12 h after slaughter. As dietary PKM supplementation level increased, L* value was increased at 3, 12h after slaughter (linear, P<0.05). However, L* value at 24 h was in the normal range of pork (L* value : 38~50). Bendall and Wismer-pederson (1962) found that by increasing in yellowness, redness was decreased, resulted in a negative affect on the pork freshness. But, there was any negative effect on redness and yellowness of LM by PKM supplementation level. These findings are in accordance with those of Kim et al. (2011), who demonstrated that a* and b* values were not affected by 10% PKM inclusion level with 0.10% of β-mannanase supplementation. Therefore, these results demonstrated that up to 16% inclusion of PKM with β-mannanase did not have any detrimental effect on pork color.

The result of pH assay was presented in Table 10. There was no significant difference among treatments in pH value after slaughter. At 3h after slaughter, pH value was increased as the level of PKM supplementation increased (linear, P<0.05). Also, tendency of increasing pH was observed at 6h as increasing level of PKM with β-mannanase in diet (linear, P=0.07). Change of pH value would be an essential factor that determined the quality of pork and had an influence over freshness, WHC, tenderness, binding ability, pork color, texture and shelf life (Brewer and McKeith, 1999 ; Binder et al., 2004). Generally the initial pH indicated of PSE (pale soft exudative) pork and the final pH is regarded as a DFD (dark firm and dry) (Maganhini et al., 2007). Based on the results of the present study, supplementation of PKM with β-mannanase did not have any detrimental effect on pH value which is correlated with pork quality.

Fatty acid composition

Table 10 showed effect of PKM supplementation with β-mannnanase on fatty acid composition. Palmitic acid, saturated fatty acid (SFA), unsaturated fatty acid (USFA) and USFA/SFA ratio were showed significant differences, respectively. As the dietary PKM supplementation levels increased, palmitic acid and SFA were increased linearly ($P<0.05$). In USFA and USFA/SFA ratio, those were linearly decreased as pigs were fed higher PKM treatment diets. In monogastric animal, dietary modification could affect fatty acid composition in meat (Miller et al., 1990; Larick et al., 1992). It can be interpreted that PKM contained with highly SFA rather than USFA although it was a plant source. Thus, SFA in pork was increased by higher level of PKM in growing-finishing pigs.

Lipid oxidation (TBARS)

Table 11 showed effect of PKM supplementation with β-mannnanase on TBARS analysis. There were no significant differences in TBARS values among treatments. TBARS value was decreased linearly at day 1 as increasing PKM level with β-mannanase (linear, $P<0.05$). TBARS analysis is an index of oxidation rate and shelf life (McMillin, 2008). Hur et al. (2005) reported, increasing the USFA in meats induced higher oxidative deterioration. In current study, the USFA composition of pork could influence on TBARS value, and it was considered increasing level of PKM supplementation was affected TBARS value in pork.

Therefore, by increasing level of dietary PKM with β-mannanase, TBARS value tended to decrease.

Economical analysis

The effect of PKM with β-mannanase on feed cost per weight gain, days to market weight, estimated feed cost to market weight were presented in Table 12. There were no significant difference in feed cost per weight gain, days to market weight and estimated feed cost to market weight during the whole experimental period. Although it was not significant difference, days to market weight and estimated feed cost to market weight tended to decrease as supplementation of PKM was increased.

This result demonstrated that the replacement of corn and SBM with PKM could reduce feed cost when PKM was supplemented up to 16% in diets of growing-finishing pig. But the highest economical efficiency was observed when PKM was supplemented at 8% in growing-finishing pigs.

Conclusion

There were no significant difference in BW, ADG and G:F ratio among dietary treatments of PKM. As the dietary PKM supplementation levels increased, ADFI was increased linearly ($P<0.05$). The concentration of BUN was within the normal ranges regardless of dietary level of PKM during the whole experimental period. In economical analysis, days to market weight and estimated feed cost to market weight could reduce when PKM was supplemented up to 16% in diets but the highest economical efficiency was observed when 8% of PKM was supplemented in diet of pigs.

Consequently, this experiment demonstrated that supplementation of PKM in diets of growing-finishing pigs did not show negative responses in growth performance and pork quality.

Table 1. Formula and chemical composition of diets in growing phase1.

Ingredients, %	Treatments[1]				
	CON	PKM4	PKM8	PKM12	PKM16
Corn	65.59	61.86	58.16	54.43	50.70
Soy bean meal	27.35	26.68	25.99	25.32	24.65
Wheat bran	4.00	4.00	4.00	4.00	4.00
Palm kernel meal	0.00	4.00	8.00	12.00	16.00
Tallow	0.73	1.18	1.62	2.07	2.52
MDCP	1.26	1.20	1.13	1.07	1.01
Limestone	0.47	0.47	0.47	0.47	0.47
L-lysine-HCl	0.00	0.01	0.03	0.04	0.05
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
ß-mannanase[4]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]					
ME, kcal/kg	3265.00	3265.00	3265.07	3265.07	3265.08
Crude protein, %	18.00	18.00	18.00	18.00	18.00
Lysine, %	0.95	0.95	0.95	0.95	0.95
Methionine, %	0.28	0.28	0.28	0.28	0.28
Ca, %	0.60	0.60	0.60	0.60	0.60
P, %	0.50	0.50	0.50	0.50	0.50

[1]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β -mannanase 0.1% .

[2]Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d-Biotin, 128ug; Vit.B_{12}, 20ug.

[3]Provided the following quantities of minerals per kg of complete diet: Fe, 187 mg; Cu, 88 mg; Mn, 167 mg; I, 1 mg; Se, 1mg; Zn, 103 mg.

[4]Calculated value.

[5]β-Mannanase (800 IU/Kg), provided from CTC bio inc. Korea

Table 2. Formula and chemical composition of diets in growing phase2.

Ingredients, %	Treatments[1]				
	CON	PKM4	PKM8	PKM12	PKM16
Corn	70.62	66.90	63.15	59.45	55.75
SBM	22.83	22.15	21.50	20.81	20.13
Wheat bran	4.00	4.00	4.00	4.00	4.00
Palm kernel meal	0.00	4.00	8.00	12.00	16.00
Tallow	0.35	0.80	1.25	1.69	2.13
MDCP	1.19	1.13	1.07	1.00	0.93
Limestone	0.41	0.41	0.41	0.41	0.41
L-lysine-HCl	0.00	0.01	0.02	0.04	0.05
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
ß-mannanase[4]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]					
ME, kcal/kg	3265.02	3265.05	3265.00	3265.07	3265.02
Crude protein, %	16.30	16.30	16.30	16.30	16.30
Lysine, %	0.83	0.83	0.83	0.83	0.83
Methionine, %	0.26	0.26	0.26	0.26	0.26
Ca, %	0.54	0.54	0.54	0.54	0.54
P, %	0.47	0.47	0.47	0.47	0.47

[1]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1% .

[2]Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d-Biotin, 128ug; Vit.B_{12}, 20ug.

[3]Provided the following quantities of minerals per kg of complete diet: Fe, 187 mg; Cu, 88 mg; Mn, 167 mg; I, 1 mg; Se, 1mg; Zn, 103 mg.

[4]Calculated value.

[5]β-Mannanase (800 IU/Kg), provided from CTC bio inc. Korea

Table 3. Formula and chemical composition of diets in finishing phase1.

Ingredients, %	Treatments[1]				
	CON	PKM4	PKM8	PKM12	PKM16
Corn	70.82	67.08	63.35	59.64	55.95
SBM	20.43	19.73	19.06	18.40	17.69
Wheat bran	6.00	6.00	6.00	6.00	6.00
Palm kernel meal	0.00	4.00	8.00	12.00	16.00
Tallow	0.66	1.12	1.57	2.01	2.45
MDCP	1.11	1.07	1.01	0.93	0.87
Limestone	0.38	0.38	0.38	0.38	0.38
L-lysine-HCl	0.00	0.02	0.03	0.04	0.06
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
ß-mannanase[4]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]					
ME, kcal/kg	3265.06	3265.02	3265.02	3265.09	3265.00
Crude protein, %	15.50	15.50	15.50	15.50	15.50
Lysine, %	0.78	0.78	0.78	0.78	0.78
Methionine, %	0.25	0.25	0.25	0.25	0.25
Ca, %	0.50	0.50	0.50	0.50	0.50
P, %	0.45	0.45	0.45	0.45	0.45

[1]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1% .

[2]Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d-Biotin, 128ug; Vit.B_{12}, 20ug.

[3]Provided the following quantities of minerals per kg of complete diet: Fe, 187 mg; Cu, 88 mg; Mn, 167 mg; I, 1 mg; Se, 1mg; Zn, 103 mg.

[4]Calculated value.

[5]β-Mannanase (800 IU/Kg), provided from CTC bio inc. Korea

Table 4. Formula and chemical composition of diets in finishing phase2.

Ingredients, %	Treatments[1]				
	CON	PKM4	PKM8	PKM12	PKM16
Corn	77.48	73.78	70.07	66.37	62.64
SBM	14.34	13.66	12.98	12.30	11.63
Wheat bran	6.00	6.00	6.00	6.00	6.00
Palm kernel meal	0.00	4.00	8.00	12.00	16.00
Tallow	0.20	0.64	1.08	1.52	1.97
MDCP	0.98	0.91	0.84	0.77	0.71
Limestone	0.40	0.40	0.40	0.40	0.40
L-lysine-HCl	0.00	0.01	0.03	0.04	0.05
DL-methionine	0.00	0.00	0.00	0.00	0.00
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
ß-mannanase[4]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	0.10
Chemical composition[5]					
ME, kcal/kg	3265.06	3265.01	3265.05	3265.00	3265.01
Crude protein, %	13.20	13.20	13.20	13.20	13.20
Lysine, %	0.62	0.62	0.62	0.62	0.62
Methionine, %	0.23	0.23	0.23	0.23	0.23
Ca, %	0.45	0.45	0.45	0.45	0.45
P, %	0.40	0.40	0.40	0.40	0.40

[1]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β -mannanase 0.1% .

[2]Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d-Biotin, 128ug; Vit.B_{12}, 20ug.

[3]Provided the following quantities of minerals per kg of complete diet: Fe, 187 mg; Cu, 88 mg; Mn, 167 mg; I, 1 mg; Se, 1mg; Zn, 103 mg.

[4]Calculated value.

[5]β-Mannanase (800 IU/Kg), provided from CTC bio inc. Korea

Table 5. Effects of palm kernel meal levels with ß-mannanase supplementation on growth performance in growing-finishing pigs.[1]

Criteria	Treatments[2]					SEM[3]	*P*-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
Body weight[4], kg								
Initial	30.50	30.50	30.50	30.50	30.50	0.586	-	-
3 wk	44.64	44.42	44.76	44.60	44.96	0.588	0.94	0.96
6 wk	63.30	62.74	63.09	64.33	64.16	0.802	0.30	0.22
9 wk	79.99	80.52	81.51	81.65	80.60	1.010	0.36	0.89
12 wk	96.67	99.09	101.45	101.17	98.73	1.328	0.13	0.55
ADG, g								
0-3 wk	673	663	679	672	688	14.3	0.94	0.96
4-6 wk	889	873	873	940	914	17.6	0.26	0.17
7-9 wk	794	847	877	824	783	21.3	0.62	0.34
10-12 wk	794	884	949	930	863	32.9	0.23	0.52
0-6 wk	781	768	776	806	801	11.4	0.30	0.22
7-12 wk	794	865	913	877	823	18.5	0.14	0.22
0-12 wk	788	817	845	841	812	12.7	0.14	0.56
ADFI, g								
0-3 wk	1,826	1,734	1,828	1,876	1,877	24.1	0.31	0.20
4-6 wk	2,702	2,984	3,050	3,090	3,001	61.3	0.03	0.29
7-9 wk	2,877	2,945	2,952	3,049	2,953	44.1	0.26	0.88
10-12 wk	3,251	3,456	3,616	3,652	3,681	68.1	0.03	0.51
0-6 wk	2,264	2,359	2,439	2,483	2,439	36.4	0.02	0.70
7-12 wk	3,064	3,200	3,284	3,351	3,317	48.3	0.04	0.71
0-12 wk	2,664	2,780	2,862	2,917	2,878	40.2	0.03	0.70
G:F ratio								
0-3 wk	0.369	0.383	0.371	0.360	0.367	0.0080	0.67	0.51
4-6 wk	0.329	0.294	0.288	0.305	0.305	0.0061	0.22	0.08
7-9 wk	0.276	0.289	0.299	0.271	0.267	0.0084	0.96	0.36
10-12 wk	0.245	0.256	0.261	0.255	0.236	0.0076	0.70	0.67
0-6 wk	0.345	0.326	0.318	0.324	0.329	0.0041	0.09	0.17
7-12 wk	0.260	0.271	0.278	0.262	0.249	0.0058	0.62	0.57
0-12 wk	0.296	0.295	0.295	0.289	0.283	0.0043	0.65	0.82

[1]A total 120 crossbred pigs was fed from average initial body 30.50 ± 3.039 kg and the average final body weight was 99.42 kg.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.
[4]Values are means for four pens of six pigs per pen.

Table 6. Effect of palm kernel meal levels with ß-mannanase supplementation on blood profiles in growing-finishing pigs[1].

Criteria	Treatments[2]					SEM[3]	*P*-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
BUN, mg/dL								
Initial	--------------------------------10.7 ------------------------------					-	-	-
3 week	11.3	13.0	11.7	13.7	10.8	0.61	0.36	0.91
6 week	11.3	9.8	14.0	11.0	10.6	0.51	0.55	0.57
9 week	14.0	17.2	15.0	13.1	15.3	0.64	0.47	0.10
12 week	12.2	14.0	12.6	12.6	13.9	0.44	0.96	0.40

[1]Least squares means of 6 observations per treatment.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.

Table 7. Effects of palm kernel meal with ß-mannanase supplementation on pork quality of longissimus muscle[1].

Criteria	Treatments[2]					SEM[3]	*P*-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
Proximate analysis, %								
Moisture	74.90	74.24	74.06	74.24	73.36	0.234	0.37	0.44
Crude protein	21.40	20.83	21.76	22.28	21.74	0.216	0.12	0.27
Crude fat	3.60	3.17	3.17	3.23	3.23	0.240	0.78	0.76
Crude ash	1.42	1.50	1.63	1.46	1.49	0.048	0.83	0.24
Physiochemical property								
Cooking loss[4]	36.45	35.03	33.65	33.93	36.02	0.398	0.04	0.34
Shear force[5]	5.60	4.90	4.54	5.03	5.39	0.267	0.49	0.38
WHC[6]	97.57	98.37	98.01	98.01	97.80	0.093	0.09	<0.01

[1]Least squares means for four pigs per treatment.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.
[4]Cooking loss unit: %
[5]Shear force unit: kg/0.5 inch^2
[6]WHC: water holding capacity

Table 8. Effect of palm kernel meal supplementation levels with ß-mannanase on pork color after slaughter[1].

Criteria	Treatments[2]					SEM[3]	*P*-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
CIE value[4], L								
0 hr	39.85[ab]	38.35[bc]	39.76[ab]	37.63[c]	40.29[a]	0.361	0.06	0.59
3 hr	40.87[AB]	39.44[BC]	39.35[BC]	38.26[C]	41.45[A]	0.333	0.01	0.75
6 hr	41.41	39.45	39.58	39.57	42.99	0.516	0.29	0.39
12 hr	44.80[a]	40.86[b]	42.12[ab]	40.81[b]	43.74[a]	0.497	0.02	0.17
24 hr	45.81	42.77	42.92	43.58	45.12	0.510	0.22	0.13
CIE value, a								
0 hr	0.73	0.90	1.11	1.37	1.37	0.248	0.10	0.87
3 hr	1.30	1.75	1.79	1.97	2.06	0.361	0.17	0.68
6 hr	2.09	2.60	2.25	2.62	3.71	0.287	0.61	0.89
12 hr	2.70	2.59	2.84	3.44	3.10	0.238	0.25	0.45
24 hr	3.27	3.35	2.96	3.15	3.62	0.473	0.78	0.92
CIE value, b								
0 hr	3.51	3.27	3.60	3.34	3.90	0.778	0.77	0.95
3 hr	4.45	4.27	4.32	4.05	4.84	0.101	0.25	0.82
6 hr	4.90	4.86	4.34	4.63	5.67	0.183	0.50	0.71
12 hr	5.80	4.91	5.20	5.25	5.59	0.148	0.40	0.21
24 hr	6.15	5.52	5.53	5.49	6.11	0.183	0.35	0.53

[1]Least squares means for four pigs per treatment.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.
[4]CIE L: luminance or brightness (vary from black to white), a: red and green component (+a:red, -a:green), b: yellow and blue component (+b:yellow, -a:blue)
[ABC] Means in a same row with different superscript letters significantly differ ($P<0.01$)
[abc] Means in a same row with different superscript letters significantly differ ($P<0.05$)

Table 9. Effect of palm kernel meal supplementation levels with ß-mannanase on pork pH after slaughter[1].

Criteria	Treatments[2]					SEM[3]	P-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
pH value after slaughter								
0 hr	6.07	6.17	6.14	6.15	6.06	0.027	0.47	0.52
3 hr	5.86	6.01	6.02	6.03	5.94	0.024	0.03	0.16
6 hr	5.86	5.94	5.97	5.97	5.93	0.020	0.07	0.37
12 hr	5.82	5.85	5.95	5.92	5.85	0.024	0.15	0.56
24 hr	5.73	5.73	5.87	5.79	5.76	0.025	0.22	0.54

[1]Least squares means for four pigs per treatment.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.

Table 10. Effect of palm kernel meal supplementation levels with ß-mannanase on pork fatty acid composition in longissimus muscle[1].

Criteria	Treatments[2]					SEM[3]	P-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
Fatty acid composition, %								
C14:0	1.83	2.17	1.87	1.82	2.00	0.070	0.63	0.24
C16:0	22.26^{b}	22.39^{b}	23.55^{a}	24.08^{a}	23.98^{a}	0.237	<0.01	0.56
C16:1	4.18	4.12	4.42	4.13	3.96	0.122	0.89	0.70
C18:0	11.48	11.48	11.25	11.51	11.41	0.138	0.93	0.70
C18:1 n-9	38.26	38.18	38.02	38.58	38.47	0.206	0.75	0.57
C18:2 n-6	12.66	12.42	12.27	11.69	11.83	0.213	0.23	0.75
C20:0	0.18	0.18	0.16	0.15	0.16	0.005	0.05	0.95
C18:3 n-6	0.36	0.35	0.31	0.35	0.34	0.019	0.68	0.59
C20:1	0.83	0.86	0.74	0.66	0.63	0.037	0.10	0.52
C18:3 n-3	0.77	0.68	0.60	0.64	0.76	0.031	0.16	0.35
C20:2	0.78	0.71	0.61	0.57	0.64	0.031	0.02	0.83
C22:0	0.82	0.80	0.81	0.78	0.81	0.041	0.81	0.96
C20:3 n-6	1.12	1.15	0.96	0.98	1.02	0.040	0.17	0.96
C20:4 n-6	3.36	3.41	3.43	3.10	3.07	0.104	0.49	0.45
C22:6 n-3	1.11	1.10	1.02	0.95	0.95	0.050	0.33	0.84
SFA[4]	36.58^{C}	37.03^{BC}	37.63^{AB}	38.35^{A}	38.34^{A}	0.208	<0.01	0.70
UFA[5]	63.42^{A}	62.91^{AB}	62.37^{BC}	61.65^{C}	61.66^{C}	0.206	<0.01	0.77
UFA/SFA ratio	1.73^{A}	1.70^{AB}	1.66^{BC}	1.61^{C}	1.61^{C}	0.015	<0.01	0.79
MUFA[6]	43.26	43.15	43.17	43.37	43.05	0.193	0.88	0.77
PUFA[7]	20.16	19.82	19.20	18.28	18.61	0.283	0.04	0.64

[1]Least squares means for four pigs per treatment.
[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[3]Standard error of mean.
[4]SFA = saturated fatty acids
[5]UFA = unsturated fatty acids
[6]MUFA = monounsaturated fatty acids
[7]PUFA = polyunsturated fatty acids

Table 11. Effect of palm kernel meal supplementation levels with ß-mannanase on TBARS in longissimus muscle[1].

Criteria	Treatments[2]					SEM[3]	P-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
Day								
1	0.337	0.313	0.289	0.295	0.292	0.0064	0.01	0.22
3	0.511	0.494	0.499	0.489	0.497	0.0059	0.40	0.77
7	0.353	0.386	0.362	0.326	0.311	0.0101	0.19	0.07

[1]Least squares means for four pigs per treatment.

[2]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.

[3]Standard error of mean.

Table 12. Effect of palm kernel meal supplementation levels with ß-mannanase on economical efficiency.

Criteria	Treatments[1]					SEM[2]	P-value	
	CON	PKM4	PKM8	PKM12	PKM16		Lin.	Quad.
Feed cost per weight gain, won/kg								
0-3 wk	996	951	971	993	949	21.3	0.96	0.51
4-6 wk	1,066	1,188	1,191	1,107	1,090	23.5	0.59	0.07
7-9 wk	1,242	1,202	1,136	1,239	1,240	37.3	0.86	0.48
10-12 wk	1,318	1,246	1,219	1,252	1,305	39.1	0.63	0.61
0-6 wk	1,037	1,088	1,095	1,061	1,035	12.9	0.52	0.13
7-12 wk	1,280	1,216	1,166	1,237	1,270	27.1	0.55	0.33
0-12 wk	1,166	1,162	1,139	1,154	1,160	16.5	0.76	0.83
Days to market weight(110kg) from 31.5kg, days								
	100.78	96.98	94.60	95.15	97.10	1.809	0.23	0.54
Estimated feed cost to market weight(110kg) from 31.5kg, won								
	94,053	92,611	91,230	92,837	92,910	1801.0	0.78	0.71

[1]Con : PKM 0% + β-mannanase 0.1%, PKM4 : PKM 4% + β-mannanase 0.1%, PKM8 : PKM 8% + β-mannanase 0.1%, PKM12 : PKM 12% + β-mannanase 0.1%, PKM16 : PKM 16% + β-mannanase 0.1%.
[2]Standard error of mean.

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Ⅴ. Summary in Korean

본 연구는 사료 내 0.1%의 β-mannanase를 첨가한 팜박을 수준별로 첨가하여, 육성비육돈의 성장성적, 혈액성상, 돈육품질, 그리고 경제성에 미치는 영향에 대해 알아보고, 이를 바탕으로 옥수수-대두박 위주의 사료에 팜박의 첨가수준을 규명하기 위해 수행되었다. 평균 체중 30.50 ± 3.039의 3원 교잡종([Yorkshire × Landrace] × Duroc) 육성돈 120두를 공시하였으며, 5처리 4반복, 돈방당 6두씩 성별과 체중에 따라 난괴법 (RCBD: randomized complete block design)으로 배치되었다. 처리구는 5수준의 PKM (0, 4, 8, 12, 16%)에 따라 구분되었으며 각 처리구에 모두 0.1%의 β-mannanase가 첨가되었다. 사양실험 결과, 실험전체 기간에서는 성장성적에서 처리구간 유의차는 나타나지 않았다. 하지만, 육성후기, 비육후기, 육성기, 실험전체기간의 사료섭취량에서 팜박의 첨가량에 따라 증가하는 효과가 나타났다.(linear, P=0.05). 혈액성상을 분석한 결과, BUN의 농도는 모든기간 유의차가 나타나지 않았다. 도축후 채취한 등심근에 대한 일반성분 분석 결과 수분, 조단백질, 조지방 및 조회분 함량에서 팜박의 첨가에 따른 효과는 발견되지 않았으며, 육색 및 pH에서도 정상육 범위 내에서 유의적인 차이가 나타나지 않았다. 돈육의 이화학적 특성인 보수력, 전단력, 가열감량에서는 팜박의 첨가에 따른 처리구간 유의적차이는 보이지 않았다. 팜박의 첨가량이 증가함에 따라 가열감량은 증가하였지만 (linear, P=0.04), 보수력은 오히려 감소하는 경향을 나타냈다.(linear, P=0.09). 돈육의 지방산 분석에서는 팜박의 첨가량이 증가함에 따라 포화지방산 비율이 유의적으로 증가하는 효과가 나타났다 (linear, P<0.01). 돈육의 산패도를 결정하는 TBARS 분석에서는 팜박의 첨가량이 증가함에 따라 TBARS value도 유의적으로 감소하는 효과가 나타났다 (linear, P=0.01). 경제성 분

석 결과, 사료가격은 팜박의 함량이 높아질수록 감소하였으며, 전체실험 기간 동안 증체량 당 사료비와 출하일령에서 팜박을 첨가한 처리구들이 대조구와 비교하여 더 높은 경제적인 효과가 나타났다.

결론적으로 육성비육돈 사료 내 0.10%의 β-mannanase와 함께 팜박을 첨가하였을 시, 전체 기간동안 성장 성적과 돈육품질에 부정적인 영향 없이, 옥수수와 대두박을 16%까지 대체할 수 있으며, 농가에서 사료비 및 생산비 절감효과를 최대로 얻을 수 있는 팜박의 첨가수준은 8%인 것으로 검증되었다.