Nutritional studies in native, Thai Kadon pigs

Kraisit Vasupen

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Kraisit Vasupen

Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands

Faculty of Natural Resources, Rajamangala University of Technology Isan, Sakon Nakhon Campus, Phang Khon, Sakon Nakhon, Thailand

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In Memory of My Father

In Dedication to My Mother

To My Family for their eternal love

Contents

Scope of the thesis

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Kadon pigs are native to the North-East of Thailand. The appearance of Kadon pigs is typical (Figures 1-3). The Kadon pig is a small, black breed of pigs, normally of black color all over the body. Individual pigs in a herd may have white tips at the end of each of the legs and on the snout and tail (Figure 4). Kadon pigs have a short snout and small prick ears that are spread apart. The body is stocky and is low on the ground. In the North-East of Thailand, Kadon pigs are typically kept on small holdings. The feed normally is based on rice and by-products.

Figure 1. Adult Kadon sow.

Figure 2. Adult Kadon boar.

Figure 3. Female Kadon pig with litter aged 8 weeks.

Figure 4. Atypical Kadon pig with white tips at legs, snout and tail.

For pigs kept on a small-holder farm, technical data were recorded. The average age and weight of gilts at first heat were 4.7 months and 23.8 kg, respectively. Mean total litter size at birth was 7.6 $\pm$ 2.4 piglets (first farrow) and 9.0 $\pm$ 2.7 piglets (second farrow). The number of stillborn piglets per litter was 0.5 and total piglet losses during lactation was 1.8 pigs per litter. The farrow interval of Kadon sows was 213.8 $\pm$ 18.6 days. Mean birth weight of Kadon pigs at first and second farrow were 0.58 $\pm$ 1.0 and 0.55 $\pm$ 1.0 kg, respectively. The teat number of Kadon sows was 10.9 $\pm$ 1.0 teats, which may be a factor limiting piglet survival. The piglet losses depend on the ability of the farm to manage prolific sows.

The Kadon pig is believed to be on the edge of extinction. In 2003, the Kadon pig was designated as a protected species of production animals. At the Department of Animal Science of the Sakon Nakhon Agricultural Research and Training Center, the herd of Kadon pigs descends from 20 animals from the Kudbark district in Sakon Nakhon province. The production of Kadon pigs is suitable for small-holder farms because they attain puberty at low body weight, reproduce well on a low plane of nutrition and have good disease resistance (Serres, 1992). Growing Kadon pigs fed a diet based on rice bran gain approximately 200 g/day (Vasupen *et al.*, 2004).

In the North-East of Thailand, the local people appreciate pork from Kadon pigs favorably over pork from exotic breeds of pigs. Kadon pork is said to have better texture and flavor. Nevertheless, the Kadon pigs in smallholder farms have been replaced by exotic, commercial pigs that are kept in intensive pig production systems. In the light of the protection and preservation of Kadon pigs, nutritional research on this breed of pig may be useful. By rendering the production of Kadon pigs more cost effective through controlling feed costs, preservation of the species may be enhanced. One method of preservation of the Kadon pig would be to stimulate the utilization of Kadon meat in the diet of people and in the food processing industry, because this would require mass breeding.

Efficient animal production requires a careful balance between the animal's genetic potential and the quantity and quality of nutrients that are consumed. The diet fed to the animals should be formulated using feedstuffs that the animal accepts and that meet its nutrient requirements. To maximize economic efficiency, the nutrients should be provided close to the requirements rather than exceeding them. Clearly, the feeding of nutrients below the requirements would diminish growth performance and could even induce deficiency diseases. The main objective of this thesis was to study various nutritional aspects of Kadon pigs. There only is very limited literature on nutritional aspects of Kadon pigs, while the papers are written in the Thai language and have been published in meeting proceedings only (Buakeeree and Thepparat, 2006 , Tuntivisoottikul and Chasap, 2006). It would be anticipated that improvement of our knowledge of the nutrition of the Kadon pig would contribute to the development of new feeding strategies for optimal growth, reproduction and lactation of Kadon pigs. To meet the main objective, six trials were carried out and are described in the chapters of this thesis.

The stage is set by Chapter 1, providing quantitative information on growth performance, organ weights, carcass composition and fatty acid profiles in the meat of female and male Kadon pigs. The pigs were either housed individually or in groups.

In quantitative terms, carbohydrates represent the major component of common pig diets. Cereal grains and other carbohydrate sources are not only a source of energy, but they provide protein, fat, fiber, vitamins and minerals. It was reasoned that the dietary carbohydrate source in the diet of Kadon pigs may influence performance and macronutrient digestibility in growing animals. Chapter 2 describes a study in which macronutrient digestibility was determined in Kadon pigs fed diets containing either ground corn, rice bran, broken rice or cassava chips.

In further studies the use of broken rice and cassava chips were compared as to different variables. The measurements involved growth performance, ileal and fecal nutrient digestibility, bacterial composition of cecal contents and feces, volatile fatty acids in ileal digesta, carcass quality and nitrogen utilization (Chapters 3-5).

There is no evidence-based information on the adequate level of protein in the diet for Kadon pigs. It was considered relevant to determine the optimum dietary protein level in order to support practical pig diet formulation. The objective in Chapter 6 was to evaluate the effect of different dietary protein levels on growth, protein digestibility and nitrogen utilization in growing Kadon pigs.

Chapter 7 documents a study that addressed the possible beneficial effect of adding fumaric acid to the diet. The variables measured to assess the efficacy of fumaric acid were the concentrations of fermentation end-products along the gastro-intestinal tract, macronutrient digestibility and nitrogen utilization.

At the end of this thesis, the general conclusions of the various studies are listed.

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CHAPTER 1

Carcass and meat characteristics of Kadon pigs

K. Vasupen*[1], C. Yuangklang[1], S. Wongsuthavas[1], P. Srenanul[1], J. Mitchaothai[2] and A. C. Beynen[3]

[1]Sakon Nakhon Agricultural Research and Training Center, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand.

[2] Department of Clinic for Swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.

[3] Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.

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Abstract

This study describes the carcass and meat characteristics of native, Thai Kadon pigs. Female and male Kadon pigs were either housed individually or in groups and growth performance, organ weights and carcass composition were determined. There were 8 females and 8 males housed in individual pens. Another 8 females were housed together and so were 8 males. The female pigs were heavier than the male pigs, the difference being most pronounced in the individually housed animals. For male pigs between 8 and 20 kg of body weight, average daily gain was about 290 g/day. For the group-housed pigs there were no significant differences in weight gain, carcass weight, percentage of carcass and back fat between female and male pigs. The carcass weight was about 65% of slaughter weight. The weight of head, tail, heart, liver, lung, spleen, kidney and large intestine were not different between males and females, but the stomach and small intestine were heavier in females than in males. The loin meat contained about 8.7 % fat and 21.4 % protein. Palmitic and oleic acid represented about 26 and 40 % of the total loin fatty acids. There was no gender difference in carcass composition and fatty acid profile of meat. It is appreciated that the data presented will be affected by diet composition and management, but this study is the first to document reference data for Kadon pigs.

Key words: Kadon pig, growth performance, carcass composition

Introduction

In the North-East of Thailand, native, so-called Kadon pigs are kept on small-holder farms. It is assumed that the Kadon pigs are on the edge of extinction. Therefore in 2003, this Thai native pig was listed as preserved species. Within the framework of the Kadon pig project in the Department of Animal Science, Sakon Nakhon Agricultural Research and Training Center, 20 Kadon pigs were purchased in the Kudbark district in Sakon Nakhon province. These animal were used for breeding. In a recent study in Kadon pigs fed on rice bran as a basal diet, weight gain was found to be approximately 200 g/day (Vasupen *et al.*, 2004), which would make the pig suitable for production under conditions of limited resources on small-holder farms. Furthermore, the Kadon pig attains puberty at low body weight, reproduces on a low plane of nutrition and has good disease resistance (Serres,1992).

The meat from Kadon pigs is well appreciated by the local people in the North-East of Thailand. It is said that Kadon meat has better texture and flavor than the meat of exotic pigs. Nevertheless, on small-holder farms the Kadon pigs have been by commercial pigs kept in intensive pig production systems. Preservation of the Kadon pig on small-holder farms may be stimulated by objective information on its technical and meat characteristics. Thus, in this study, we collected data on growth performance, carcass and meat characteristics.

Materials and Methods

The Kadon pigs used were bred in the Department of Animal Science, Sakon Nakhon Agricultural Research and Training Center. There were ten sows which were mated with unrelated boars. The piglets produced from the ten sows were monthly monitored as to body weight, body length and height at the shoulder and the rump.

Eight male growing pigs with average body weight 8.4$\pm$1.7 kg and 8 females with average body weight 10.4$\pm$1.8 kg were housed individually in a metabolic cage. They had free access to water from a nipple drinker. The pigs were fed ad libitum (4% dry matter of body weight) twice daily at 07.00 am and 04.30 pm. The diet contained 160 g crude protein per kg dry matter (DM). The diet composition was as follows (g/kg diet): rice bran, 820; soybean meal, 160; premix, 15; salt, 5. Feed consumption was determined as the difference between the amount of feed offered and that refused. Pigs were weighed weekly for the 45-days experimental period. Changes in live weight were used to estimate average daily gain (ADG). Feed conversion ratio (FCR) was calculated as the ratio of the amount of consumed feed to 1 kg gain of body weight.

Another group of pigs were housed 8 animals of the same sex per pen. The males had an average body weight of 8.44 kg and the females had an average body weight of 8.73 kg. Feed and water were freely available throughout the study. Body weight and feed consumption were measured for the 90-days experimental period. At the end of the experiment, four pigs per group were slaughtered. Carcass characteristics evaluation was performed according to the Thai style of carcass cutting (Jaturasitha, 2004). The weights of the head, tail, liver, kidney, spleen, heart, lungs, full digestive tract, and hot carcass were recorded. In addition, dressing percentage, thickness of back fat and ham proportion were determined. The loin muscles (longissimus dorsi) were collected to determine proximate composition and fatty acid profile of the fat component. The meat samples were dried at 60 ^{o}C for 72 hr in a forced-hot air oven to quantify the percentage of moisture and were subsequently analyzed for crude protein, crude fat and ash (AOAC, 1990). Total fat in dried meat (loin) was extracted with a chloroform-methanol (2:1, v/v) mixture (Folch et al., 1957). Then, the fat was saponified with 0.5 N methanolic sodium hydroxide and methylated with boronitrifluoride-methanol according to the procedure of Metcalfe et al. (1966) followed by gas chromatography to determine individual fatty acids.

The data were evaluated for statistical significance of sex differences by the Student's t test (SPSS, 1998). All results are expressed as mean and pooled SE.

Results and Discussion

As from birth, female pigs tended to be heavier than male pigs until 12 months of age (Table 1). However, when mature at 12 months of age, the male pigs tended to be taller with large body length, pointing at a better body conformation (Table 1). Kadon pigs raised in groups tended to have lower growth rate than those raised in individual pens (Tables 2 and 3). This may be related to more activity, more competition for feed and more feed losses in the group-housed pigs. Furthermore, the growth interval was 60 days for the pigs housed individually and 90 days for those housed in groups. During the last 30 days in the group-housed pigs, growth rates were lower than in the preceding period.

Table 1 Mean body weight and body conformation in group-housed Kadon pigs as from birth

Age	Weight (kg)		Height at shoulder (cm)		Height at rump (cm)		Body length (cm)	
	male	female	male	female	male	female	male	female
Birth	0.57	0.58	11.29	11.54	11.56	11.68	14.34	14.29
1 month	3.04	3.08	17.92	18.46	19.00	19.69	22.08	22.46
2 month	6.09	6.11	22.83	23.36	25.50	26.25	30.13	32.89
3 month	12.43	12.58	27.76	29.16	30.71	33.04	39.76	45.54
4 month	18.93	19.13	32.11	34.52	35.76	38.26	46.42	50.41
5 month	24.11	25.79	35.27	38.13	39.18	43.07	49.00	56.13
6 month	30.82	37.50	37.00	40.67	41.44	45.93	51.33	59.27
12 month	65.50	74.20	55.67	51.50	58.33	56.90	77.00	74.70

Piglets birth weight is between 0.4-1.0 kg with an average of 0.58 kg. There were 16 males and 20 females.

There were no sex differences in daily feed intake, ADG and FCR (Table 2). Average back fat thickness tended to be higher in females than in males (2.23 cm vs. 1.81 cm) (Table 3). In the females, the higher back fat thickness may be related to retention of energy for reproductive performance. The full digestive tract of female pigs was heavier than that of male pigs.

Table 2 Growth performance of Kadon pigs that were raised in individual pens

Item	Male pigs (n=8)	Female pigs (n=8)	Pooled SE
Initial weight (kg)	8.4[a]	10.4[b]	0.62
Final weight (kg)	21.2[a]	24.6[b]	1.02
Average daily gain (g/d)	285.6	315.0	18.32
Feed consumption (g DM/d)	741.1	816.7	46.29
Feed conversion ratio	2.74	2.67	0.12

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

There was no significant effect of sex on the composition of loin (Table 4). The average amount of intra-muscular fat in loin of the Kadon pigs was 8.74 % of the DM, which is in agreement with data from the study of Jun and Fei (2002), showing a fat content of 8.27 % in loin muscle from Liangguang Xiaohua pigs. However, the amount of intra-muscular fat in Kadon meat was higher than that in various native Chinese pigs (Jinhua pigs, 3.7 0%; Wujin pigs, 3.08 %; Ming pigs, 5.22 %; Wuzhishan pigs, 2.26 %) (Jun and Fei, 2002).

Table 3 Carcass characteristics of Kadon pigs that were raised in groups

Items	Male pigs	Female pigs	Pooled SE
Number of pigs	8	8	-
Initial weight (kg)	8.44	8.73	0.60
Slaughter weight (kg)	23.20	26.10	1.11
Weight gain (kg)	14.76	17.38	1.03
Average daily gain (g/d)	164.13	193.00	11.48
Feed consumption (g DM/d)	551.88	619.47	20.99
Feed conversion ratio	3.36	3.21	0.06
Hot carcass weight (kg)	15.08	17.49	0.90
Percentage of carcass (%)	64.85	66.75	1.19
Loin weight (kg)	0.82	0.94	0.07
Percentage of loin/carcass weight	5.40	5.40	0.34
Back fat (cm)	1.81	2.23	0.17
Ham percentage (% of live weight)	14.35	13.51	0.80
Head (kg)	2.32	2.26	0.11
Tail (g)	37.50	41.87	3.34
Heart (g)	117.50	123.13	11.04
Liver (g)	560.63	578.75	33.44
Lungs (g)	266.25	268.13	41.37
Spleen (g)	50.00	48.44	4.92
Kidneys (g)	110.63	111.25	7.77
Stomach (g)	383.13^{a}	521.87^{b}	36.89
Small intestine (kg)	0.91^{a}	1.13^{b}	0.64
Large intestine (kg)	1.37	1.59	1.58

^{a,b} Means in the same rows with different superscripts differ significantly ($P < 0.05$)

The results of fatty acid determination in loin meat are listed in Table 4. It was found that the content of polyunsaturated fatty acids in Kadon meat was relatively low, whereas the contents of saturated monounsaturated fatty acids were relatively high, when compared with the commercial breeds of pigs (Nguyen et al., 2003). However, when compared with the fatty acids composition of Wuzhishan pig meat, the fatty acid composition of Kadon meat was not very different (Jun and Fei, 2002). It should be noted that the fatty acid composition of the diet is a major determinant of the fatty acid composition of intramuscular fat in pigs (Mitchaothai et al., 2007).

Table 4 Proximate composition and fatty acid profile of Kadon loin

Item	Male pigs (n=4)	Female pigs (n=4)	Pooled SE
Dry matter, %	30.88	32.35	2.02
Crude protein, % (% of DM)	20.81 (67.40)	21.96 (67.87)	0.99
Ash, % (% of DM)	1.03 (3.35)	1.14 (3.53)	0.27
Total fat, % (% of DM)	8.62 (27.93)	8.85 (27.36)	0.82
Fatty acids (g/100 g methyl esters)			
14:0	1.29	1.20	0.04
16:0	25.89	25.91	0.38
18:0	13.53	15.58	0.88
18:1 (n-9)	40.48	40.07	0.49
18:2c (n-6)	8.92	8.16	0.84
18:3 (n-3)	0.36	0.20	0.03
20:0	0.28	0.37	0.03
20:1 (n-9)	0.88[a]	1.11[b]	0.06
20:2 (n-6)	0.35	0.33	0.04
20:4 (n-6)	0.40	0.20	0.09
Total SFA	43.12	44.81	1.36
Total MUFA	46.58	46.11	0.85
Total PUFA	10.30	9.09	0.96

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Conclusions

The present experiment has provide quantitative information on growth performance, organ weight, carcass composition and the fatty acid profiles in meat from Kadon pigs. The data indicate that sex of Kadon pigs is not a major determinant of growth performance and carcass composition. The Kadon pigs raised under semi-intensive conditions, had relatively low growth performance and dressing percentage of carcass. However, the nutritional requirements of Kadon pigs are not well defined and they may differ from those of commercial pigs, whereas the nutrient requirements of the latter are generally used for Kadon pigs as well. It could be suggested that growth performance of Kadon pigs may be improved by nutrition more tailored to the species. Thus, research is needed to determine the nutritional requirements of Kadon pigs.

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CHAPTER 2

Macronutrient digestibility in Kadon pigs fed diets with isonitrogenous amounts of various carbohydrate sources

K. Vasupen[*], C. Yuangklang, S. Wongsuthavas, P. Srenanul, J. Mitchaothai[1] and A. C. Beynen[2]

Faculty of Natural Resources, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand,

[1]Department of Clinic for Swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand and

[2]Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands

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Abstract

In this experiment, the apparent digestibility of diets with isonitrogenous amounts of different carbohydrate sources was determined in Kadon pigs, native to the North-East of Thailand and kept on small-holder farms. Eight male and eight female pigs were used in a 4x4 Latin square design with diets containing either ground corn (GC), rice bran (RB), broken rice (BR) or cassava chips (CC). The diet with BR induced the highest digestibilities for protein and energy, but also had the highest ingredients costs. In essence, the diet with CC had produced the second highest digestibilities, whereas this diet was 18% less expensive than the diet with BR. The N retention was expressed as % of N intake, it was found to be highest in the pigs fed the diet containing BR, which is explained by the high protein digestibility and thus their low N output with feces. The outcome of this study may contribute to the formulation of pig diets when aiming at optimizing ingredient costs and growth performance.

Key Words: Broken rice, Cassava chips, Ground corn, Kadon pigs, Nitrogen retention, Rice bran

Introduction

In the rural, North-Eastern area of Thailand, small numbers of a species of native pigs are kept. The so-called Kadon pigs are believed to be on the edge of extinction. In 2003, the Kadon pig was designated as a protected species of production animals. At the Department of Animal Science of the Sakon Nakhon Agricultural Research and Training Center, Kadon pigs are bred that descend from 20 animals from the Kudbark district in Sakon Nakhon province. The production of Kadon pigs is suitable for small-holder farms because they attain puberty at low body weight, reproduce well on a low plane of nutrition and have good disease resistance (Serres, 1992). Growing Kadon pigs fed a diet based on rice gain approximately 200 g/day (Vasupen *et al.*, 2004). Meat from Kadon pigs is more popular among local people than that of exotic breeds because the texture and flavor are considered to be better. In spite of all advantages, the Kadon pigs have been put aside by the intensive, large-scale production of exotic pigs and even on small-holder farms exotic pigs are usually kept.

Carbohydrates from cereal grains are the main source of energy in pig diets. In the North-East of Thailand, ground corn, broken rice and rice bran are commonly used for the formulation of pig diets, while cassava chips may be used as an alternative, depending on availability and price of the various carbohydrate sources. So far there was no information on the impact of the type of carbohydrate source on macronutrient digestibility in Kadon pigs. It was the objective of this study to determine macronutrient digestibility in Kadon pigs fed diets containing different either ground corn, rice bran, broken rice or cassava chips. These carbohydrate sources not only contain different amounts of non-structural carbohydrates, but also different amounts of protein, fat and fiber. It was decided not to balance the diets for the multiple variables in the carbohydrate sources, but the dietary protein concentration was kept constant by varying the amount of soybean meal. Thus, the experimental diets differed in their contents of fat, fibre and non-structural carbohydrates, but not their calculated content of protein. In fact, the carbohydrate sources were compared in terms of equal protein supply or rather on an isonitrogenous basis. This approach can be defended as the protein component of the carbohydrate sources is the most expensive one and therefore is practical. However, it is appreciated that the multiple variables in the diet complicate the interpretation of the digestibility results.

Material and Methods

Eight male and 8 female, growing Kadon pigs were used. The average body weight of the males was 8.4±1.7 kg and that of the females was 10.4±1.8 kg. The experiment had a 4x4 Latin square design with 4 experimental diets and 4 periods of 12 days each. The diets contained either ground corn (GC), rice bran (RB), broken rice (BR) or cassava chips (CC) as carbohydrate source.

Each pig was individually housed in a metabolic cage with slatted floor and had free access to tap water from a nipple drinker. Each period included 7 days as pre-treatment and 5 days for sample collection. Pigs were fed twice daily at 07.00 am and 16.30 pm. The animals were fed ad libitum and feed leftovers were always removed before feeding.

Feces were collected quantitatively twice daily from the wire-mesh under the cages, and stored at –20°C until analysis. Urine was collected into a container via a funnel underneath the wire-mesh. It was removed twice daily and stored at –20 ˚C. To prevent nitrogen (N) losses during collection and storage, 10 ml of 25% H_2SO_4 was added daily to each container. Diets and feces were analyzed for their proximal components, dry matter, nitrogen, crude fat, crude fiber and ash (AOAC, 1990). The energy value was analyzed by adiabatic bomb calorie meter as described by Mitchaothai et al.(2007). The amount of protein was calculated as amount of nitrogen x 6.25. The nitrogen-free extract (non-structural carbohydrates) was assessed as residual fraction. Urine samples were used for N analysis.

The total tract apparent digestibility of macronutrients was calculated as intake minus excretion and expressed as a percentage of intake. N retention was calculated as N intake – N.excretion with feces plus urine. The data were statistically analyzed using the General Linear Model of SAS Software (1985).

Results and Discussion

Table 1 shows the analyzed composition of the four carbohydrate sources. CC was lowest in protein and RB was highest. RB was rich in crude fiber and crude fat and CC was high in fiber only. The ash contents of BR and GC were lowest and RB was highest. The amount of non-structural carbohydrates decreased in the order of CC, BR, GC, and RB.

Table 1. The analyzed composition of the four carbohydrate sources.

	GC	RB	BR	CC
Dry matter, %	87.2	90.8	87.5	90.1
Organic matter, % of DM	98.9	91.2	99	95.2
Crude protein, % of DM	9.5	10.9	7.0	1.9
Crude fat, % of DM	3.5	16.3	3.0	0.7
Crude fibre, % of DM	1.7	8.6	2.0	6.4
Ash, % of DM	1.1	8.8	1.0	4.8
Nitrogen-free extract, % of DM	84.2	55.4	87.0	86.2

The calculated protein concentration of the four diets was identical, but chemical analysis showed that the diet with GC was somewhat higher in protein than the other three diets. As would be anticipated, the diet containing RB was rich in fat and fiber and the diets with CC was high in fibre only. The calculated energy values of the GC, RB, BR and CC diets were 3,284, 2,859, 3,232 and 3,203 kcal metabolizable energy/kg, respectively. The calculated prices of the GC, RB, BR and CC diets were 9.22, 7.93, 9.70 and 7.98 THB/kg, respectively (46 THB = 1 Euro). Thus, on an energy basis, the ingredient price of the CC diet was lowest.

The total tract digestibility values for the macronutrients are shown in Table 3. The diet effects on digestibility did not differ significantly between sexes (P> 0.05). In both male and female Kadon pigs, the diets with BR or CC induced significantly higher digestibilities for dry matter, organic matter, crude protein and nitrogen-free extract than did the diets containing either GC or RB. It is known that a high crude fiber content of the diet interferes with protein and carbohydrate digestibility in pigs (Anderson and Lindberg, 1997a, 1997b). The low digestibilities for protein and carbohydrates in pigs fed the diet with RB may relate to the high fiber content of the diet. The high digestibilities found for the CC diet, which also was high in fiber, are in agreement with data published by Wilfart et al. (2007).

Table 2. Ingredient and analyzed composition of the experimental diets expressed as percentage of the diets as fed

Ingredient	GC diet	RB diet	BR diet	CC diet
Ground corn (GC)	70.0	0.0	0.0	0.0
Rice bran (RB)	0.0	78.0	0.0	0.0
Broken rice (BR)	0.0	0.0	68.0	0.0
Cassava chips (CC)	0.0	0.0	0.0	58.0
Soybean meal	28.0	20.0	30.0	40.0
Salt	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.5	0.5	0.5	0.5
Premix*	1.0	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0
Macronutrient				
Dry matter, %	88.8	91.8	89.3	90.5
Organic matter, % of DM	95.0	90.4	96.6	94.0
Crude protein, % of DM	17.5	16.1	16.2	16.5
Crude fat, % of DM	3.4	13.7	2.5	1.9
Crude fibre, % of DM	3.5	8.3	3.8	7.2
Ash, % of DM	5.0	9.6	3.4	6.0
Gross energy, kcal/kgDM	4,688.3	4,259.2	4,235.7	4,193.6

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

The apparent fat digestibility was highest in the pigs fed the diet with RB, but the difference compared to the other diets reached statistical significance in the female pigs only. The higher fat digestibility for the RB diet may be explained by its high fat content. A high fat intake will diminish the lowering effect of endogenous fecal fat on the calculated value for apparent fat digestibility. The digestibilities for dry matter and organic matter are determined by the efficiency of digestion of the sum of protein, fat, fibre and nitrogen-free extract. The digestibility of the nitrogen-free extract will have the greatest impact because this extract represents the largest fraction of the diet. The energy digestibility for the four diets followed the pattern of the digestibilities of dry matter, organic matter and nitrogen-free extract.

Table 3. Calculated composition of the experimental diets

Nutrients	GC	RB	BR	CC
Nitrogen-free extract, % of DM	70.6	52.3	74.1	68.4
ME, kcal/kgDM	3284	2859	3232	3203
Lys, % of DM	0.85	0.90	0.90	1.01
Met, % of DM	0.30	0.30	0.30	0.24
Met+Cys, % of DM	0.60	0.62	0.60	0.50
Trp, % of DM	0.18	0.21	0.21	0.22
Thr, % of DM	0.64	0.66	0.63	0.65
Ile, % of DM	0.69	0.66	0.72	0.74
Leu, % of DM	1.59	1.24	1.31	1.27
Phe. % of DM	0.88	0.82	0.87	0.88
Arg. % of DM	1.09	1.28	1.26	1.21

Under the conditions of *ad libitum* intake and the diets having nutrient levels well above the requirements, it would be expected that growth and N retention would be similar for the four experimental diets. However, due to feed refusals the mean feed intake was lowest in the pigs fed the diet with RB so that N intake also was lowest in these pigs (Table 5). As a consequence, N retention in the pigs fed the RB diet was significantly lower than in their counterparts fed the other experimental diets (Table 5). When N retention was expressed as % of N intake, it was found to be highest in the pigs fed the diet containing BR, which is explained by the high protein digestibility and thus their low N output with feces. As based on the amino acid composition of the diet and urinary N excretion, the low N retention in pigs fed the RB diet was not caused by an amino acid imbalance of the diet.

In a separate experiment we used six female pigs that were fed soybean meal and the premix in a 99:1 (w/w) ratio. The measured apparent crude protein digestibility was found to be 92.2 % (SEM = 1.0 %). Using this outcome, the digestibility of the protein component of GC, RB, BR and CC was calculated to be 44.3, 49.9, 67.1 and – 111.4 %, respectively. The aberrant value for the protein in CC may relate to its low protein level. In the CC diet a large proportion of the protein comes from soybean meal so that the calculated apparent digestibility for the protein component of CC becomes inaccurate.

Table 4. Effects of experimental diets on macronutrient and energy digestibility

Digestibility (% of intake)	Sex	GC	RB	BR	CC	SEM
Dry matter	male	86.4[b]	81.9[c]	94.0[a]	92.0[a]	0.56
	female	88.7[c]	83.6[d]	94.6[a]	91.9[b]	0.58
	combined	87.2[b]	82.8[c]	94.3[a]	91.5[a]	0.91
Organic matter	male	88.4[b]	85.3[c]	95.7[a]	93.8[a]	0.35
	female	89.4[c]	86.2[d]	95.8[a]	93.8[b]	0.47
	combined	88.9[b]	85.8[c]	95.7[a]	93.8[a]	0.69
Crude protein	male	73.6[bc]	67.9[c]	87.1[a]	79.0[b]	2.48
	female	74.5[bc]	70.1[c]	84.9[a]	78.7[ab]	2.33
	combined	74.0[c]	69.0[d]	86.0[a]	78.8[b]	1.13
Crude fat	male	87.0	89.9	89.3	86.4	0.71
	female	86.0[c]	89.9[a]	88.2[b]	81.6[d]	0.86
	combined	86.5[ab]	89.9[a]	88.7[a]	84.0[b]	1.21
Crude fibre	male	57.4	57.2	58.4	56.5	1.87
	female	56.2	51.5	62.4	55.8	1.81
	combined	56.8	54.4	60.4	56.2	1.30
Nitrogen-free extract	male	89.4[b]	87.3[b]	97.4[a]	96.2[a]	0.39
	female	91.5[c]	87.9[d]	97.8[a]	96.7[b]	0.43
	combined	90.4[b]	87.6[c]	97.6[a]	96.5[a]	0.63
Energy	male	87.2[bc]	84.9[c]	94.3[a]	90.2[b]	0.47
	female	88.6[bc]	85.7[c]	93.9[a]	91.5[ab]	0.67
	combined	87.9[bc]	85.3[c]	94.1[a]	90.9[b]	0.81

[a, b, c, d] Means in the same row with different superscripts differ significantly ($P < 0.05$)

Table 5. Effects of experimental diets on nitrogen balance.

	Sex	GC	RB	BR	CC	SEM
DM intake (g/d)	male	790.4	620.6	820.8	770.1	43.0
	female	868.3	743.3	894.1	761.0	47.7
	combined	829.3	681.9	857.4	765.6	32.1
N intake (g/d)	male	22.1	16.0	21.3	20.3	2.29
	female	24.3	19.1	23.2	20.1	2.56
	combined	23.2^{a}	17.6^{c}	22.2^{ab}	20.2^{ab}	1.68
N faecal output (g/d)	male	7.3^{a}	5.7^{ab}	3.6^{b}	4.7^{ab}	1.06
	female	7.0^{a}	6.0^{a}	3.1^{b}	4.9^{ab}	0.70
	combined	7.1^{a}	5.8^{ab}	3.4^{c}	4.8^{bc}	0.62
N absorbed (g/d)	male	14.8^{ab}	10.3^{b}	17.7^{a}	15.6^{ab}	1.79
	female	17.4^{ab}	13.1^{b}	20.0^{a}	15.1^{ab}	2.13
	combined	16.1^{b}	11.7^{b}	18.9^{a}	15.4^{ab}	1.37
N urinary output (g/d)	male	1.8	1.4	1.4	1.7	0.34
	female	1.2	0.9	1.4	1.2	0.21
	combined	1.5	1.2	1.4	1.5	0.21
N retention (g/d)	male	13.0^{ab}	8.8^{b}	16.2^{a}	13.9^{a}	1.67
	female	16.2	12.2	18.6	13.9	2.08
	combined	14.6^{a}	10.5^{b}	17.4^{a}	13.9^{ab}	1.33
N retention (g/kg$^{0.75}$*d)	male	1.6	1.4	2.0	1.8	0.26
	female	1.9^{a}	1.3^{b}	2.0^{a}	1.6^{ab}	0.18
	combined	1.8^{ab}	1.4^{b}	2.0^{a}	1.7^{ab}	0.15
N retention/N absorbed (%)	male	88.7^{ab}	82.9^{b}	91.3^{a}	89.4^{ab}	2.49
	female	92.6	90.9	92.5	92.7	1.75
	combined	90.7^{ab}	86.9^{b}	91.9^{a}	91.1^{ab}	1.59
N retention /N intake (%)	male	61.2^{ab}	53.3^{b}	75.0^{a}	70.5^{a}	4.95
	female	65.9^{b}	61.7^{b}	80.0^{a}	70.0^{b}	3.18
	combined	63.5^{bc}	57.5^{c}	77.5^{a}	70.2^{ab}	2.93

[a, b, c] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

In conclusion, the present data indicate that in Kadon pigs fed diets with different carbohydrate sources differences in macronutrient digestibility can be measured. The diet with BR induced the highest digestibilities for protein and energy, but also had the highest ingredients costs. In essence, the diet with CC had produced the second highest digestibilities, whereas this diet was 18% less expensive than the diet with BR. Thus, when compared on an isonitrogenous basis, cassava chips may be used instead of ground corn, rice bran or broken rice in order to reduce costs of diets to be used in pig production, including on small-holder farms. The carbohydrate sources with different protein contents must be fed in combination with different amounts of protein sources. In this experiment, soybean meal was used as a protein source. Clearly, the price of the protein source also has an impact on the comparision of the whole diet costs using different carbohydrate sources.

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CHAPTER 3

Effect of dietary broken rice and cassava chips on growth, nutrient digestibility and nitrogen retention in growing Kadon pigs

K. Vasupen[1*], C. Yuangklang[1], S. Wongsuthavas[1], P. Srenanul[1], J. Mitchaothai[2] and A. C. Beynen[3]

[1]*Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand.*
[2]*Department of Clinic for swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.*
[3]*Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.*

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Abstract

The aim of this study was to determine the effects of dietary broken rice (BR) and cassava chips (CC) on growth, nutrient digestibility and nitrogen retention in growing Kadon pigs in a parallel design. There were four measurement periods over the entire experiment lasting 56 days. Slaughter and meat characteristics were determined at the end of the experiment. For the entire experimental period there was no significant diet effect on average daily gain (ADG), but ADG on the CC diet was on average 12 % lower. In the pigs fed the BR diet the digestibilities of dry matter (DM), organic matter (OM), crude protein (CP), crude fat (EE, ethereal extract) and carbohydrates (NFE, nitrogen-free extract) were all higher. The higher digestibility of OM in the pigs fed on the BR diet was associated with a higher digestibility of gross energy in the diet. The higher digestibility CP in the pigs fed the BR diet was reflected by a smaller fecal nitrogen (N) output, but N retention in the two groups of pigs was similar. This study shows that the carbohydrates in BR are more easily digested than those in CC. The higher amount of protein and the higher digestible carbohydrate content of BR, in combination with the actual prices and availability of BR and CC, will determine which carbohydrate source will be used in pig production, including on small-holder farms.

Keyword: Kadon pigs, broken rice, cassava chip, digestibility, nitrogen retention

Introduction

Pig production in the small-holder sector of North-Eastern Thailand relies heavily on the use of the indigenous Kadon pig. In this breed of pigs we have compared four carbohydrate sources as to digestibility of macronutrients and nitrogen metabolism (Chapter 2). In that study, the pigs were fed on diets containing either ground corn (GC), rice bran (RB), broken rice (BR) or cassava chips (CC). The feeding of BR and CC was found to induce the highest and second highest digestibilities.

The type of dietary carbohydrate may influence diet palatability and nutrient utilization in pigs (Bach Knudsen and Jorgensen, 2001) and it can alter the gut microflora (Pluske, 2001). An increase in available carbohydrates in the diet through using feedstuffs rich in starch may improve growth rate of pigs. Recent studies provide evidence that an increase in available carbohydrate in the diet improved growth performance in growing-finishing pig (Camp et al., 2003). Khajarern and Khajarern (1986) reported that growing-finishing pigs fed a diet containing cassava had poorer average daily gain and feed conversion ratio than did their counterparts fed on diets containing broken rice or sorghum diets, but the differences failed to reach statistical significance. The positive results for broken rice in our earlier study (Chapter 2) and in the literature prompted us to further compare and contrast BR and CC as feedstuffs for growing Kadon pigs. The aim of this study was to determine the effects of dietary broken rice and cassava chips on growth, nutrient digestibility and nitrogen retention in growing Kadon pigs. To a certain extent, this study repeats our earlier work (Chapter 2), but the measurements were made over a longer period of time in a parallel design. Furthermore, slaughter and meat characteristics were determined at the end of the experiment.

Materials and Methods

Animals

The experiment was performed with 16 male growing Kadon pigs with average body weight of 10.4±1.8 kg. The pigs (8 pigs per diet) were fed one of the two experimental diets. The pigs were individually penned in metabolic cages and had free access to water from nipple drinkers. The experiment was conducted in the period of November and December, 2005.

Experimental design

The 16 pigs were arranged in a randomized parallel design and were fed the diets based on either BR or CC. The experimental period lasted 56 days. There were four measurement periods of is 14 days each. Each period consisted of 9 days for feed intake measurements followed by 5 days for sample collection.

Diets and feeding

The carbohydrate source for the experimental diets were broken rice (BR) and cassava chips (CC) that were available locally. The ingredient composition of the diets is shown in Table 1. The BR diet contained 68 % BR and the CC diet contained 58 % CC. The experimental diets were formulated to contain the same amount of crude protein by adding extra soybean meal to the CC diet. The amounts of added vitamins and minerals were identical for the two diets. Pigs were fed ad libitum twice daily at 07.00 am and 16.30 pm, with the daily allowance being equally divided between the two meals.

Measurements

Feed consumption was measured as the difference between the amount of feed offered and refused. Pigs were weighed at the beginning and at the end of each measurement period just before the morning meal. Changes in live weight were used to estimate the average daily gain (ADG). Feed conversion ratio (FCR) was calculated as the ratio of the amount of consumed feed to 1 kg gain of body weight. For the determination of total tract digestibility, feces were collected in plastic bags attached to the pigs. The bags were changed at least twice daily, and stored frozen (–20 ^{o}C) pending analysis. Urine was collected in containers via the funnels underneath the cages. Urine was removed twice each day and stored at –20 °C until the time of analysis. To prevent nitrogen (N) losses during collection and storage, 10 ml of 25% H_2SO_4 was added to each container every day. Diets and feces were dried at 60 °C in a forced-air oven for 96 h, and ground to pass through a 1-mm screen. All samples were analyzed for proximal components (AOAC, 1990) in duplicate. Urine was used to determine N excretion.

At the end of the experiment, eight pigs per group were slaughtered. Carcass characteristics were evaluated according to the Thai style of carcass cutting (Jaturasitha, 2004). The weights of the head, tail, liver, kidney, spleen, heart, lungs, full digestive tract, and hot carcass weight were recorded. The characteristics measured included dressing percentage, thickness of back fat, and loin proportion. The loin muscles (*longissimus dorsi*) were collected to determine the proximate composition. The pH value of muscle was determined using the meat pH meter (Model HI99163, Hanna Instruments, Portugal) at 45 min (pH_1) and at 24 h (pH_U) after slaughter. The right loin muscle was collected and stored at –20 °C until analysing the remaining meat quality parameters. The meat samples were dried at 60 °C for 72 h in a forced-hot-air oven to quantify the percentage of moisture and were then analyzed for crude protein, crude fat and ash (AOAC, 1990).

Statistical analysis

The effects of dietary carbohydrate were evaluated for statistical significance by the Student's t-test (SPSS, 1998). All results are expressed as means $\pm$ SD. The level of statistical significance of diet effects was preset at $P < 0.05$.

Results and Discusion

The experimental diets containing either BR or CC as carbohydrate source were isonitrogenous, but analysis showed that the CC diet contained more crude fiber, both calculated (Table 1) and analyzed (Table 2) than did the CC diet. The CC diet also contained more ash even though the calcium and phosphorus concentrations in the two experimental diets were similar (Table 2). The higher fiber content of the CC diet will tend to lower the digestibilities of carbohydrates and protein, which should be taken into account when interpreting the results.

Table 1. Ingredient and calculated composition of the experimental diets for the growing Kadon pigs

Ingredient	BR	CC
Broken rice	68	0
Cassava chip	0	58
Soybean meal	30	40
Salt	0.1	0.1
Di-calcium phosphate	0.5	0.5
L-lysine	0.3	0.2
DL-methionine	0.1	0.2
Premix*	1.0	1.0
Total	100	100
DM (% as fed basis)	89.34	90.53
OM	96.60	94.01
CP	16.19	16.50
EE	2.52	1.94
CF	3.80	7.22
NFE	74.09	68.35
Calculated ME, kcal	3,232	3,203

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

In period 2, the ADG of the pigs was significantly lower when CC instead of BR was present in the diet (Table 3). However, for the entire experimental period there was no significant diet effect on ADG, albeit that ADG on the CC diet was on average 12 % lower. This outcome corroborates the results of Khajarern and Khajarern (1986), using growing-finishing pigs (17-100 kg) and also showing that those fed the diet containing cassava tended to have poorer ADG and FCR than their counterparts fed on diets containing either broken rice or sorghum diets. The pigs fed on the CC diet tended to higher feed intake. The lower group mean ADG and higher dry matter intake (DMI) in the pigs fed on the CC diet led to a higher group mean FCR.

Table 2 Analyzed composition of the experimental diets.

Item	BR	CC
Dry matter, %	87.7	87.9
Organic matter, % of DM	95.3	93.3
Crude protein, % of DM	17.4	17.8
Crude fat, % of DM	2.6	1.4
Crude fibre, % of DM	2.4	4.4
Ash, % of DM	4.7	6.7
Nitrogen-free extract, % of DM	71.5	69.1
Gross energy, kcal/kgDM	4,203	4,124

In the pigs fed the BR diet the digestibilities of dry matter (DM), organic matter (OM), crude protein (CP), crude fat (EE, ethereal extract) and carbohydrates (NFE, nitrogen-free extract) were all higher, when compared with the pigs fed the CC diet (Table 4). An exception was the digestibility of crude fiber (CF), this parameter being similar for the two dietary groups. The higher digestibility of OM in the pigs fed on the BR diet was associated with a higher digestibility of gross energy in the diet. Clearly, this study shows that the carbohydrates in BR are more easily to digested than those in CC. In addition, the type of carbohydrate may have affect the digestibility of other components of the diet as well. The present results in the native, Thai Kadon pig are similar to those published for commercial pigs (Khajarern and Khajarern, 1986). The lower digestibility of the CC diet was associated with a tendency towards a higher feed intake, the increase in DMI being on average 4.7 % for the entire experimental period. The increase in feed intake was associated with a 6.7 % lower final body weight (BW), but the lowering was not statistically significant.

Table 3 Effects of carbohydrate source on growth performance in growing pigs

Period	Performance	BR	CC	P value
Period I	Initial BW, kg	14.51±1.09	14.55±2.26	0.97
	Final BW, kg	20.06±1.66	19.66±2.72	0.73
	ADG, g/d	346.88±126.07	319.53±75.55	0.61
	DMI, g/d	666.50±141.22	736.07±138.72	0.37
	FCR	2.13±0.69	2.37±0.55	0.44
Period II	Initial BW, kg	20.06±1.66	19.66±2.72	0.89
	Final BW, kg	25.35±2.21	23.70±2.01	0.14
	ADG, g/d	395.54±88.47[b]	288.39±86.56[a]	0.03
	DMI, g/d	820.72±154.64	747.71±166.05	0.38
	FCR	2.13±0.41	2.76±0.78	0.07
Period III	Initial BW, kg	25.35±2.21	23.70±2.01	0.14
	Final BW, kg	30.03±3.14	27.7±2.33	0.11
	ADG, g/d	333.93±109.31	285.71±50.65	0.28
	DMI, g/d	920.48±202.92	1010.57±141.58	0.32
	FCR	3.02±1.02	3.60±0.58	0.19
Period IV	Initial BW, kg	30.03±3.14	27.70±2.33	0.11
	Final BW, kg	32.56±3.46	30.39±3.05	0.21
	ADG, g/d	215.31±88.49	244.05±83.59	0.56
	DMI, g/d	823.76±176.92	903.54±226.71	0.50
	FCR	4.15±1.23	3.98±1.47	0.19
Over all	Initial BW, kg	14.51±1.90	14.55±2.26	0.97
	Final BW, kg	32.56±3.46	30.39±3.05	0.21
	ADG, g/d	326.38±119.04	287.11±75.40	0.13
	DMI, g/d	807.36±186.86	845.67±197.88	0.44
	FCR	2.81±1.17	3.13±1.04	0.28

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

Table 4 Effects of carbohydrate source on nutrient digestibility in growing Kadon pigs.

Period	Digestibility, %	BR	CC	P value
Period I	DM	90.43±2.47[b]	83.68±3.68[a]	0.0010
	OM	92.00±2.02[b]	85.83±3.01[a]	0.0004
	CP	87.34±3.73[b]	80.21±5.10[a]	0.0071
	EE	63.55±7.20[b]	43.80±14.61[a]	0.0062
	CF	42.38±10.94	43.36±14.45	0.8815
	NFE	96.06±1.35[b]	93.57±1.32[a]	0.0022
	Ash	58.79±12.44	51.51±13.84	0.2874
	Energy	90.12±2.25[b]	82.54±3.87[a]	0.0005
Period II	DM	91.64±1.72[b]	83.08±3.14[a]	0.00003
	OM	93.01±1.59[b]	85.45±2.73[a]	0.0000
	CP	89.18±2.49[b]	78.68±5.03[a]	0.0003
	EE	74.81±5.82[b]	40.72±13.76[a]	0.0001
	CF	42.32±12.08	35.76±16.80	0.3871
	NFE	95.98±0.91[b]	93.02±1.84[a]	0.0021
	Ash	59.38±7.22[b]	45.59±11.92[a]	0.0166
	Energy	91.58±1.62[b]	82.19±3.61[a]	0.0001
Period III	DM	91.19±1.59[b]	85.33±1.83[a]	0.00001
	OM	92.39±152[b]	93.62±1.05[a]	0.0000
	CP	87.52±1.89[b]	81.96±2.70[a]	0.0004
	EE	68.88±6.52[b]	35.65±6.59[a]	0.0000
	CF	44.80±5.27	46.64±7.01	0.5643
	NFE	95.53±134	95.35±0.79	0.6354
	Ash	66.42±4.19[b]	47.04±6.94[a]	0.0000
	Energy	90.57±1.62[b]	85.11±2.12[a]	0.0001

Table 4 (continue)

Period	Digestibility, %	BR	CC	P value
Period IV	DM	92.46±1.23[b]	85.69±3.11[a]	0.0030
	OM	93.62±1.05[b]	88.62±2.81[a]	0.0030
	CP	87.87±2.25	83.23±5.01	0.0762
	EE	76.51±4.42[b]	53.13±10.20[a]	0.0015
	CF	55.22±8.01	51.14±16.87	0.6046
	NFE	96.28±0.53[b]	93.58±1.23[a]	0.0019
	Ash	67.94±7.20[b]	52.78±11.77[a]	0.0251
	Energy	91.86±0.98[b]	85.74±3.08[a]	0.0037
Over all	DM	91.33±1.81[b]	84.37±3.05[a]	0.0000
	OM	92.67±1.57[b]	86.75±2.67[a]	0.0000
	CP	87.98±2.66[b]	80.87±4.63[a]	0.0000
	EE	70.70±7.81[b]	42.67±12.78[a]	0.0000
	CF	45.89±10.42	43.76±14.51	0.5150
	NFE	95.95±1.08[b]	93.90±1.58[a]	0.0000
	Ash	62.98±8.93[b]	49.00±11.18[a]	0.0000
	Energy	91.00±1.77[b]	83.77±3.45[a]	0.0000

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

DM = Dry matter, OM = Organic matter, CP = Crude protein, EE = Ether extract, CF = Crude fiber, NFE = Nitrogen-free extract, Ash = Inorganic matter.

The higher digestibility of CP in the pigs fed the BR diet is reflected in the data for the nitrogen balance (Table 6). As would be expected the faecal N output was significantly smaller for the pigs fed the BR diet. N retention in the two groups of pigs was similar. This can be explained by the intake of N not limiting growth and N retention. The higher group mean ADG in the pigs fed the BR diet was not associated with a tendency towards more N retention. This might point at a difference in body composition or gut fill between the two groups of pigs.

Table 5 Effects of carbohydrate source on calculated nutrient intake in growing Kadon pigs

Period	Nutrient	BR	CC	P value
Period I	DMI, g	666.50±141.22	736.07±138.72	0.3371
	OMI, g	635.10±134.57	681.32±134.97	0.5039
	CPI, g	116.70±24.41	131.43±25.68	0.2592
	EEI, g	18.33±3.26[b]	10.29±1.94[a]	0.0001
	CFI, g	16.10±3.07[a]	32.96±6.12[b]	0.0000
	NFEI, g	449.07±99.27	484.93±97.29	0.4776
	AshI, g	31.41±6.65[a]	49.05±9.84[b]	0.0012
	Energy I, kcal	2779.97±605.22	3002.29±596.73	0.4716
Period II	DMI, g	820.72±154.64	747.71±166.05	0.3782
	OMI, g	786.38±145.96	693.48±156.45	0.2398
	CPI, g	143.77±26.67	135.10±29.03	0.5438
	EEI, g	23.33±3.26[b]	10.48±2.20[a]	0.0000
	CFI, g	18.13±4.28[a]	32.79±7.45[b]	0.0005
	NFEI, g	558.04±109.35	502.01±110.29	0.3249
	AshI, g	34.04±8.81[a]	47.28±11.75[b]	0.0242
	Energy I, kcal	3480.19±640.07	3059.54±692.51	0.2278
Period III	DMI, g	920.48±202.92	1010.57±141.58	0.3226
	OMI, g	877.75±193.00	925.96±147.44	0.5840
	CPI, g	161.02±34.97	180.91±24.78	0.2127
	EEI, g	24.72±4.62[b]	13.94±1.99[a]	0.0001
	CFI, g	22.14±4.88[a]	44.15±6.88[b]	0.0000
	NFEI, g	624.04±137.35	677.99±89.69	0.3705
	AshI, g	42.73±9.92[a]	66.04±10.55[b]	0.0005
	Energy I, kcal	3893.31±839.18	4086.44±654.02	0.6161

Table 5 (continue)

Period	Nutrient	BR	CC	P value
Period IV	DMI, g	809.15±168.94	903.54±226.71	0.5017
	OMI, g	771.02±160.98	770.70±238.95	0.5987
	CPI, g	142.30±28.39	162.94±39.65	0.3158
	EEI, g	22.85±4.41[b]	13.06±2.88[a]	0.0007
	CFI, g	19.81±4.25[a]	40.00±10.04[b]	0.0030
	NFEI, g	559.15±121.74	602.74±153.48	0.5879
	AshI, g	38.82±8.34[a]	60.16±15.11[b]	0.0163
	Energy I, kcal	3506.88±739.40	3745.01±928.79	0.6246
Over all	DMI, g	807.36±186.86	845.87±197.88	0.4380
	OMI, g	770.60±177.89	782.21±186.35	0.8043
	CPI, g	140.90±31.91	151.91±35.11	0.2058
	EEI, g	22.29±4.47[b]	11.87±2.68[a]	0.0000
	CFI, g	19.02±4.57[a]	37.31±8.74[b]	0.0000
	NFEI, g	547.20±129.08	564.53±133.80	0.6088
	AshI, g	36.68±9.24[a]	55.33±13.72[b]	0.0000
	Energy I, kcal	3412.13±791.43	3455.21±825.08	0.8359

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

Table 6 Effects of carbohydrate source on nitrogen balance in Kadon growing pigs.

	BR	CC	P value
Period I			
N intake (g/d)	18.67±3.91	21.03±4.11	0.259
N fecal out put (g/d)	2.33±0.86[a]	4.23±1.59[b]	0.013
N absorbed (g/d)	16.34±3.40	16.80±3.14	0.785
N urine output (g/d)	3.33±0.95	3.56±1.58	0.721
N retention (g/d)	13.02±3.28	13.24±2.12	0.878
N retention /N intake (%)	69.23±5.75	63.51±5.94	0.070

Table 6 (continue)

	BR	CC	P value
Period II			
N intake (g/d)	23.00±4.27	21.62±4.65	0.544
N fecal out put (g/d)	2.55±0.91[a]	4.45±0.89[b]	0.001
N absorbed (g/d)	20.45±3.52	17.16±4.53	0.129
N urine output (g/d)	4.60±1.65	5.80±1.70	0.173
N retention (g/d)	15.86±2.60[b]	11.37±3.80[a]	0.017
N retention /N intake (%)	69.48±6.44[b]	52.58±8.74[a]	0.001
Period III			
N intake (g/d)	25.76±5.60	28.95±3.96	0.213
N fecal out put (g/d)	3.24±0.92[a]	5.22±1.07[b]	0.001
N absorbed (g/d)	22.53±4.86	23.73±3.37	0.576
N urine output (g/d)	3.06±0.92	3.54±2.11	0.615
N retention (g/d)	19.47±4.99	20.19±2.81	0.728
N retention /N intake (%)	75.36±7.76	69.75±7.10	0.178
Period IV			
N intake (g/d)	22.77±4.54	26.07±6.34	0.316
N fecal out put (g/d)	2.79±0.80	4.50±1.80	0.070
N absorbed (g/d)	19.98±3.88	21.57±4.94	0.212
N urine output (g/d)	3.46±2.92	3.36±1.18	0.935
N retention (g/d)	16.52±2.34	18.21±4.10	0.400
N retention /N intake (%)	73.86±10.38	70.50±7.13	1.212
Over all			
N intake (g/d)	22.54±5.11	24.30±5.62	0.206
N fecal out put (g/d)	2.72±0.90[a]	4.61±1.34[b]	0.000
N absorbed (g/d)	19.82±4.40	19.70±4.85	0.918
N urine output (g/d)	3.62±1.87	4.11±1.92	0.3101
N retention (g/d)	16.21±4.07	15.59±4.81	0.5896
N retention /N intake (%)	71.92±7.78[b]	63.55±10.37[a]	0.001

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Table 7 shows the results of carcass analysis. There were significant differences between the two dietary groups. The CC diet had induced less back fat and a lower weight of heart. The lower back fat content in pigs fed the CC diet implies a change in body composition, which is difficult to explain in the light of unchanged nitrogen retention and tendency towards a decrease in final body weight. The lower heart weight in the pigs on the CC diet cannot be easily explained. The loin weight of the pigs fed either the BR or CC diet was not different (Table 7) and the proximate composition was not different either (Table 8).

Table 7 Effects of carbohydrate source on carcass in growing Kadon pigs.

Item	BR	CC	P value
Number of pigs	8	8	-
Initial BW (kg)	14.51±1.09	14.55±2.26	0.972
Slaughter BW (kg)	32.56±3.50	30.39±3.05	0.206
Percentage of carcass (%)	68.74±5.75	65.45±4.17	0.213
Loin weight (kg)	2.47±0.51	2.18±0.37	0.223
Percentage of loin/carcass weight	10.98±1.40	11.08±1.16	0.878
Back Fat (cm)	1.83±0.42 [a]	1.04±0.42 [b]	0.002
Head (kg)	2.89±0.33	2.53±0.36	0.056
Heart (g)	164.38±30.52 [a]	120.63±15.22 [b]	0.004
Liver (g)	675.00±115.05	691.88±148.80	0.804
Lungs (g)	658.13±187.08	558.13±158.92	0.269
Spleen (g)	78.13±23.29	71.25±13.82	0.487
Kidneys (g)	178.13±18.31	165.63±25.13	0.276
Stomach (g)	587.50±313.68	666.88±434.34	0.682
Small intestine	726.25±195.59	765.00±160.00	0.671
Large intestine	990.00±231.52	874.00±274.75	0.377

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Table 8 Chemical composition of loin from Kadon pigs fed either the BR or CC diet

Item	BR	CC	P value
Dry matter, %	30.2±2.9	28.0±4.6	0.260
Crude protein, (% of DM)	67.6±3.9	69.7±4.91	0.351
Ash, (% of DM)	5.5±0.5	5.4±0.5	0.755
Total fat, (% of DM)	24.7±7.1	23.2±7.8	0.692
pH_1	6.18±0.10	6.25±0.32	0.578
pH_U	5.98±0.28	6.14±0.29	0.256

[a, b] Means in the same rows with different superscripts differ significantly (P < 0.05). There were 8 pigs per dietary treatment.

This study with growing Kadon pigs clearly shows that the nutritional quality of BR is better than that of CC when looking at the digestibilities of macronutrients. However, as noted earlier (Chapter 2), BR is more expensive than CC, but is also contains more protein. Thus, the higher amount of protein and the higher digestible carbohydrate content of BR, in combination with the actual prices and availability of BR and CC, will determine which carbohydrate source will be used in pig production, including on small-holder farms.

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CHAPTER 4

Calcium and phosphorus balance in growing Kadon pigs fed diets containing either broken rice or cassava chips

K. Vasupen[1*], C. Yuangklang[1], S. Wongsuthavas[1], P. Srenanul[1], J. Mitchaothai[2] and A. C. Beynen[3]

[1]*Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand.*
[2]*Department of Clinic for swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.*
[3]*Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.*

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Abstract

In the present experiment, the effect of consumption of either broken rice (BR) or cassava chips (CC) on calcium and phosphorus balance was studied in growing Kadon pigs. Sixteen male pigs with initial body weight of 10.4 ± 1.8 kg were used in a completely randomized design. The experimental diets contained similar concentrations of calcium and phosphorus, but the intakes were somewhat higher in pigs fed the CC diet. Apparent calcium and phosphorus absorption, when expressed as a percentage of intake, was significantly lower in the pigs fed the CC diet. In the pigs fed the CC diet instead of the BR diet, fecal calcium and phosphorus excretion were significantly increased. These data indicate that when formulating pig diets containing either BR or CC as carbohydrate source the levels of calcium and phosphorus may be adjusted to take into account the different efficiencies of absorption.

Keywords: Kadon pigs, broken rice, cassava chips, calcium balance, phosphorus balance

Introduction

Studies with rats (Heijnen et al., 1993; Schulz et al., 1993) and dogs (Beynen et al., 2001, 2002) have shown that the carbohydrate source of the diet can influence the absorption of minerals such as calcium, magnesium and phosphorus. The general idea is that less digestible carbohydrates stimulate mineral absorption. Less digestible carbohydrates will be fermented in the small intestine, leading to a lowering of the pH and an increase in the solubility of minerals (Heijnen et al., 1993). Soluble, rather than insoluble minerals are available for absorption (Brink et al., 1992) so that an increase in mineral solubility is associated with an increased absorption efficiency. For pigs it also has been reported that poorly digestible, but fermentable carbohydrates in the diet stimulate mineral absorption (Heijnen and Beynen, 1998). In the course of our studies (Chapters 2 and 3) with growing Kadon pigs we found that the carbohydrates in broken rice (BR) have a higher digestibility than those in cassava chips (CC). In the light of the above mentioned, it would be hypothesized that pigs fed a diet with BR would show a lower apparent absorption than those fed a diet with CC.

Materials and Methods

Animals and Experimental design

The pigs and diets had been used in the study described in Chapter 3. The experiment involved 16 male growing Kadon pigs with an average body weight of 10.4$\pm$1.8 kg. The experimental diets were given to 8 pigs each. The pigs were individually penned in metabolic cages and had free access to water from nipple drinkers.

The pigs were subjected to a completely randomized, parallel design. The experimental period lasted 56 days. During the last 14 days feces and urine were collected quantitatively. During the first 9 days feed intake was measured followed by 5 days for sample collection.

Diets and feeding

The dietary carbohydrate sources were broken rice (BR) and cassava chips (CC)) that were obtained at a local market. The ingredient composition of the diets is shown in

Table 1. The diets containing either BR or CC were formulated so that they were similar in crude protein content by adding soybean meal. Pigs were fed ad libitum twice daily at 07.00 am and 16.30 pm, with the daily allowance being equally divided between the two meals.

Table 1. Composition of the experimental diets for native growing pigs

Ingredient	BR	CC
Broken rice	68	0
Cassava chip	0	58
Soybean meal	30	40
Salt	0.1	0.1
Di-calcium phosphate	0.5	0.5
L-lysine	0.3	0.2
DL-methionine	0.1	0.2
Premix*	1.0	1.0
Total	100	100

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

Table 2 Analyzed composition of the experimental diets.

Item	BR	CC
Dry matter, %	87.7	87.9
Crude protein, % of DM	17.4	17.8
Crude fat, % of DM	2.6	1.4
Crude fiber, % of DM	2.4	4.4
Ash, % of DM	4.7	6.7
Nitrogen-free extract, % of DM	71.5	69.1
Nitrogen, % of DM	2.78	2.85
Calcium, % of DM	0.51	0.56
Phosphorus, % of DM	0.42	0.44

Measurements

For the determination of total tract digestibility of calcium and phosphorus, fecal samples were quantitatively collected in plastic bags attached to the pigs. The bags were changed at least twice daily and stored frozen (–20 ^oC) pending analysis. Urine was collected in containers via the funnels underneath the cages. Urine was removed twice each day and stored at –20 ^oC until the time of analysis. During collection and storage, 10 ml of 25% H_2SO_4 was added to each container every day. Diets and faeces were then dried at 60 ^oC in a forced-air oven for 96 h and ground to pass a 1-mm screen. Diet samples were analyzed for proximate composition (AOAC, 1990). Urine and faeces were determined for calcium and phosphorus as described (Mitchaothai et al., 2007).

Statistical analysis

The effects of dietary carbohydrate source were evaluated for statistical significance by the Student's t-test (SPSS, 1998). All results are expressed as means $\pm$ SD. The level of statistical significance was preset at $P < 0.05$.

Results and Discussion

Table 2 shows the analyzed composition of the experimental diets and confirms that the protein content of the BR and CC diet was similar. The calcium and phosphorus content did not differ much between the two diets. However, the CC diet contained more ash than did the BR diet.

The source of dietary carbohydrate did not have significant effects on growth performance (Table 3). However, the BR diet tended to raise body-weight gain, lower dry matter (DM) intake and have a favorable effect on the feed conversion ratio(FCR). It is likely that the increased digestibility of macronutrients as seen on the BR diet (Chapter 3) had caused the tendency towards a lower DM intake because the requirement of metabolic energy would be met with less feed.

The main purpose of this study was to examine the influence of the feeding of BR versus CC diets on the apparent absorption of calcium and phosphorus. Table 4 shows that the pigs fed the BR diet had somewhat lower intake of both calcium and phosphorus. The Kadon pigs fed the BR diet instead of the CC diet showed a significantly increased apparent absorption when expressed as a percentage of intake (Table 4). In keeping with the effect on the efficiency of absorption, the BR diet produced a significant decrease in the fecal excretion of both calcium and phosphorus. Urinary excretion of the two minerals was not affected by the carbohydrate source of the diet. The absolute amounts of calcium and phosphorus absorbed were similar for the BR and CC diet, which is explained by the combination of lower group mean intake and the higher efficiency of absorption on the BR diet.

The outcome in that the BR diet versus the CC diet stimulated the absorption efficiency of calcium and phosphorus is contrary to our hypothesis. It was expected that the higher digestibility of the carbohydrates in BR would be associated with a lower absorption efficiency of calcium and phosphorus. However, the observed (Chapters 2 and 3) difference in carbohydrate digestibility refers to faecal digestibility so that the location and extent of fermentation remains unknown. The hypothesis was formulated under the assumption that the less digestibile carbohydrates in CC would lead to extra fermentation and a lowering of the pH in the small intestinal contents. There is no experimental evidence for this assumption.

Table 3 Effects of carbohydrate source on growth performance in growing Kadon pigs.

Item	BR	CC	P value
Initial BW, kg	14.5±1.9	14.6±2.3	0.972
Final BW, kg	32.6±3.5	30.4±3.1	0.206
Growth, kg	18.1±3.5	15.8±1.8	0.141
ADG, g/d	326.4±119.0	287.1±75.4	0.129
DMI, g/d	807.4±186.9	845.9±197.9	0.438
FCR	2.81±1.2	3.13±1.0	0.277

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Table 4 Intake, excretion and absorption (g/d) of calcium and phosphorus.

Diets	BR	CC	P-value
Calcium			
Intake (g/d)	4.28±0.91[a]	4.88±1.07[b]	0.020
Faeces (g/d)	1.32±0.39[a]	2.03±0.71[b]	0.000
Absorbed (% of intake)	68.75±8.16[b]	58.90±9.99[a]	0.000
Absorbed (g/d)	2.95±0.75	2.85±0.70	0.597
Urine (g/d)	0.06±0.04	0.08±0.04	0.054
Phosphorus			
Intake (g/d)	3.21±0.79[a]	3.65±0.85[b]	0.039
Feces (g/d)	1.13±0.47[a]	1.53±0.57[b]	0.005
Absorbed (% of intake)	65.46±8.69[b]	58.78±10.00[a]	0.007
Absorbed (g/d)	2.07±0.49	2.12±0.51	0.701
Urine (g/d)	0.11±0.10	0.09±0.06	0.187

[a, b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

As mentioned above, the ash content of the BR diet was much lower than that of the CC diet. The lower ash intake on the BR diet was associated with a lower digestibility of ash (Chapter 3). Possibly, the CC contained a high amount of insoluble ash. Perhaps the insoluble ash had formed complexes with calcium and phosphorus in the intestinal lumen (Brink et al., 1992), leading to diminished absorption of the two minerals on the CC diet. The inhibitory effect of the insoluble ash may have overruled the stimulatory effect, if any, of the carbohydrate source in the CC. As a consequence, the efficiency of mineral absorption was found to be greater instead of lower on the BR diet. The CC diet contained more soybean meal than the BR diet and thus may contained more phytate than the BR diet. Phytate may form insoluble complexes with calcium, whereas the phosphorus in phytate is poorly available. It is not unlikely that the higher level of phytate in the CC diet had contributed to a lowering of calcium and phosphorus absorption.

In conclusion, apparent calcium and phosphorus absorption, when expressed as a percentage of intake, was significantly lower in the pigs fed the CC diet. In the pigs fed the CC diet instead of the BR diet, faecal calcium and phosphorus excretion were significantly increased. These data indicate that when formulating pig diets containing either BR or CC as carbohydrate source, the levels of calcium and phosphorus may be adjusted to take into account the different efficiencies of absorption.

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CHAPTER 5

Effects of dietary broken rice and cassava chips on ileal nutrient digestibility and on volatile fatty acids and bacteria in the ileum of growing Kadon pigs

K. Vasupen[1*], C. Yuangklang[1], S. Wongsuthavas[1], P. Srenanul[1], J. Mitchaothai[2], H. Everts[3] and A. C. Beynen[3]

[1]*Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand.*
[2]*Department of Clinic for swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.*
[3]Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.

To be submitted

Abstract

Earlier studies have shown that broken rice (BR) instead of cassava chips (CC) in the diet of Kadon pigs increases the fecal digestibility of crude protein, carbohydrates and fats. To evaluate nutrient availability for the pigs, the ileal digestibility of the macronutrients is more relevant than the fecal digestibility. Thus, it was decided to revisit the effects of BR and CC on macronutrient digestion in growing Kadon pigs, but now by measuring ileal digestibility in fistulated animals. In this study, the bacterial composition and contents of VFAs in ileal digesta were determined. In addition, carcass quality was determined. The fecal digestibilities of dry matter (DM), organic matter (OM), crude protein (CP), carbohydrates (NFE) and crude fiber (CF) were greater than the ileal digestibility of these macronutrients. On the other hand, the faecal digestibility of crude fat (EE) was lower than its ileal digestibility. The ileal digestibilties of DM, OM, CP, EE and NFE were all significantly higher for the BR diet when compared with the CC diet. The BR diet and CC diet had different effects on the bacterial composition and concentrations of volatile fatty acids in ileal contents. Feeding the BR diet instead of the CC diet had no major impact on carcass quality.

Keywords: Kadon pigs, broken rice, cassava chips, ileal and fecal nutrient digestibility, volatile fatty acids, ileal bacterial composition

Introduction

We have shown that broken rice (BR) and cassava chips (CC) in the diet have differential effects on the fecal digestibility of macronutrients in growing Kadon pigs (Chapters 2-4). When the diet contained BR instead of CC, the apparent fecal digestibility of crude protein, carbohydrates, fats, calcium and phosphorus were increased. However, as to nutrient availability for the pigs, the ileal digestibility of crude protein and carbohydrates is more relevant than the fecal digestibility. Dietary proteins and carbohydrates that have not been digested will enter the hindgut and can be degraded by bacteria so that they will not reach the feces. This implies that the fecal digestibility of protein and carbohydrates could reflect a portion of the protein and carbohydrates that has disappeared in the hindgut and thus was not available to the animal in the form of amino acids or glucose. Thus, it was considered important to revisit the effects of BR and CC on macronutrient digestion in growing Kadon pigs, but now by measuring ileal digestibility.

It is likely that BR and CC contain a fraction of non-digestible carbohydrates. Such carbohydrates, including non-starch polysaccharides, have a strong influence on the activity and composition of the commensal microflora and the amounts of volatile fatty acids (VFAs) produced (Bach Knudsen and Jorgensen, 2001). For the Kadon pig, there is no information on the gut microflora and VFAs. Thus, in this study on the ileal digestibility of macronutrients in Kadon pigs fed diets containing either BR or CC, we decided also to measure the bacterial composition and contents of VFAs in ileal digesta. In addition, carcass quality was determined.

Materials and Methods

Experiment 1

Animals

The experiment was performed with 16 growing, male Kadon pigs. The pigs were individually penned in metabolic cages and had free access to water from nipple drinkers.

Experimental design and diets

Pigs were subjected to completely randomized, parallel design and were fed diets containing either BR or CC. The experimental period lasted 41 days. During the first 36 days feed intake and growth performance were measured followed by 5 days for sample collection.

The carbohydrate sources (BR, CC) were purchased at a local market. The ingredient composition of the diets is shown in Table 1. The experimental diets were formulated so that they had a similar crude protein content by adding soybean meal. Pigs were fed ad libitum feed twice daily at 07.00 am and 16.30 pm, with the daily allowance being equally divided between the two meals.

Table 1 Ingredient and calculated composition of the diets in experiment 1

Ingredient (%)	BR	CC
Broken rice	68	0
Cassava chip	0	58
Soybean meal	30	40
Salt	0.1	0.1
DCP	0.5	0.5
L-lysine	0.3	0.2
DL-methionine	0.1	0.2
Premix*	1.0	1.0
Total	100	100
Calculated composition		
DM (% as fed basis)	89.34	90.53
OM	96.60	94.01
CP	16.19	16.50
EE	2.52	1.94
CF	3.80	7.22
NFE	74.09	68.35
Calculated ME, kcal	3,232	3,203

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

Table 2 Analyzed composition of the diets used in experiment 1

Item	BR	CC
Dry matter, %	87.7	87.9
Organic matter, % of DM	96.4	94.0
Crude protein, % of DM	17.4	17.8
Crude fat, % of DM	2.1	1.1
Crude fibre, % of DM	4.4	5.5
Ash, % of DM	3.6	6.0
Calcium, % of DM	0.4	0.4
Phosphorus, % of DM	0.4	0.4
Nitrogen-free extract, % of DM	72.6	69.6
Gross energy, kcal/kgDM	4,119.6	4,006.2

Measurements

For the determination of total tract digestibility, feces were collected in plastic bags attached to the pigs. The bags were changed at least twice daily and stored frozen (–20 ^{o}C) pending analysis. Diets and feces were then dried at 60 ^{o}C in a forced-air oven for 96 h and ground to pass a 1-mm screen. All samples were analyzed for proximate compositions (AOAC, 1990) in duplicate.

All pigs were slaughtered at the end of the experimental period. Immediately after killing, the pigs were exsanguinated. Hot carcass weight was measured after removing all internal organs including kidney. The thickness of back fat was determined according to standard methods described previously (Sripromma, 1984). The scoring was done at 30 min after slaughtering. The colour score of *M. longissimus thoracic* was measured by using the 6-point Japanese pork colour scale (JPCS) (Nakai et al., 1975) and by determining the CIELAB colour co-ordinates (colour L*, a*, b*) in triplicate with a HunterLab (Colour flex®) device after a 30-min blooming time (D65 light source, 10° standard observer, 45°/0° geometry, 1 in. light surface, white standard; Hunter, Reston, VA). The pH value of muscle was determined using the meat pH meter (Model HI99163, Hanna Instruments, Portugal) at 45 minutes (pH_1) and at 24 hours (pH_U) after slaughter. Right *M. longissimus lumborum* (loin) was collected and stored at –20 ^{o}C until analyzing the remaining meat quality parameters. The percentage of cooking loss and shear force value were determined using a Texture Analyser (Stable Micro System Ltd., Surrey, England) as described by Mitchaothai et al.(2007).

Ileal digesta samples were collected after slaughtering and divided into two portions. The pH of ingesta samples was measured immediately after collection by using a digital, portable pH meter (Mettler-ToledoGmbH.8603 Schwerzenbach. Switzerland) that was calibrated just before use. The first portion was centrifuged at 16,000 x g for 15 minutes and the supernatant was stored at –20 ^{o}C prior to analysis of VFAs using HPLC (Shimadzu Class-VP) according to Van der Weilen et al. (2000). The second portion was taken to identify and quantify cultured groups of viable bacteria (cellulolytic, proteolytic and amylolytic) using the roll-tube technique as described by Hungate (1969).

Experiment 2

Animals

The experiment was performed with 3 male and 3 female Kadon pigs with average body weight of 34.2$\pm$1.3 kg. The pigs were fitted with a simple T-cannula according to Tartrakoon (2000). The pigs were fed diets with either BR or CC. The pigs were individually penned in metabolic cages and had free access to water from nipple drinkers.

Experimental design and diets

The experimental period lasted 12 days. The first 7 days were for adaptation followed by 5 days for sample collection.

The ingredient composition of the diets is shown in Table 3. The experimental diets contained either BR or CC and had a similar crude protein content through the addition of soybean meal. The pigs were fed a restricted amount of diet twice daily at 07.00 am and 16.30 pm, with the daily ration being equally divided between the two meals. Titanium dioxide (TiO_2, 5 g/kg) was added to the diets as an indigestible marker for the determination of nutrient digestibility (Jagger et al., 1992).

Table 3. Ingredient and analyzed composition of the diets used in experiment 2

Ingredient (%)	BR	CC
Broken rice	68	0
Cassava chip	0	58
Soybean meal	30	40
Salt	0.1	0.1
DCP	0.5	0.5
L-lysine	0.3	0.2
DL-methionine	0.1	0.2
Premix*	1.0	1.0
TiO_2	0.5	0.5
Total	100.5	100.5
Analysed composition		
Dry matter, %	88.0	89.5
Organic matter, % of DM	95.9	94.6
Crude protein, % of DM	19.3	19.1
Crude fat, % of DM	1.2	0.7
Crude fibre, % of DM	3.8	4.4
Ash, % of DM	4.1	5.4
Calcium, % of DM	0.4	0.4
Phosphorus, % of DM	0.4	0.4
Nitrogen-free extract, % of DM	71.6	70.4
Gross energy, kcal/kgDM	4,373.7	4,105.9
TiO_2 (mg/g)	3.85	3.78

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

Chemical analysis

Analyses of nitrogen (N), ethereal extract (EE), crude fiber (CF) and dry matter (DM) were carried out according to the procedures of the AOAC (1990). The concentration of TiO_2 was determined according to Jagger et al. (1992). The digestibility data were calculated as based on the concentration of TiO_2 and the concentrations of the nutrients in the test diets, faeces and the ileal digesta samples according to equations [1] and [2] (Houdijk et al. 1999).

$$FDa = [(DIa - DFEa)/ (DIa)] \times 100 \qquad [1]$$

Where : FDa = Apparent fecal nutrient digestibility (%),

DIa = Daily intake of nutrient a (g),

DFEa = Daily excretion of nutrient a via the faeces (g).

$$IDa = \{1 - [(Da \times F_{Ti})/(D_{Ti} \times Fa)]\} \times 100 \quad [2]$$

Where : IDa = Apparent ileal nutrients digestibility (%),

Da = Nutrient concentration in ileal digesta (g/kg)

D_{Ti} = Marker concentration in ileal digesta (mg/g)

F_{Ti} = Marker concentration in diet (mg/g),

Fa = Nutrient concentration in diet (g/kg),

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Measurements

Feces were collected for 2 days at 12-hour intervals followed by ileal digesta collection for 3 days after feeding at 4-hour and 8-hour intervals. Digesta were collected through soft rubber tubing, which was attached to the ileal cannula. The lower section of the tubing was kept immersed in a plastic container filled with ice. Total feces and ileal digesta contents were collected and stored at –20 ^{o}C pending freeze-drying and analysis. For the determination of total tract digestibility, feces were collected in plastic bags attached to the pigs, which were changed at least twice daily, and stored frozen (–20 ^{o}C) pending analysis. Urine was collected in containers via the funnels underneath the cages. Urine was removed twice each day and stored at –20 ^{o}C until the time of analysis. To prevent N losses during collection and storage, 10 ml of 25% H_2SO_4 was added to each container every day. Diets and feces were then dried at 60 ^{o}C in a forced-air oven for 96 h and ground to pass a 1-mm screen. All samples were analyzed for proximate components (AOAC, 1990) in duplicate. Energy value was determined by Parr oxygen bomb calorimeter as described by Galyean (1997).

Ileal digesta samples were collected for a period of one hour, starting at 0, 4 and 8 hr post feeding. The samples were divided into three portions. The first portion was used for stored at –20 °C pending freeze-drying and analysis for chemical composition. The second portion was centrifuged at 16,000 x g for 15 minutes and the supernatant was stored at –20 °C prior to analysis of VFAs using HPLC (Shimadzu Class-VP) according to Van der Weilen et al. (2000). The third portion was used to identify and quantify cultured groups of viable bacteria (cellulolytic, proteolytic, amylolytic and lactic acid bacteria) using the roll-tube technique as described by Hungate (1969).

Statistical analysis

The effects of dietary carbohydrate source were evaluated for statistical significance using Student's t-test (SPSS, 1998). All results are expressed as means ± SD. The level of statistical significance was preset at $P < 0.05$.

Results and Discussion

In keeping with our earlier studies (Chapters 2, 3), experiment 1 shows that the diets containing either BR or CC had no significant effect on ADG, DMI and FCR (Table 4). The BR diet tended to lower ADG, which was not seen earlier. However, the tendency towards a lower DMI on the BR diet agrees with the studies described in Chapters 2 and 3. In this experiment, DMI was on average 25% lower on the BR diet. The beneficial effect of the BR diet on FCR had a P value of 0.094. When taken together the present data and those obtained earlier, it is likely that the observed effects on growth performance are true effects that did not reach statistical significance due to low statistical power.

Table 4 Effect of dietary carbohydrate source on growth performance in experiment 1.

Item	BR	CC	P value
Initial BW, kg	11.8±2.0	10.9±2.5	0.432
Final BW, kg	24.6±3.9	24.9±3.0	0.490
Growth, kg	12.8±2.2	14.0±1.5	0.384
ADG, g/d	320.0±53.3	350.7±37.6	0.384
DMI, g/d	989.2±184.7	1,184.8±205.7	0.086
FCR	3.10±0.45	3.40±0.30	0.175

[a,b] Means in the same column with different superscripts differ significantly ($P < 0.05$)

Table 5 Effect of dietary carbohydrate source on faecal nutrient digestibility in experiment 1

Digestibility, % of intake	BR	CC	P value
Dry matter (DM)	94.8±2.1	92.4±2.1	0.049
Organic matter (OM)	95.6±1.9	93.4±1.8	0.045
Crude protein (CP)	94.8±3.4	93.0±1.6	0.240
Ether extract (EE)	87.1±7.1^{b}	72.8±14.1^{a}	0.041
Crude fiber (CF)	58.7±12.8	52.8±13.1	0.344
Nitrogen free extract (NFE)	96.7±1.1	95.3±1.4	0.056
Ash	59.0±13.2	60.8±16.6	0.822
Calcium	71.8±9.8^{b}	52.2±15.4^{a}	0.016
Phosphorus	68.7±9.8	66.4±11.5	0.686
Gross energy	92.5±2.8	88.9±3.1	0.041

[a,b] Means in the same column with different superscripts differ significantly ($P < 0.05$)

As would be expected on the basis of Chapter 3, the fecal digestibilities of DM, OM, EE and GE were significantly higher in the pigs fed the BR diet, when compared with the pigs fed the CC diet. Thus the effect of BR versus CC on the faecal digestibility of macronutrients is quite reproducible. As shown in Chapter 4, the BR diet raised the apparent absorption of calcium, but unlike the previous experiment there was no significant influence on phosphorus absorption. The reason for the discrepancy in BR effect on phosphorus absorption in this experiment and that described in Chapter 4 is difficult to see.

Table 6 Effect of dietary carbohydrate source on cellulolytic, proteolytic and amylolytic bacteria in ileal contents (experiment 1).

Bacteria	BR	CC	P value
Cellulolytic bacteria (x10^6CFU/ml)	24.0±10.2	31.4±9.7	0.251
Proteolytic bacteria (x10^6CFU/ml)	26.7±9.0	21.9±10.9	0.128
Amylolytic bacteria (x10^6CFU/ml)	16.0±4.8[a]	11.2±4.7[b]	0.022

[a,b] Means in the same rows with different superscripts differ significantly (P < 0.05)

Table 7 Effect of dietary carbohydrate source on the concentration of VFAs in ileal, cecal and rectal contents (experiment 1)

	BR	CC	P value
Ileum			
pH	6.14±0.33	6.24±0.21	0.495
Acetate (mmol/l)	2.88±1.15	4.50±0.87	0.013
Propionate (mmol/l)	0.34±0.32	0.16±0.28	0.334
Butyrate (mmol/l)	5.11±1.87	3.52±0.93	0.076
Total (mmol/l)	8.32±2.71	8.17±1.35	0.899
Caecum			
pH	5.61±0.34	5.81±0.28	0.229
Acetate (mmol/l)	28.4±5.40	19.89±4.53	0.005
Propionate (mmol/l)	11.37±2.25	10.50±2.54	0.498
Butyrate (mmol/l)	5.62±2.84	4.93±1.52	0.568
Total (mmol/l)	45.46±9.87	35.32±4.99	0.042
Rectum			
pH	5.92±0.14	5.95±0.22	0.750
Acetate (mmol/l)	2.09±0.57	6.74±1.70	0.000
Propionate (mmol/l)	0.94±0.17	2.37±1.03	0.010
Butyrate (mmol/l)	5.89±0.96	4.85±0.68	0.030
Total (mmol/l)	8.93±1.52	13.96±2.74	0.005

[a,b] Means in the same rows with different superscripts differ significantly (P < 0.05)

The pH value in the ileal contents from pigs fed the BR diet was not significant different from that for the pigs fed the CC diet (Table 7). Nevertheless, the number of cellulolytic bacteria in the ileal content of pigs fed the CC diet tended to be higher (Table 6). Cellulolytic bacteria prefer a basic milieu over more acidic conditions. There was significantly lower content of ileal amylolytic bacteria in the pigs fed the CC diet, when compared with those fed the BR diet. Acetate concentrations in ileal and rectal contents of pigs fed the CC diet were increased (Table 7). In cecal contents the acetate concentration was lower in pigs fed the CC diet. There was no significant diet effect on propionate and butyrate concentrations in ileal and cecal cntents, but it the propionate concentration was raised in rectal contents from pigs fed the CC diet, whereas in these pigs the rectal concentration of butyrate was decreased (Table 7). The effects seen may be explained by fermentation of non-digested starch in the pigs fed the CC diet. It has been shown that resistant starch can be fermented in the lower digestive tract (Smiricky-Tjardes et al., 2003). Mosenthin and Zimmermann (2000) showed that modification of the pig's diet can have a marked impact on the fermentative activity of bacteria in the gastrointestinal tract.

Table 8 Effect of dietary carbohydrate source on carcass and meat quality (experiment 1)

Item	BR	CC	P value
Hot carcass, kg	25.68 ± 3.79	25.29 ± 6.11	0.887
Backfat, cm	1.15 ± 0.26	1.51± 0.48	0.108
Colour(Japanness)	3.38 ± 0.74	3.14 ±0.65	0.542
CIELAB L*	49.98 ± 5.77	49.95 ±5.24	0.992
A*	6.83 ± 1.52	6.26 ±1.91	0.552
B*	14.32 ± 1.54	14.74 ± 0.89	0.548
Shear force, N	48.01 ±11.48	53.58±16.29	0.240
Cooking loss, %	16.37 ±3.07	18.41±2.24	0.176
pH_1	5.67±0.33	5.65±0.28	0.860
PH_U	5.52±0.03	5.57±0.05	0.020

[a,b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

In earlier work (Chapters 1 and 3) we shown data on carcass characteristics and meat quality of Kadon pigs. In this study additional measurements were carried out. There were no statistically significant differences in hot carcass, back fat thickness, Japanese color scale, L*, A*, B*, shear force value, cooking loss and pH in the pigs fed either the BR or CC diet. In general terms, the present data on carcass characteristics and meat quality corroborate those in our earlier work.

In essence, experiment 2 was carried out to determine the ileal digestibility of nutrients (Tables 10 and 11), but we also measured the N balance (Table 9) and faceal digestibility of nutrients (Table 12) and the numbers of cellulolytic, proteolytic, amylolytic and lactic acid bacteria in ileal digesta (Table 13) and the VFAs in ileal digeta (Table 14). In essence, the data on N balance and fecal digestibility support the data in experiment 1 and those presented in Chapters 2 and 3. The diet effects on the profiles of bacteria and VFAs are in general agreement with the observations in experiment 1.

Table 9 Effect of dietary carbohydrate source on nitrogen balance (experiment 2)

Item	BR	CC	P value
DM Intake	704.0±1.0	716.2±1.0	-
N intake (g/d)	21.8±0.2	22.0±0.2	0.356
N faecal out put (g/d)	1.3±0.3	1.9±0.2	0.076
N absorbed (g/d)	20.5±0.3	20.1±0.2	0.170
N urinary output (g/d)	6.8±0.5[b]	5.2±0.5[a]	0.018
N retention (g/d)	13.7±0.4[a]	14.9±0.3[b]	0.013
N absorbed /N intake (%)	62.8±1.6[a]	67.7±1.5[b]	0.018

[a,b] Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Table 10 Effect of dietary carbohydrate sources on ileal nutrients digestibility at 4 hours after feeding (experiment 2)

Nutrient	BR	CC	P value
DM	78.7±2.3	73.6±2.6	0.065
OM	83.6±1.9	79.0±3.2	0.119
CP	82.5±2.9	80.4±2.6	0.401
EE	80.5±1.6[a]	54.5±8.6[b]	0.031
CF	54.3±8.3	42.2±1.3	0.168
NFE	86.8±2.2	83.0±3.1	0.161
Ash	44.9±3.0	53.2±14.0	0.416
Calcium	70.0±0.9[a]	53.8±1.1[b]	0.000
Phosphorus	69.7±0.5[a]	59.3±1.1[b]	0.001

[a,b] Means in the same column with different superscripts differ significantly ($P < 0.05$)

Table 11 Effect of dietary carbohydrate source on ileal nutrients digestibility at 8 hours after feeding (experiment 2)

Nutrient	BR	CC	P value
DM	82.8±1.3	79.5±3.0	0.184
OM	86.9±1.1	84.3±2.5	0.209
CP	86.6±1.7	84.9±2.4	0.384
EE	86.2±0.2	61.4±17.8	0.137
CF	58.2±2.4	42.1±13.3	0.166
NFE	89.7±1.0	88.9±1.7	0.493
Ash	57.4±3.5	57.2±4.3	0.956
Calcium	70.3±1.1[a]	62.6±1.0[b]	0.001
Phosphorus	70.4±0.5[a]	60.8±2.1[b]	0.013

[a,b] Means in the same column with different superscripts differ significantly ($P < 0.05$)

Table 12 Effect of dietary carbohydrate source on fecal nutrient digestibility (experiment 2)

Nutrient	BR	CC	P value
DM	95.6±1.1	93.1±0.3	0.053
OM	96.7±0.8[a]	94.6±0.3[b]	0.028
CP	94.0±1.5	91.5±1.0	0.081
EE	74.5±5.6[a]	48.9±9.7[b]	0.020
CF	73.19±5.7[a]	60.63±2.6[b]	0.046
NFE	99.1±0.2[a]	98.0±0.2[b]	0.005
Ash	69.7±9.5	67.7±0.9	0.753
Calcium	76.1±7.9	70.8±1.4	0.367
Phosphorus	76.2±5.7[a]	62.1±2.3[b]	0.035

[a,b] Means in the same column with different superscripts differ significantly ($P < 0.05$)

Table 13 Effect of dietary carbohydrate source on cellulolytic, proteolytic and amylolytic bacteria in ileal contents (experiment 2)

	BR	CC	P value
before feeding			
Cellulolytic bacteria (x10^6CFU/ml)	17.5±3.7^a	31.8±4.4^b	0.014
Proteolytic bacteria (x10^6CFU/ml)	12.1±6.6	12.5±1.7	0.928
Amylolytic bacteria (x10^6CFU/ml)	5.2±1.4	5.1±1.3	0.768
Lactic acid bacteria (x10^6CFU/ml)	4.5±0.6	4.5±1.5	0.993
4 hours after feeding			
Cellulolytic bacteria (x10^6CFU/ml)	30.3±4.5	31.6±7.9	0.826
Proteolytic bacteria (x10^6CFU/ml)	12.0±0.9	15.2±1.9	0.089
Amylolytic bacteria (x10^6CFU/ml)	9.5±0.2^b	3.6±1.6^a	0.020
Lactic acid bacteria (x10^6CFU/ml)	6.5±0.5	3.1±0.2	0.053
8 hours after feeding			
Cellulolytic bacteria (x10^6CFU/ml)	35.6±5.3	31.2±10.1	0.553
Proteolytic bacteria (x10^6CFU/ml)	18.7±8.7	14.1±6.2	0.497
Amylolytic bacteria (x10^6CFU/ml)	4.3±1.4	3.8±0.8	0.618
Lactic acid bacteria (x10^6CFU/ml)	3.4±2.5	3.6±1.9	0.927

[a,b] Means in the same rows with different superscripts differ significantly (P < 0.05)

The new observation in experiment 2 relates to the ileal digestibility of nutrients. When comparing Tables 10 and 11 with Table 12, it is clear that the faecal digestibility of DM, OM, CP, NFE and CF was greater than the ileal digestibility of these macronutrients. On the other hand, the faecal digestibility of EE was lower than the ileal digestibility of EE. The higher faecal than ileal digestibility points at breakdown in the hindgut, which holds especially for CF. The lower fecal EE digestibility could point at microbial fat synthesis in the hindgut. The data illustrate that ileal digestibilties of DM, OM, CP, EE and NFE were all significantly higher for the BR diet when compared with the CC diet.

Table 14 Effect of dietary carbohydrate source on the concentration of VFAs in ileal contents (experiment 2)

	BR	CC	P value
4 hours after feeding			
Lactic acid (mmol/l)	2.3 ± 0.1^{b}	1.9 ± 0.2^{a}	0.031
Acetate (mmol/l)	61.9 ± 11.4^{b}	22.8 ± 2.7^{a}	0.022
Propionate (mmol/l)	12.4 ± 0.5^{b}	4.6 ± 2.0^{a}	0.020
Butyrate (mmol/l)	27.9 ± 0.4^{b}	24.6 ± 0.7^{a}	0.011
Total (mmol/l)	104.4 ± 11.2^{b}	53.9 ± 3.6^{a}	0.010
8 hours after feeding			
Lactic acid (mmol/l)	2.1 ± 0.3	2.1 ± 0.3	0.935
Acetate (mmol/l)	56.9 ± 7.8^{b}	28.9 ± 4.7^{a}	0.010
Propionate (mmol/l)	1.1 ± 0.0^{a}	4.4 ± 1.6^{b}	0.037
Butyrate (mmol/l)	21.4 ± 3.6	26.5 ± 3.0	0.131
Total (mmol/l)	81.5 ± 9.5	62.0 ± 8.5	0.058

^{a,b} Means in the same rows with different superscripts differ significantly ($P < 0.05$)

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CHAPTER 6

Effect of increasing dietary protein level on feed intake, growth performance and nitrogen utilization in Kadon pigs

Kraisit Vasupen[1], Chalermpon Yuangklang[1], Sasiphan Wongsuttravas[1], Jamlong Mitchaothai[2], Hendrik Everts[3] and Anton C. Beynen[3]

[1] *Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Sakon Nakhon Campus, Phang Khon, Sakon Nakhon 47160, Thailand.*
[2] *Department of Clinic for Swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.*
[3] *Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.*

To be submitted

Abstract

The objective of this study was to identify the optimum protein content in the diet of growing Kadon pigs. Diets were formulated with different protein levels and the effects on growth, protein digestibility and nitrogen utilization were measured. The diets contained either 14, 16, 18 or 20 % of crude protein. The experiment lasted for 36 days. Average daily gain (ADG) and feed conversion ratio (FCR) in the pigs fed the diet with 20% crude protein were better than those in the pigs fed the diet with 14% of crude protein in the diet. There was a linear relationship between dietary protein level and ADG. Apparent fecal protein digestibility was increased with increasing protein intake. As based on the feed cost per kg of body-weight gain, the diet containing 18 % protein was found to be most economical.

Key words : Kadon pigs, dietary protein, growth performance, protein digestibility, nitrogen retention

Introduction

In the North-East of Thailand native Kadon are kept for meat production. The pigs are typically raised on diets based on local feedstuffs, consisting of native grasses, cassava roots, banana-tree leaves and local fruits. This feeding regimen may be not suitable for optimum pork production. In generally, efficient animal production requires a careful balance between the animal's genetic potential and the quantity and quality of nutrients to be consumed. The diet should be formulated using feedstuffs that are accepted by the animal and that meet its nutrient requirements. To optimize economic meat production, the supply of nutrients should be close to the requirement and should not exceed or be below the requirement.

For the growing Kadon pig the protein requirement has not been set (Vasupen et al., 2004). Knowledge on the optimum protein level in the diet for growing Kadon pigs is essential for economic production of Kadon meat. Feeding below the requirement will diminish growth and feeding above the requirement will lead to protein being oxidized, which is uneconomic because fats and carbohydrates are cheaper energy sources than are proteins. The objective of this study was to evaluate effect of different protein levels on growth, protein digestibility and nitrogen utilization in growing Kadon pigs. It was anticipated that the information thus obtained would contribute to identifying the optimum protein content in the diet of growing Kadon pigs.

Materials and Methods

Twelve male and 12 female growing Kadon pigs aged 63 days and with initial body weight (BW) of 6.8$\pm$0.6 kg were used in this trial. The pigs were blocked according sex and the blocks were randomly assigned to the treatments. The pigs were penned individually in metabolic cages with a slatted floor and had free access to tap water from nipple drinkers. There was a separate manure pit under the slatted floor of each pen.

The experiment lasted 36 days and during the last 5 days, feces and urine samples were collected. Pigs were fed twice daily at 07.00 am and 16.30 pm. The animals were fed ad libitum and feed left-overs were always removed before feeding. The experimental diets were formulated to contain 140, 160, 180 or 200 g crude protein per kg of dry matter (DM). The difference between the amount of feed offered and refusals was taken as feed consumption. Pigs were weighed at the beginning and at the end of the experimental period (every 12 days) just before the morning feeding. Changes in live weight were used to estimate the average daily gain (ADG). Feed conversion ratio (FCR) was calculated as the ratio of the amount of consumed feed to 1 kg gain of BW.

Table 1 Ingredient and calculated composition of the experimental diets

	Crude protein level (%)			
Ingredient (%)	14	16	18	20
Cassava chips	72.0	67.0	62.5	57.5
Soybean meal	22.8	28.0	32.5	37.8
Soybean oil	2.0	2.0	2.0	2.0
L-Lysine	0.5	0.3	0.3	0.1
D,L-Methionine	0.2	0.2	0.2	0.1
Di-calcium phosphate	1.5	1.5	1.5	1.5
Premix*	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5
Total	100.0	100.0	100.0	100.0
Price (Baht)/kg DM	9.7	9.9	10.1	10.3
Calculated composition				
CP (%DM)	12.0	14.0	16.0	18.0
L-lysine	1.1	1.1	1.1	1.1
D,L-methionine	0.3	0.3	0.3	0.3
ME (kcal/kgDM)	3,017.5	3,009.7	3,004.2	2,996.2
EE (%DM)	3.8	3.9	3.9	4.0
CF (%DM)	5.9	6.2	6.5	6.9
Calcium (%DM)	0.6	0.6	0.6	0.6
Phosphorus (%DM)	0.5	0.5	0.5	0.5

*1 kg of vitamin and mineral premix contained: vitamin A 650 mg (325,000 IU); vitamin D_3 750 mg (75,000 IU); vitamin E 150 mg (75 IU); vitamin B_{12} 1 mg; vitamin K_3 80 mg; riboflavin 300 mg; niacinamide 1,200 mg; pantothenic acid 540 mg; choline chloride 6,000 mg; Fe 4,700 mg; Zn 6,500 mg; Mn 4,500 mg; Co 20 mg; Cu 1,400 mg ; I 45 mg and carrier material 973.164 g.

Feces samples were collected quantitatively twice daily from the wire-mesh under the cages, and stored at –20 °C until analysis. Urine was collected into a container via a funnel underneath the wire-mesh. It was removed twice daily and stored at –20 ˚C. To prevent nitrogen (N) losses during collection and storage, 10 ml of 25% H_2SO_4 was added daily to each container. Diets and feces were analyzed for their proximal components, DM matter, N, crude fat (EE), crude fiber (CF) and ash (AOAC, 1990). The amount of protein was calculated as the mass of N x 6.25. The nitrogen-free extract (NFE) was assessed as residual fraction. Urine samples were used for N analysis.

The total tract apparent digestibility of macronutrients was calculated as intake minus excretion and expressed as a percentage of intake. N retention was calculated as N intake – N excretion with feces plus urine. Energy value of the diets was determined by an adiabatic bomb calorimeter as described by Mitchaothai et al. (2007).

The collected data were statistically analyzed using the analysis of variance procedure (SPSS, 1998). Duncan’s multiple range test was used to compare differences between treatment means. All results are expressed as mean and standard error of the mean (SEM).

Results and Discussion

Table 1 shows the ingredient composition of the diets. The protein level of the diet was adjusted by varying the soybean meal at the expense of the L-lysine and cassava chip component. Tables 1 and 2 show that the calculated and analyzed levels of dietary protein were comparable. The increase in dietary protein was associated with an increase in crude fiber (Table 2). It could be argued that the increase in crude fiber will tend to lower protein digestibility and thus causing bias. The analyzed dietary concentrations of EE and ash were rather similar for the various diets and so was the analyzed content of gross energy.

Increasing the dietary protein level produced an increase in ADG in a dose-dependent fashion (Table 3). This outcome agrees with other work performed in Thailand (Wattanakul et al.,2004; Vasupen et al., 2004). From a nutritional point of view, it is unfortunate that the relationship between protein level and ADG was linear.

This implies that the level of protein required for maximum growth cannot be identified. It is not known at which dietary protein ADG would reach a maximum value. However, from an economical point of view, this experiment provides conclusive results. The protein component of the diet is the most expensive one, implying that adding protein to the diet at the expense of carbohydrates will increase feed costs. When the economical return was calculated as feed cost per kg of BW gain, it was found that pigs fed on the 18%-protein diet had produced most economically. The protein level of the diet did not influence DM intake. Thus, the increase in ADG seen with increasing protein intakes caused a decrease in FCR which reached its lowest value at the level of 18% of protein in the diet. This corroborates the outcome that economical return was also highest for this protein concentration in the diet.

Table 2 Analyzed composition of the experimental diets

	Crude protein level (%)			
Chemical composition	14	16	18	20
DM (%)	88.5	88.8	88.8	89.4
OM (%DM)	94.7	94.7	94.6	94.3
CP (%DM)	14.0	15.7	17.9	19.6
EE (%DM)	4.7	5.0	4.7	4.9
CF (%DM)	4.6	4.7	5.2	5.7
Ash (%DM)	5.3	5.3	5.4	5.7
NFE (%DM)	71.4	69.3	66.8	64.0
Gross energy (kcal/kgDM)	4,263.9	4,269.9	4,274.0	4,271.0
Calcium (%DM)	0.5	0.5	0.5	0.5
Phosphorus (%DM)	0.4	0.4	0.4	0.4

The amount of protein in the diet did not affect the digestibility of DM (Table 4). The apparent fecal digestibility of N was found to increase with increasing protein intakes. This is explained by the fact that with increasing protein intakes the amount of endogenous N becomes a smaller fraction of total fecal N, which consists of endogenous N plus undigested N. It appears that the well-known inhibitory effect of CF on protein digestibility was smaller than the stimulatory effect of the fraction of fecal endogenous protein. As mentioned above, increasing protein intake was associated with higher intakes of CF.

Table 3 Effect of crude protein level in the diets on growth performance

Item	Crude protein level (%)				SEM
	14	16	18	20	
Initial weight (kg)	6.9	6.9	6.8	6.5	0.145
Final weight (kg)	11.3^{a}	11.8^{ab}	12.1^{ab}	12.9^{b}	0.233
DMI (g/d)	229.9	252.5	233.2	253.3	4.237
ADG (g/d)	120.2^{a}	134.3^{ab}	147.9^{ab}	161.4^{b}	5.321
FCR	2.0^{b}	1.9^{ab}	1.6^{a}	1.6^{a}	0.056
Feed cost, Baht/kg of BW gain	19.8	19.4	16.7	17.3	1.105

^{a,b,c} Means in the same rows with different superscripts differ significantly ($P < 0.05$)

Table 4 Effect of crude protein level in the diets on DM and CP digestibilities and N retention

Item	Crude protein level (%)				SEM
	14	16	18	20	
DM digestibility (% of intake)	88.7	89.7	89.7	89.7	0.381
CP digestibility (% of intake)	84.8^{a}	85.9^{ab}	87.3^{ab}	88.5^{b}	0.555
N intake (g/d)	5.1^{a}	6.0^{b}	5.9^{b}	6.9^{c}	0.121
N fecal out put (g/d)	0.7^{a}	0.9^{ab}	0.8^{ab}	1.0^{b}	0.026
N absorbed (g/d)	4.4^{a}	5.1^{a}	5.1^{a}	5.9^{b}	0.124
N urine output (g/d)	0.5^{a}	0.6^{ab}	0.7^{b}	0.9^{c}	0.030
N retention (g/d)	3.9^{a}	4.5^{ab}	4.4^{ab}	5.1^{b}	0.121
N retention/N intake (%)	75.4	75.4	74.9	73.7	0.839

^{a,b,c} Means in the same rows with different superscripts differ significantly ($P < 0.05$)

It is evident that N intake rose with increased protein level in the diet and so did N excretion with urine (Table 4). High protein intake caused an increase in N excretion with faeces, but there was no clear dose-response relationship, which had also been shown earlier by Zijlstra (2002). It would appear that N retention was similar for the diets containing either 16 or 18% protein, but when the protein level was increased to 20%, N retention rose further. Thus, the linear relationship between dietary protein level and ADG (Table 3) may agree with the N retention data (Table 4) in that maximum growth was not yet reached at the 18%-protein level and perhaps not even on the 20%-level.

In conclusion, this experiment shows a clear effect of protein intake on ADG in growing Kadon pigs. The protein level allowing maximum growth could not be established. However, the economical return should be considered to formulate the diet for meat-producing Kadon pigs. It would the be concluded that the optimum dietary protein level for growing Kadon pigs is 18%. It is relevant to communicate the outcome of this study to the small-holder farmers keeping Kadon pigs for meat production.

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CHAPTER 7

Effect of fumaric acid supplementation on nutrient digestibility in growing Kadon pigs

K. Vasupen[1*], C. Yuangklang[1], S. Wongsuthavas[1], J. Mitchaothai[2] and A. C. Beynen[3]

[1]*Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Phang Khon, Sakon Nakhon 47160, Thailand.*
[2]*Department of Clinic for swine, Faculty of Veterinary Medicine, Mahanakorn University of Technology, Bangkok, Thailand.*
[3]*Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, The Netherlands.*

To be submitted

Abstract

The current experiment was conducted to determine the effect of addition of fumaric acid to the diet of growing Kadon pigs with regard to total tract digestibility of macronutrients. Six pigs with initial body weight of 20.7 $\pm$ 3.2 kg were used in 3x3 Latin square design. The diets were either without (control) or with 3.0 or 6.0 % fumaric acid. The addition of fumaric acid was found not to influence the apparent fecal digestibility of crude protein, crude fat and carbohydrates. The nitrogen balance variables were not affected either by the feeding of fumaric acid. Interestingly, the ingestion of fumaric acid had a marked influence on the concentrations of volatile fatty acids in the large intestine. This observation indicates that fumaric acid had changed microbial activity in the hindgut.

Keyword: Kadon pigs, fumaric acid, macronutrient digestibility, volatile fatty acids

Introduction

Experiments with pigs have shown that organic acids such as citric acid, fumaric acid, formic acid and propionic acid have a positive influence on growth performance (Partanen and Mroz, 1999). The positive effect of organic acids is most pronounced in weanling pigs (Gabert and Sauer, 1994, Roth and Kirchgessner, 1998). Insufficient production of hydrochloric acid and digestive enzymes, the feeding of a pre-starter diets with a high protein content and a high acid-binding capacity are held responsible for the problems at weaning (Eidelsburger, 1997). Dietary acidification has been shown to increase protein digestibility and most organic acids serve as substrates in intermediary metabolism (Kirchgessner and Roth, 1988). Dietary organic acids are being used as alternatives to classical anti-microbial growth enhancers. The organic acids have been shown to antagonize the colonization of pathogenic bacteria in the intestinal tract of pigs (Partanen and Mroz, 1999).

The aim of the present study was to determine whether the addition of fumaric acid to the diet would influence nutrient digestibility and nitrogen retention in growing Kadon pigs. In pigs there is substantial fermentation in the intestinal tract. To monitor whether the feeding of fumaric acid had an effect on microbial activity, we analyzed the concentrations of volatile fatty acids in intestinal contents.

Materials and Methods

Experimental design

The feeding trial had a 3x3 Latin square design. The three experimental treatments were diets either without (control) or with 3.0 or 6.0 % fumaric acid. Six growing Kadon pigs, aged three months, were used. There were three periods of 12 days each. The first 7 days of each period was for feed intake measurement followed by 5 days for sample collection. The pigs were housed individually and had free access to water. To ensure complete consumption of the food supplied, the pigs were fed at 90% of the *ad libitum* intake. The pigs were fed twice daily at 07.00 am and 16.30 pm, with the daily allowance being equally divided between the two meals.

Diets and feeding

The analyzed composition of the diets is shown in Table 1. The control diet was a complete, commercial starter diet containing about 18 % protein. The experimental diets were the commercial starter diet mixed with either 3 or 6 % of fumaric acid.

Table 1. Analyzed composition of the experimental diets.

	pH	DM (%)	OM	CP	EE	CF	Ash	NFE	GE kcal/kg
Control diet	5.63	91.51	93.83	19.84	7.41	3.34	6.17	63.25	3,968.9
Diet with 3 % fumaric acid	3.88	91.21	93.96	19.29	7.35	3.19	6.04	64.13	3,849.8
Diet with 6 % fumaric acid	3.68	92.07	94.08	18.71	7.31	3.15	5.92	64.91	3,738.0

Measurements

Feed refusals, if any, were recorded and weighed. At the beginning of each period, body weights (BW) of the pigs were determined. During the last 5 days of each period, faeces were collected quantitatively using plastic bags attached to the pigs. The bags were changed at least twice daily, and stored frozen (–20 ^oC) pending analysis. Urine was collected in containers via the funnels underneath the cages. Urine was removed twice each day and stored at -20 ^oC until analysis. To prevent nitrogen (N) losses during collection and storage, 10 ml of 25 % H_2SO_4 was added to each container every day. Feed and feces samples were processed for the analysis of macronutrients: dry matter (DM), crude fat (EE), crude protein (CP), crude fibre (CF) and ash (AOAC, 1990). The carbohydrates (NFE) were calculated as residual fraction. Diets and faeces were then dried at 60 ^oC in a forced-air oven for 96 hours and ground to pass a 1-mm screen. All samples were analyzed for proximate components in duplicate. Gross energy (GE) in diet samples was analyzed using bomb calorimetry.

Slaughtering and sampling

The pigs were killed by an intravenous overdose of sodium pentobarbital (200 mg/kg of body weight) on the last day of the experiment. The entire gastro-intestinal tract (GIT) was removed from the abdominal cavity. The GIT was ligated at various locations to avoid mixing of digesta. Then, in the laboratory, the GIT was divided into stomach, small intestine and large intestine. The digesta of each compartment was properly mixed and samples were collected for pH and analysis volatile fatty acids (VFA).

pH of intestinal contents was determined using a pH meter (Model HI99163, Hanna Instruments, Portugal). VFA concentrations in the intestinal contents were analyzed by HPLC (Shimadzu Class-VP), using a Aminex® column (HPX-87H, 300m x 7.8 mm) UV detector, N_2 saturated with methanolic acid as carrier gas at 190 °C. Iso-caproic acid was used as an internal standard.

Statistical analysis

The data were subjected to analysis of variance for a 3x3 Latin square design, using the General Linear Model of SAS Software (1985). Duncan' multiple comparisons test was used to determine differences between treatment means. The level of statistical significance was preset at $P < 0.05$.

Results and Discussion

Growth performance and nutrient digestibility

BW gains of the pigs ranged from 1.8 to 4.1 kg over entire experimental period. There was no diet effect on feed intake, average daily gain (ADG), feed conversion ratio (FCR) and final BW (Table 3).

The ingestion of fumaric acid had no significant effect on the apparent fecal digestibility of macronutrients (Table 4). Increasing intakes of fumaric acid tended to be associated with increased digestibilities of NFE and GE.

Table 3 Effect of fumaric acid supplementation on growth performance in growing Kadon pigs

Item	Control	3% fumaric acid	6% fumaric acid	SEM
Initial BW, kg	21.1	20.4	20.8	0.867
Final BW, kg	24.1	23.8	23.7	0.869
ADG, g/d	235.0	285.0	245.8	12.826
DMI, g/d	982.3	1053.7	1006.9	60.815
FCR	4.1	3.7	4.3	0.270

Table 4 Effects of fumaric acid supplementation on macronutrient digestibility in growing Kadon pigs

Item	Treatment			SEM
	Control	3% fumaric acid	6% fumaric acid	
Digestibility, % of intake				
DM	89.1	89.3	90.7	0.733
OM	88.1	89.2	91.2	0.791
CP	85.3	85.7	86.8	1.110
EE	83.8	86.0	89.1	1.229
CF	64.3	62.8	70.2	2.285
NFE	90.9	92.1	93.6	0.632
Ash	61.5	67.0	66.6	2.358
Gross energy	84.8	86.3	88.5	0.995

The concentration of acetate in the stomach was significantly different between treatments. The pigs fed the diet with 6.0% fumaric acid had significantly higher acetate, propionate, butyrate and total VFAs in their stomach contents than did pigs fed either the control diet or the diet with 3.0% fumaric acid. Between treatments there was no significant difference in pH and the levels of acetate, propionate, butyrate and total VFAs in the small intestine. The butyrate concentration in the large intestine section was decreased by fumaric acid supplementation in a dose-dependent fashion.

Table 5 Effect of fumaric acid on VFA concentrations in various sections of the GIT of growing Kadon pigs

Item	Treatment			SEM
	Control	3% fumaric acid	6% fumaric acid	
Stomach				
pH	4.17	3.95	4.16	0.300
Acetate (mmol/l)	0.54[b]	0.26[a]	4.47[c]	0.038
Propionate (mmol/l)	4.08	4.07	4.59	0.070
Butyrate (mmol/l)	2.69[a]	3.16[ab]	3.31[b]	0.070
Total (mmol/l)	6.67[a]	7.25[a]	12.36[b]	0.095
Small intestine				
pH	6.82	6.40	6.84	0.093
Acetate (mmol/l)	39.09	52.90	49.60	3.054
Propionate(mmol/l)	14.16	15.58	12.90	0.449
Butyrate (mmol/l)	4.21	2.95	2.59	0.199
Total (mmol/l)	57.46	71.43	65.09	3.418
Large intestine				
pH	6.19	6.48	6.10	0.171
Acetate (mmol/l)	36.61[ab]	19.12[a]	48.91[b]	3.509
Propionate(mmol/l)	4.00	4.30	4.02	0.090
Butyrate (mmol/l)	62.14[b]	55.87[b]	38.58[a]	1.692
Total (mmol/l)	102.75	79.28	91.51	5.119

[a,b] Means in the same rows with different superscripts differ ($P < 0.05$)

Nitrogen utilization

N balance parameters were not affected by the intake of fumaric acid (Table 6). Likewise, Garbert and Sauer (1994) also found that fumaric acid supplementation did not change the utilization of N in pigs. Furthermore, Radecki et al. (1988) reported that the addition of citric acid and fumaric acid to the starter diet of pigs did not affect N balance, the percentage of N retained and apparent N digestibility.

Table 6 Effect of fumaric acid on N balance in growing Kadon pigs

Item	Treatment			SEM
	Control	3% fumaric acid	6% fumaric acid	
N intake (g/d)	29.6	30.3	30.3	1.846
N faecal out put (g/d)	4.1	4.1	4.0	0.298
N absorbed (g/d)	25.6	26.3	26.4	1.754
N urine output (g/d)	11.7	13.1	14.2	0.654
N retention (g/d)	13.9	13.1	12.1	1.655
N absorbed /N intake (%)	39.9	41.2	38.6	3.130

Conclusion

It is clear that under the conditions of this study the supplementation of the diet with fumaric acid did not affect the digestibility of macronutrients in growing Kadon pigs. Dietary fumaric acid did influence bacterial activity in the hindgut as based on the changes in VFA concentrations in large intestinal contents. The impact of this observation is not known.

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CHAPTER 8

General conclusions

In the North-East of Thailand, native, so-called Kadon pigs are kept on small-holder farms. The pig is suitable for production under conditions of limited resources on small-holder farms. Furthermore, the Kadon pig attains puberty at low body weight, reproduces on a low plane of nutrition and has good disease resistance. Growing Kadon pigs show growth rates of 200-300 g/day. Thus, the Kadon pig would be excellent as a local source of meat. However, it is assumed that the Kadon pigs are on the edge of extinction because exotic commercial breeds of pigs have gained more popularity. In 2003, this native Thai Kadon pig was listed as preserved species. Within the framework of the Kadon pig project in the Department of Animal Science, Sakon Nakhon Agricultural Research and Training Center, 20 Kadon pigs were purchased in the Kudbark district in Sakon Nakhon province. These animal were used for breeding and the descendents were used in the studies described in this thesis.

The main objective of this thesis was to study various nutritional aspects of Kadon pigs. There only is very limited literature on nutritional aspects of Kadon pigs, the limited number of papers being written in the Thai language and having been published in meeting proceedings only. It would be anticipated that improvement of our knowledge of the nutrition of the Kadon pig would contribute to the development of new feeding strategies for optimal growth, reproduction and lactation of Kadon pigs. In an attempt to meet the main objective of this thesis, six trials were carried out and are described in the chapters of this thesis. In this section the main conclusions from the various studies are listed and discussed briefly.

Chapter 1 is the first paper documenting reference data for the meat and carcass characteristics of Kadon pigs; Chapters 3 and 5 also provide data on slaughter characteristics

In the study described in Chapter 1, female and male Kadon pigs were slaughtered at a body weight of 23 – 26 kg. The carcass weight was about 65% of slaughter weight. The loin meat contained about 8.7 % fat and 21.4 % protein. Palmitic and oleic acid represented about 26 and 40 % of the total loin fatty acids. There was no gender difference in carcass composition and fatty acid profile of meat. However, average back fat thickness tended to be higher in females than in males (2.23 cm versus 1.81 cm). The amount of back fat was found to be decreased when the diet contained cassava chips instead of broken rice as carbohydrate source (Chapter 3). In Chapter 5, meat quality characteristics such as the color score of *M. longissimus lumborum* (loin), the pH value of muscle, the percentage of cooking loss and shear force value.

Kadon pigs digest the carbohydrate source in broken rice better than that in either ground corn, rice bran or cassava chips

Carbohydrates from cereal grains are the main source of energy in pig diets. In the North-East of Thailand, ground corn, broken rice and rice bran are commonly used for the formulation of pig diets, while cassava chips may be used as an alternative, depending on availability and price of the various carbohydrate sources. So far there was no information on the impact of the type of carbohydrate source on macronutrient digestibility in Kadon pigs. Thus, the apparent digestibility of diets with isonitrogenous amounts of different carbohydrate sources was determined. The diets used contained either ground corn, rice bran, broken rice or cassava chips. The diet with broken rice induced the highest digestibilities for carbohydrates, protein and energy, but also had the highest ingredients costs.

Broken rice instead of cassava chips as carbohydrate source raises the efficiency of calcium and phosphorus absorption in growing Kadon pigs

There is evidence that the carbohydrate source of the diet can influence the absorption of minerals such as calcium and phosphorus. The general idea is that less digestible carbohydrates stimulate mineral absorption. Less digestible carbohydrates will be fermented in the small intestine, leading to a lowering of the pH and an increase in the solubility of minerals. Soluble, rather than insoluble minerals are available for absorption so that an increase in mineral solubility is associated with an increased absorption efficiency. In growing Kadon pigs it was found that the carbohydrates in broken rice have a higher digestibility than those in cassava chips. Thus, it was hypothesized that pigs fed a diet with broken rice would show a lower apparent absorption than those fed a diet with cassava chips. However, the data in Chapter 4 show that apparent calcium and phosphorus absorption, when expressed as a percentage of intake, was significantly higher in the pigs fed the diet with broken rice. Possible explanations for the unexpected observation are give in the Chapter 4. In the pigs fed the broken rice diet instead of cassava chips, faecal calcium and phosphorus excretion were significantly decreased.

The ileal digestibility of dietary dry matter, organic matter, crude protein, crude fat and carbohydrates are higher in growing Kadon pigs fed a diet with broken rice as carbohydrate source instead of cassava chips

When Kadon pigs were fed a diet containing broken rice instead cassava chips as carbohydrate source, the apparent fecal digestibility of crude protein, carbohydrates and fats were increased. However, as to nutrient availability for the pigs, the ileal digestibility of crude protein and carbohydrates is more relevant than the fecal digestibility. Dietary proteins and carbohydrates that have not been digested will enter the hindgut and can be degraded by bacteria so that they will not reach the feces. This implies that the fecal digestibility of protein and carbohydrates could reflect a portion of the protein and carbohydrates that has disappeared in the hindgut and thus was not available to the animal in the form of amino acids or glucose. Fistulated Kadon pigs were used to measure both ileal and fecal digestibility of macronurients (Chapter 5). The fecal digestibilities of dry matter, organic matter, crude protein, carbohydrates and crude fiber were greater than the ileal digestibility of these macronutrients. On the other hand, the fecal digestibility of crude fat was lower than its ileal digestibility. The ileal digestibilties of dry matter, organic matter, crude protein, crude fat and carbohydrates were all significantly higher for the diet containing broken rice instead of cassava chips.

For growing Kadon pigs, a dietary protein concentration of 18 % is most economical as based on the feed cost per kg of body-weight gain

For the growing Kadon pig the protein requirement was not known. Knowledge on the optimum protein level in the diet is essential for economic production of Kadon meat. Feeding below the requirement will diminish growth and feeding above the requirement will lead to protein being oxidized, which is uneconomic because fats and carbohydrates are cheaper energy sources than are proteins.

Chapter 6 describes a study in which diets with different protein levels were formulated and the effects on growth, protein digestibility and nitrogen utilization were measured. The diets contained either 14, 16, 18 or 20 % of crude protein. Average daily gain and feed conversion ratio in the pigs fed the diet with 20% crude protein were better than those in the pigs fed the diet with 14% of crude protein in the diet. There was a linear relationship between dietary protein level and average daily gain. Apparent fecal protein digestibility was increased with increasing protein intake. As based on the feed cost per kg of body-weight gain, the diet containing 18 % protein was found to be most economical.

The addition of fumaric acid to the diet on growing Kadon pigs does not influence the apparent fecal digestibility of crude protein, crude fat and carbohydrates

It is generally accepted that the feeding of organic acids such as citric acid, fumaric acid, formic acid and propionic acid have a positive influence on growth performance in pigs. Dietary acidification has been repeatedly shown to increase protein digestibility. Dietary organic acids are commonly used as alternatives to the classical anti-microbial growth enhancers.

In the study described in Chapter 7 growing Kadon pigs were fed diets either without (control) or with 3.0 or 6.0 % fumaric acid. The addition of fumaric acid was found not to influence the apparent fecal digestibility of crude protein, crude fat and carbohydrates. Interestingly, the ingestion of fumaric acid had a marked influence on the concentrations of volatile fatty acids in the large intestine. This observation indicates that fumaric acid had changed microbial activity in the hindgut.

Summary

In the North-East of Thailand, native pigs, Kadon, are typically kept on small-holder farms. Kadon pork is said to have better texture and taste than the commercial breeded pigs. Nevertheless, the Kadon pig was under the risk of extinction and in 2003 it was designated as a protected species of production animals. The production of Kadon pigs is suitable for small-holder farms because they show reasonable growth rates, attain puberty at low body weight, reproduce well on plain quality nutrition and have good disease resistance.

In the light of the protection and preservation of Kadon pigs, nutritional research on this breed of pig may be useful. By rendering the production of Kadon pigs more cost effective through controlling feed costs, preservation of the species may be enhanced. Efficient animal production requires a careful balance between the animal's genetic potential and the quantity and quality of nutrients that are consumed. The diet fed to the animals should be formulated using feedstuffs that the animal accepts and that meet its nutrient requirements. To maximize economic efficiency, the nutrients should be provided close to the requirements rather than exceeding them. Clearly, the feeding of nutrients below the requirements would diminish growth performance and could even induce deficiency diseases.

The main objective of this thesis was to study various nutritional aspects of Kadon pigs. To meet the main objective, a number of feeding trials was carried out. The stage is set by Chapter 1, providing quantitative information on growth performance, organ weights, carcass composition and fatty acid profiles in the meat of female and male Kadon pigs. Carcass weight was about 65% of slaughter weight and loin meat contained about 8.7 % fat and 21.4 % protein. Average back fat thickness tended to be higher in females than in males (2.23 cm versus 1.81 cm). The amount of back fat was found to be decreased when the diet contained cassava chips instead of broken rice as carbohydrate. Meat quality characteristics such as the color score of loin, the pH value of muscle, the percentage of cooking loss and shear force value were also measured.

In quantitative terms, carbohydrates represent the major component of common pig diets. Macronutrient digestibility was determined in Kadon pigs fed diets containing ground corn, rice bran, broken rice or cassava chips (Chapter 2). The diet with broken rice induced the highest digestibility for carbohydrates, protein and energy, but also had the highest ingredients costs. In contrast to what would be expected, the data in Chapter 4 show that apparent calcium and phosphorus absorption, when expressed as a percentage of intakes, was significantly higher in the pigs fed the diet with broken rice. In the pigs fed the broken rice diet instead of cassava chips, fecal calcium and phosphorus excretion were significantly decreased.

When Kadon pigs were fed a diet containing broken rice instead cassava chips as carbohydrate source, the apparent fecal digestibility of crude protein, carbohydrates and fats were increased. However, as to nutrient availability for the pigs, the ileal digestibility of crude protein and carbohydrates is more relevant than the fecal digestibility. Fistulated Kadon pigs were used to measure both ileal and fecal digestibility of macronutrients (Chapter 5). The fecal digestibility of dry matter, organic matter, crude protein, carbohydrates and crude fiber were greater than the ileal digestibility of these macronutrients. On the other hand, the faecal digestibility of crude fat was lower than its ileal digestibility. The ileal digestibility of dry matter, organic matter, crude protein, crude fat and carbohydrates were all significantly higher for the diet containing broken rice instead of cassava chips.

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Samenvatting

In noord-oost Thailand worden inheemse, zogenaamde Kadon-varkens gehouden door keuterboeren. Van het vlees van de Kadon-varkens wordt beweerd dat het een betere textuur en smaak heeft dan dat van uitheemse, commerciële varkensrassen. Desalniettemin wordt aangenomen dat het Kadon-varken met uitsterven wordt bedreigd en in 2003 werd het aangewezen als een beschermde soort van productiedieren. De houderij van Kadon-varkens is geschikt voor kleine bedrijfjes omdat de dieren een redelijke groeisnelheid hebben, geslachtsrijp worden bij een laag lichaamsgewicht, goede fokprestaties laten zien op relatief arme voeders en een goede weerstand tegen ziekten hebben.

In het licht van de bescherming en conservatie van het Kadon-varken is voedingsonderzoek bij dit varkensras nuttig. Door de productie van Kadon-vlees economischer te maken, door beheersing van voerkosten, zou de conservatie van het ras worden gestimuleerd. Een efficiënte dierproductie vereist een zorgvuldige balans tussen de genetische potentie van het dier en de kwaliteit en kwantiteit van de voedermiddelen die worden gebruikt. Het rantsoen voor de dieren zou gebaseerd moeten zijn op voedermiddelen die worden geaccepteerd en de nutriëntbehoeften dekken. Teneinde de economische efficiëntie te optimaliseren, zou het niveau van de voedingsstoffen dicht bij dat van de behoefte moeten liggen en dit niet overschrijden. Het is duidelijk dat verstrekking van nutriënten onder het behoefteniveau de groei vermindert en zelfs deficiëntieziekten zou kunnen veroorzaken.

Het onderzoek beschreven in dit proefschrift betreft diverse nutritionele aspecten van Kadon-varkens. Hiertoe is een aantal voedingsproeven uitgevoerd voorafgegaan door een beschrijving (Hoofdstuk 1) van kwantitatieve gegevens over groeiprestatie, orgaangewichten, carcassamenstelling en vetzuursamenstelling van het vlees van mannelijke en vrouwelijke Kadon-varkens. Het carcasgewicht was ongeveer 65% van het geslacht gewicht en het lendestuk bevatte ongeveer 8.7 % vet en 21.4 % eiwit. De dikte van het rugvet was gemiddeld hoger bij vrouwelijke dan bij mannelijke dieren (2,23 versus 1,81 cm). De hoeveelheid rugvet nam af wanneer de koolhydraatbron van de voeding tapioca was in plaats van gebroken rijst. Als karakteristieken van de vleeskwaliteit zijn ondermeer de kleur van het lendestuk, de pH waarde van spierweefsel, het percentage kookverlies en de shear force gemeten.

In kwantitatieve zin zijn koolhydraten de belangrijkste component van gebruikelijke varkensvoeders. De verteerbaarheid van macronutriënten is bepaald bij Kadon-varkens die voeders kregen met gemalen maïs, rijstevoermeel, gebroken rijst of tapioca (Hoofstuk 2). Het voeder met gebroken rijst induceerde de hoogste schijnbare verteerbaarheden voor koolhydraten, eiwit en energie, maar had de hoogste kosten aan grondstoffen. In tegenstelling tot de verwachting geeft Hoodstuk 4 aan dat de schijnbare absorptie van calcium en fosfor, uitgedrukt als percentage van de opname, significant hoger was bij de dieren die het voeder met gebroken rijst kregen. Bij de varkens die gebroken rijst in plaats van tapioca kregen was de excretie van calcium en fosfor met de mest significant verlaagd.

Wanneer Kadon-varkens een voeder kregen met gebroken rijst in plaats van tapioca was de schijnbare verteerbaarheid van ruw eiwit, koolhydraten en vet verhoogd. Met betrekking tot beschikbaarheid van nutriënten is echter de ileale verteerbaarheid van ruw eiwit en koolhydraten relevanter dan de fecale verteerbaarheid. Gefistuleerde Kadon-varkens werden gebruikt om de zowel de ileale als fecale verteerbaarheid van macronutriënten te bepalen (Hoofdstuk 5). De schijnbare fecale verteerbaarheden voor droge stof, organische stof, ruw eiwit, koolhydraten en ruwe celstof waren groter dan de schijnbare ileale verteerbaarheden voor deze macronutriënten. Anderzijds was de fecale verteerbaarheid van ruw vet lager dan de ileale verteerbaarheid. De ileale verteerbaarheden voor droge stof, organische stof, ruw eiwit, ruw vet en koolhydraten waren significant hoger voor het voeder met gebroken rijst in plaats van tapioca.

Voor het groeiende Kadon-varken is de eiwitbehoefte niet bekend. Kennis van het optimale eiwitgehalte in het voeder is echter essentieel voor de economische productie van Kadon-vlees. Hoofdstuk 6 beschrijft een onderzoek waarin voeders met verschillende eiwitgehalten werden geformuleerd en de invloed op groei, eiwitverteerbaarheid en stikstofbenutting werden gemeten. De voeders bevatten 14, 16, 18 of 20 % ruw eiwit. De gemiddelde groei per dag en de voederconversie bij Kadon-varkens die het voeder met 20% ruw eiwit kregen waren beter dan bij de dieren die het voeder met 14% ruw eiwit kregen. Er was een lineair verband tussen de hoeveelheid eiwit in de voeding en de gemiddelde groei per dag. De schijnbare fecale verteerbaarheid van eiwit nam toe met hogere eiwitopname. Gebaseerd op de voerkosten per kg gewichtstoename was het voeder met 18 % eiwit het meest economisch.

บทสรุป

ภาคตะวันออกเฉียงเหนือของประเทศไทยมีสุกรพื้นเมืองที่เกษตรกรรายย่อยเลี้ยงไว้จำนวนหนึ่ง มีชื่อสามัญว่า หมูกระโดน เนื้อของสุกรชนิดนี้มีชื่อเสียงในหมู่ชาวบ้านว่ามีรดชาติอร่อยกว่าเนื้อสุกรที่เลี้ยงเชิงการค้า อย่างไรก็ตามสุกรพันธุ์นี้มีโอกาสที่จะสูญพันธุ์เนื่องจากความนิยมเลี้ยงของเกษตรกรลดลง ในปี ค.ศ. 2003 มีโครงการเก็บสุกรพันธุ์กระโดนบางส่วนมาศึกษาวิจัยสำหรับเกษตรกรรายย่อย เนื่องจากมีข้อมูลว่าสุกรสายพันธุ์นี้น่าจะเหมาะสมกับเกษตรกรรายย่อยเพราะสุกรกระโดน สามารถเจริญเติบโตและสืบพันธุ์ได้ ในสภาพที่ได้รับอาหารคุณภาพต่ำและมีความทนทานต่อโรค

แนวทางที่จะอนุรักษ์สายพันธุ์สุกรกระโดน การศึกษาด้านอาหารเป็นแนวทางที่น่าจะเป็นประโยชน์สำหรับการผลิตสุกรกระโดนแบบมีต้นทุนต่ำ ความนิยมเลี้ยงสุกรพันธุ์นี้มีโอกาสเพิ่มขึ้นหลักการในการผลิตสัตว์อย่างมีประสิทธิภาพโดยทั่วไป การประกอบสูตรอาหารอย่างรอบคอบให้เกิดสมดุลย์ ระหว่างศักยภาพทางพันธุกรรมของตัวสัตว์กับปริมาณและคุณภาพของอาหารที่สัตว์ควรได้รับ เพื่อความคุ้มค่าทางเศรษฐกิจ เป็นที่ทราบโดยทั่วไปว่าการที่สัตว์ได้รับอาหารไม่เพียงพอไม่ว่าจะด้านปริมาณหรือคุณภาพมีผลทำให้สัตว์เจริญเติบโตช้า สุขภาพอ่อนแอ และมีความต้านทานต่อโรคต่ำลง

จากข้อมูลเบื้องต้น วัตถุประสงค์ของวิทยานิพนธ์ฉบับนี้ เพื่อศึกษาความต้องการโภชนะของสุกรกระโดนในบางด้านจากหลายๆ ด้านที่ควรศึกษา เพื่อให้ได้องค์ความรู้ตามวัตถุประสงค์ จึงวางแผนการทดลองและเก็บข้อมูลโดย บทที่ 1 เก็บข้อมูลเชิงปริมาณ สมรรถภาพการเจริญเติบโต น้ำหนักอวัยวะภายใน องค์ประกอบซาก และรายละเอียดของกรดไขมันในเนื้อของสุกรกระโดนทั้งสองเพศ สุกรพันธุ์กระโดนมีน้ำหนักของซากอุ่นประมาณร้อยละ 65 ของน้ำหนักมีชีวิต ส่วนเนื้อสันนอก (loin) มีไขมันและโปรตีนเป็นองค์ประกอบอยู่ร้อยละ 8.7 และ 21.4 ตามลำดับ สุกรเพศเมียมีแนวโน้มมีไขมันสันหลังหนากว่าเพศผู้ (2.23 เซนติเมตร เทียบกับ 1.81 เซนติเมตร) การเลี้ยงสุกรด้วยอาหารที่ใช้มันสำปะหลังแห้งทดแทนปลายข้าวในสูตรพบว่าทำให้สุกรมีการสะสมไขมันสันหลังลดลง และบันทึกข้อมูลลักษณะคุณภาพเนื้อ ได้แก่ ระดับสีเนื้อ ความเป็นกรดด่าง (pH) ของกล้ามเนื้อ ร้อยละของการสูญเสียน้ำจากการทำให้เนื้อสุก (cooking loss) และค่าแรงตัดผ่านกล้ามเนื้อ (shear force)

คาร์โบไฮเดรตเป็นโภชนะที่ใช้ปริมาณมากในการประกอบสูตรอาหารสุกร จึงทดลองเปรียบเทียบวัตถุดิบแหล่งคาร์โบไฮเดรต ได้แก่ ข้าวโพดบด รำข้าว(รำละเอียด) ปลายข้าว และ มันสำปะหลังแห้ง ในสูตรอาหารเพื่อทราบค่าสัมประสิทธิ์การย่อยได้ของโภชนะของสุกรกระโดน (บทที่ 2) พบว่าสูตรอาหารที่ใช้ปลายข้าวเป็นแหล่งคาร์โบไฮเดรตมีค่าสัมประสิทธิ์การย่อยได้ของคาร์โบไฮเดรต โปรตีนหยาบ และพลังงานดีที่สุด โดยมีราคาสูงที่สุดด้วย และเป็นไปตามความ

สุกรกระโดนที่ได้รับการผ่าตัดใส่ท่อเก็บตัวอย่าง (fistula) ของเหลวในลำไส้เล็กส่วนปลาย เพื่อศึกษาเปรียบเทียบค่าสัมประสิทธิ์การย่อยได้ของโภชนะ ณ ตำแหน่งลำไส้เล็กส่วนปลายเทียบกับการย่อยได้ตลอดทางเดินอาหาร (บทที่ 5) พบว่าค่าสัมประสิทธิ์การย่อยได้ตลอดทางเดินอาหารของวัตถุแห้ง อินทรียวัตถุ โปรตีนหยาบ เยื่อใย และ คาร์โบไฮเดรต ทั้งหมดมีค่าสูงกว่าค่าสัมประสิทธิ์การย่อยได้ ณ ตำแหน่งลำไส้เล็กส่วนปลาย ยกเว้นค่าสัมประสิทธิ์การย่อยได้ของไขมัน สุกรที่กินอาหารสูตรปลายข้าวมีค่าสัมประสิทธิ์การย่อยได้ ณ ลำไส้เล็กส่วนปลายของวัตถุแห้ง อินทรียวัตถุ โปรตีนหยาบ ไขมัน และ คาร์โบไฮเดรต สูงกว่าสุกรกระโดนกลุ่มที่กินอาหารสูตรมันสำปะหลังแห้ง

สำหรับสุกรกระโดนช่วงกำลังเจริญเติบโต (ขุน) ยังขาดข้อมูลความต้องการโปรตีน การทราบระดับโปรตีนที่เหมาะสมในสูตรอาหารมีความจำเป็นสำหรับการผลิตเนื้อสุกรให้มีต้นทุนต่ำ บทที่ 6 กล่าวถึงการทดสอบสูตรอาหารที่มีระดับโปรตีนที่แตกต่างกันให้ผลต่อการเจริญเติบโต การย่อยได้ของโปรตีนหยาบ และการใช้ประโยชน์ได้ของไนโตรเจนในสุกรกระโดนอย่างไร สูตรอาหารประกอบด้วยระดับโปรตีนหยาบร้อยละ 14, 16, 18 หรือ 20 ของวัตถุแห้ง ผลการทดลองพบว่าสุกรกระโดนที่กินอาหารที่มีโปรตีนหยาบเป็นองค์ประกอบร้อยละ 20 มีอัตราการเจริญเติบโตเฉลี่ยต่อวัน และอัตรการเปลี่ยนอาหารเป็นน้ำหนักตัว ดีกว่าสุกรที่กินอาหารที่มีโปรตีนหยาบเป็นองค์ประกอบร้อยละ 14 ระดับโปรตีนในอาหารมีความสัมพันธ์เชิงเส้นตรงกับอัตราการเจริญเติบโตเฉลี่ยต่อวัน ค่าสัมประสิทธิ์การย่อยได้ของโปรตีนเพิ่มขึ้นเมื่อระดับโปรตีนที่สุกรกินได้เพิ่มขึ้น จากผลการทดลองนี้เมื่อคิดบนฐานค่าอาหารที่ใช้ต่อน้ำหนักตัวของสุกรที่เพิ่มขึ้นหนึ่งกิโลกรัมพบว่าอาหารที่มีโปรตีนหยาบเป็นองค์ประกอบร้อยละ 18 มีความคุ้มค่ามากที่สุด

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Curriculum vitae

Kraisit Vasupen was born on July 7, 1972 in Bangkok, Thailand. He was the fourth child in his family. He started his study of animal science at the Chiangmai University in 1991. He received his Bachelor degree in animal science at Chiangmai University in 1995. He worked for one year as a teacher of animal husbandry. In 1997, he continued his studies at the Department of Animal Science, Faculty of Agriculture, Chiangmai University. The topic of his thesis involved ruminant nutrition which was done under the supervision of Assoc. Prof. Dr. Boonserm Cheva-Isarakul. He received his M.Sc. diploma in animal sciences in 2000. In January 2001, he officially became a tenured lecturer at the Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Thailand. In 2004, he started a PhD program on the nutrition of Kadon pigs in collaboration with Professor A.C. Beynen of the Department of Nutrition, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands. The author still is a lecturer at the Department of Animal Science, Faculty of Natural Resources, Rajamangala University of Technology Isan, Sakon Nakhon Campus.

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