

# Effects of replacing fish meal with ensiled catfish (*Pangasius hypophthalmus*) by-products on the performance and carcass quality of finishing pigs\*

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## ABSTRACT

Thirty castrated finishing male pigs were used to evaluate the effects of replacing fish meal (FM) with ensiled Tra catfish (*Pangasius hypophthalmus*) by-products (ECM) on performance and carcass quality. Pigs were allocated to individual pens and fed a control diet (ECM0) with FM as sole protein supplement, and experimental diets where 100 (ECM100), 75 (ECM75), 50 (ECM50) and 25% (ECM25) of the crude protein (CP) from FM was replaced by the CP from ECM. Feed intake was highest in ECM25 and lowest in ECM75 ( $P<0.05$ ), and daily weight gain was higher in ECM100 than in the other treatments ( $P<0.01$ ). Feed conversion ratio was improved ( $P<0.05$ ) with higher inclusion of ECM in the diets. Carcass yield and dressing percentage were not affected ( $P>0.05$ ) by treatment, but leaf fat and backfat thickness were higher and loin eye area lower in ECM100 compared with ECM0 ( $P<0.01$ ). Ether extract and polyunsaturated fatty acid contents and meat colour values in *Longissimus dorsi* muscle increased ( $P<0.01$ ) with ECM replacement level. Feed costs were lower in ECM100 and ECM75 compared with ECM25 and ECM0.

**KEY WORDS:** ensiled catfish by-products, tra catfish, finishing pig

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## INTRODUCTION

*Pangasius hypophthalmus*, fresh water Tra catfish, is the main commercially farmed fish in the Mekong Delta of Vietnam, and Tra catfish fillet is exported to many countries in the world (Lam et al., 2009). Tra catfish by-products (CBP), which include head, bone, skin, and the abdominal organs that remain after the two side fillets are removed are abundant. The CBP is ground fresh, boiled, and the oil removed, then dried to produce catfish by-product meal (CBM) in commercial catfish by-product processing companies. The CBM is included in livestock diets and exported to China, but the price is as high as that of marine fish meal. Although relatively inexpensive, it is not common for pig producers to use wet CBP in diets for pigs, because of problems of preservation, as the product deteriorates rapidly in tropical climates. Many studies have shown however that wet fish by-products can become a valuable protein source in animal feeds if converted into silage. Ensiling the fresh by-products in combination with other locally available feeds rich in fermentable carbohydrates, such as sugar cane molasses, is a simple and appropriate method of conservation (Samuels et al., 1992; Kjos et al., 1999; Zahar et al., 2002). A study by Thuy et al. (2010) carried out in the Mekong Delta showed that catfish by-products can be successfully ensiled with 20-40% of sugar cane molasses and preserved for 1-2 months without affecting the quality.

Pig production is the dominant livestock enterprise in Vietnam, and pork production accounts for over 70% of the total meat production of the country, of which smallholders supply around 80% of the total (FAO, 2005). Under village conditions, production is mainly by small-scale farmers for income generation. The animals are fed using cheap local materials and unconventional feed resources rather than expensive high quality imported feeds. Feed represents approximately 65% of the production costs of market pigs, so decreasing the cost of feed is essential. Fermented liquid feed is inexpensive and is used to inhibit the growth of pathogenic bacteria such as *E. coli* in the feed and in the gastrointestinal tract of piglets, and to increase lactic acid bacteria in the stomach of growing pigs (Canibe and Jensen, 2003). Fermented liquid feed is characterized by low pH, high concentration of organic acids, especially lactic acid, and can improve the digestibility of some dietary components (Hong and Lindberg, 2007). This study was conducted to evaluate the effects of replacing fish meal with ensiled catfish by-products on growing pig performance, carcass quality and economic benefits.

## MATERIAL AND METHODS

### *Animals and experimental design*

A total of 30 crossbreed castrated (Yorkshire x Landrace) male pigs with an initial average liveweight of  $45.0 \pm 3.1$  kg (mean  $\pm$  SD) was used in the experiment. Before starting the experiment, the pigs were given the same commercial feed until 35 kg liveweight, and then were given the experimental feeds for 2 weeks of adaptation. All pigs were vaccinated against hog cholera and foot and mouth disease, and were allocated into six groups of five, balanced for initial body weight, and were housed in 30 individual 60 x 150 cm pens, each with a feeder and an automatic nipple drinker. The daytime temperature during the experiment ranged from 30 to 33°C. The experimental feed was given *ad libitum* twice per day at 9.00 and 15.00 h, and refusals were collected the following morning before the first meal, and samples stored in a freezer for dry matter (DM) analysis. The experiment lasted ten weeks and the pigs were weighed every two weeks. Feed intake was recorded, and then feed conversion ratio (FCR) was calculated as feed intake divided by weight gain.

### *Diets and feeding*

The study was conducted according to a randomized complete block design with 5 treatments and 6 replications. Before the experiment started, samples of feed ingredients were taken for analysis of DM and chemical composition. Metabolizable energy (ME) values of the feed ingredients were calculated according to tables of the Chemical Composition of Animal Feed in Vietnam (Chinh et al., 1995). Five experimental diets were introduced to the pigs, and were formulated to contain 13.3 to 13.4% crude protein (CP), and 13.0 to 13.1 MJ/kg of ME. Rice bran, broken rice and maize meal were the basal ingredients, with fish meal (FM) as the sole protein supplement, and 4 experimental diets were formulated in which 100, 75, 50 and 25%, respectively, of the CP from FM was replaced by the CP from ensiled catfish by-product (ECM). All diets were supplemented with a standard mixture of vitamins and minerals.

Fish meal was bought from factories that specifically process small marine fish. The boiled, ground catfish by-product was purchased once per week at a catfish by-product meal factory near to the experimental farm, and then mixed with sugar cane molasses (M) of 71 degree Brix (wet weight basis) in a ratio of 8:2 (CBP: M). The mixture was placed in plastic bags and sealed to prevent air contamination and then ensiled. The ensiled product (ECM) was made every week and then stored at room temperature (29 to 31°C) for one month before mixing daily with the basal ingredients.

### *Carcass measurements*

After the ten weeks of the feeding trial, all pigs were transported to a local abattoir over a period of 3 days (10 pigs/day). The pigs were slaughtered after 12 h of starvation; they were stunned, exsanguinated and eviscerated. The hot carcass weight was the weight after slaughter, but excluding blood, hair, visceral organs and gastrointestinal tract. Dressed weight was the hot carcass weight minus head, lower legs, tail and leaf fat, and dressing percentage was calculated. All the parameters were measured on the left side of each carcass, including backfat thickness at the 10<sup>th</sup> rib, three-quarters of the lateral length of the *Longissimus dorsi* (LD) muscle perpendicular to the outer skin surface, and at three other points at the 1<sup>st</sup> rib, last rib and last lumbar vertebra using a ruler, and the average backfat thickness was calculated. The loin eye area was measured by tracing the LD muscle surface area at the 10<sup>th</sup> rib on acetate paper, and by using a compensating planimeter at slaughter. Finally, fresh loin muscle samples were taken at the 10<sup>th</sup> rib and transported to the laboratory for pH measurement, chemical analysis of DM, CP, ether extract (EE), and ash, colour value and fatty acid content.

### *Chemical analysis*

The pH of the meat was measured at 24 h post-mortem using a digital pH meter. Approximately 10 g samples were ground into small pieces and 90 ml of distilled water was added. Slurry was then made using a homogenizer and the pH was recorded after the pH meter had been calibrated with standard buffers of pH 4.0 and 7.0 at room temperature. The chemical composition of feed ingredients, diets and meat was determined using the following standard AOAC (1990) methods. Dry matter of ECM, diets, feed refusals and meat was determined by drying the fresh samples at 105°C until dry. Crude protein was determined by the Kjeldahl method. Total ash was the residue after ashing the sample at 550°C and organic matter (OM) was calculated by difference. Ether extract was determined by Soxhlet extraction. Fatty acid composition of loin muscle samples from the 10<sup>th</sup> rib was analysed by gas chromatography (GC), and total lipid content of muscle was following the chloroform-methanol extraction procedure of Folch et al. (1957). Extracted lipids were converted to fatty acid methyl ester using BF<sub>3</sub> and methanolic KOH, and analysed by GC (HP5890, Hewlett-Packard, FID- ISO 5509). The objective meat colour on the LD was evaluated on the 10<sup>th</sup>-11<sup>st</sup> rib surface using a colorimeter (Chromameter Minolta, CR- 200, Japan), and expressed as Hunter L\*, a\*, b\* values of objective colour. The L\* reading is a measure of the lightness or darkness of a meat sample, the a\* reading is a measure of the redness or greenness of the sample (the more positive the number, the redder the sample), while the b\* reading is a measure of yellowness and blueness (the more positive the number, the yellower the sample).

### Statistical analysis

Analysis of variance was performed according to a randomized block design, using the General Linear Model of Minitab Statistical Software Version 15. Leaf fat, backfat thickness and loin eye area were corrected by covariance for differences in carcass weight. Tukey pair - wise comparisons were used to determine differences between treatment means at  $P < 0.05$ .

## RESULTS

### Chemical composition of the diets

The chemical composition and metabolizable energy content of the raw materials used to compose the experimental diets are presented in Table 1.

Table 1. Dry matter (%), chemical composition <sup>1</sup>(% of DM) and metabolizable energy contents (MJ/kg DM) of ingredients in the experimental diets

Ingredient	DM	CP	EE	Ash	CF	NFE	OM	ME
Rice bran	81.2	9.8	9.5	7.6	10.2	62.9	92.4	11.4
Maize meal	86.7	8.1	0.7	3.3	3.6	84.3	96.7	14.2
Broken rice	87.5	7.0	0.6	3.8	7.0	81.6	96.2	14.1
Sugar cane molasses (M)	71.0	3.4	-	12.3	-	-	87.7	13.1
Catfish by-product (CBP)	43.5	37.7	19.4	33.0	2.1	7.8	67.0	12.8
Fish meal	90.1	51.5	8.3	30.4	3.2	6.6	69.6	11.9
ECM <sup>2</sup>	48.5	30.5	14.3	22.1	2.1	31.0	77.9	12.9

<sup>1</sup> DM - dry matter; CP - crude protein; EE - ether extract; CF - crude fibre; NFE - N-free extractives; OM - organic matter; ME - metabolizable energy; <sup>2</sup> catfish by-product ensiled with sugar cane molasses at a ratio of 8:2 (CBP: M)

The DM, CP and EE contents of fish meal (90.1, 51.5 and 8.3%, respectively) were different to those of the catfish by-products (43.5, 37.7 and 19.4%, respectively), which was the material used to make silage with sugar cane molasses, so as a result the ensiled catfish by-product was low in DM and CP (48.5 and 30.5%, respectively) but high in EE (14.3%) content. The chemical composition of the experimental diets is presented in Table 2, and the DM of the diets decreased with increasing inclusion of ECM, from 85.7% in ECM0 to 76.6% in ECM100. All experimental diets had the same contents of CP (13.3-13.4%) and calculated ME (13.0-13.1 MJ/kg). Ether extract and ash contents increased with increasing inclusion of ECM, from 3.9 and 7.9% in ECM0 to 6.5 and 8.9% in ECM100, respectively.

Table 2. Ingredient (% of DM), chemical composition (% of DM), energy content (MJ/kg feed) and cost (VND/kg DM) of the experimental diets

Item	Diet <sup>1</sup>				
	ECM0	ECM25	ECM50	ECM75	ECM100
<i>Ingredients</i>					
broken rice	29.1	25.0	23.1	22.0	18.3
rice bran	26.7	30.6	33.0	32.0	33.0
maize meal	32.0	30.0	27.5	27.0	27.0
fish meal	12.0	9.0	6.0	3.0	0
ensiled catfish by-products(ECM)	0	5.2	10.2	15.8	21.5
vitamin-mineral premix <sup>2</sup>	0.2	0.2	0.2	0.2	0.2
<i>Chemical composition</i>					
dry matter	85.7	83.4	81.2	79.0	76.6
organic matter	92.1	91.8	91.6	91.4	91.1
crude protein	13.4	13.4	13.3	13.3	13.3
ether extract	3.9	4.8	5.4	5.9	6.5
ash	7.9	8.2	8.7	8.6	8.9
crude fibre	6.3	6.3	6.4	6.2	6.1
N-free extractives	68.3	67.1	66.3	65.9	65.1
Metabolizable energy	13.1	13.0	13.0	13.0	13.0
Cost	6893	6569	6290	6082	5815

<sup>1</sup> ECM0: 100% crude protein (CP) from fish meal (FM); ECM25 - 75% CP from FM and 25% CP from ensiled catfish by-products (ECM); ECM50 - 50% CP from FM and 50% CP from ECM; ECM75 - 25% CP from FM and 75% from ECM; ECB100: 100% CP from ECM

<sup>2</sup> per kg complete diet: IU: A 48 x 10<sup>5</sup>, vit. D 48 x 10<sup>4</sup>, vit. E 44 x 10<sup>2</sup>; mg: vit. K<sub>3</sub> 280, vit. B<sub>1</sub> 600, vit. B<sub>2</sub> 200, vit. B<sub>6</sub> 320, folic acid 160, nicotinic acid 44 x 10<sup>2</sup>, pantothenic acid 24 x 10<sup>2</sup>; mcg: vit. B<sub>12</sub> 6 x 10<sup>3</sup>, biotin 10<sup>4</sup>; minerals: mg: Fe 475 x 10<sup>2</sup>, Cu 315 x 10<sup>2</sup>, Zn 475 x 10<sup>2</sup>, I 350, Co 47, Mn 195 x 10<sup>2</sup>, Se 39

### *Growth performance and economic efficiency*

The experiment was carried out without any health problems. The effect of ensiled catfish by-product on pig performance is shown in Table 3. There was significantly higher ( $P < 0.01$ ) final body weight in pigs fed ECM50 (95.7 kg), ECM75 (96.0 kg) and ECM100 (98.0 kg) compared with ECM25 (93.0 kg) and ECM0 (93.2 kg). The highest average daily gain (ADG) was in ECM100 (760 g/day), the lowest in ECM0 (683 g/day) and ECM25 (686 g/day). Decreasing average daily feed intake (ADFI) ( $P < 0.05$ ) was found with increasing inclusion of ECM. The highest ADFI was in ECM0 (2.47 kg DM/day) and ECM25 (2.48 kg DM/day), and the lowest in ECM75 (2.35 kg DM/day). Feed conversion ratio (FCR) was highest in ECM0 (3.62 kg feed DM/kg gain) and lowest in ECM100 (3.15 kg feed DM/kg gain) ( $P < 0.05$ ). The cost of feed per kg gain decreased with increasing inclusion of ECM in the diet, and in ECM25, ECM50, ECM75 and ECM100 was 96, 83, 79 and 72%, respectively, compared with ECM0.

Table 3. Effects of ensiled catfish by-products on the growth performance of finishing pigs

Item	Diet <sup>1</sup>					SE	P
	ECM0	ECM25	ECM50	ECM75	ECM100		
Initial liveweight, kg	45.3	45.0	44.8	45.1	44.8	0.23	0.56
Final liveweight, kg	93.2 <sup>b</sup>	93.0 <sup>b</sup>	95.7 <sup>ab</sup>	96 <sup>ab</sup>	98.0 <sup>a</sup>	0.95	0.001
Duration, days	70	70	70	70	70		
Liveweight gain, g/day	683 <sup>b</sup>	686 <sup>b</sup>	727 <sup>ab</sup>	727 <sup>ab</sup>	760 <sup>a</sup>	10.7	0.001
ADFI, kg DM/day <sup>2</sup>	2.47 <sup>ab</sup>	2.48 <sup>a</sup>	2.40 <sup>ab</sup>	2.35 <sup>b</sup>	2.39 <sup>ab</sup>	0.03	0.02
FCR, kg feed/kg gain <sup>2</sup>	3.62 <sup>a</sup>	3.62 <sup>a</sup>	3.30 <sup>ab</sup>	3.23 <sup>ab</sup>	3.15 <sup>b</sup>	0.08	0.001
Cost/kg gain, thousand VND	24.9 <sup>a</sup>	23.9 <sup>a</sup>	20.9 <sup>b</sup>	19.6 <sup>b</sup>	18.3 <sup>b</sup>	0.65	0.001
Cost/gain comparison, %	100	96	83	79	72		

<sup>1</sup> explanation see Table 2; <sup>2</sup> ADFI - average daily feed intake; FCR - feed conversion ratio

<sup>a,b</sup> within rows, values with different superscript letters are different (P<0.05)

### *Carcass characteristics and meat quality*

The carcass traits, backfat thickness and loin eye area are presented in Table 4. There was no significant difference in carcass yield and dressing percentage among diets, but leaf fat and backfat thickness increased (P<0.05) when pigs were fed higher levels of ECM. The highest leaf fat was 1.47 kg (ECM100) and 1.42 kg (ECM75) and lowest 1.22 kg (ECM0) and 1.24 kg (ECM25). The backfat thickness at the 10<sup>th</sup> rib and average backfat thickness were highest in ECM100 (2.24 and 2.38 cm, respectively) and lowest in ECM0 (2.07 and 2.14 cm, respectively). Loin eye area was lowest in ECM100 (39.5 cm<sup>2</sup>) and ECM75 (40.2 cm<sup>2</sup>) and highest in ECM0 (42.5 cm<sup>2</sup>) and ECM25 (42.2 cm<sup>2</sup>).

Table 4. Effect of ensiled catfish by-products on carcass characteristics of finishing pigs

Item	Diet <sup>1</sup>					SE	P
	ECM0	ECM25	ECM50	ECM75	ECM100		
Slaughter weight, kg	93.9	93.8	96.5	96.5	98.8		
Hot carcass weight, kg	70.9	71.3	73.3	74.0	75.7		
Carcass yield, %	75.5	76.0	75.9	76.6	76.7	0.31	0.08
Dressing percentage, %	71.0	71.2	71.6	72.1	72.2	0.35	0.10
Leaf fat, kg	1.22 <sup>b</sup>	1.24 <sup>b</sup>	1.34 <sup>ab</sup>	1.42 <sup>a</sup>	1.47 <sup>a</sup>	0.03	0.001
<i>Backfat thickness, cm</i>							
at 10 <sup>th</sup> rib	2.07 <sup>b</sup>	2.14 <sup>ab</sup>	2.19 <sup>a</sup>	2.14 <sup>ab</sup>	2.24 <sup>a</sup>	0.02	0.001
average backfat thickness	2.14 <sup>c</sup>	2.23 <sup>b</sup>	2.26 <sup>b</sup>	2.31 <sup>ab</sup>	2.38 <sup>a</sup>	0.02	0.001
Loin eye area, cm <sup>2</sup>	42.5 <sup>a</sup>	42.2 <sup>a</sup>	41.4 <sup>ab</sup>	40.2 <sup>bc</sup>	39.5 <sup>c</sup>	0.40	0.001

<sup>1</sup> explanation see Table 2

<sup>a,b,c</sup> within rows, values with different superscript letters are different (P<0.05)

The chemical composition and colour of the longissimus dorsi (LD) muscle is shown in Table 5. There was no significant difference in DM, CP and ash contents of LD muscle, but the EE content in the LD muscle of pigs fed ECM100 (5.24%) was higher than in ECM0 (4.62%) and ECM25 (4.65%). The meat colour values

Table 5. Effects of ensiled catfish by-products on the chemical composition and colour of *Longisimus dorsis* (LD) muscle in finishing pigs

Item	Diet <sup>1</sup>					SE	P
	ECM0	ECM25	ECM50	ECM75	ECM100		
<i>Chemical composition, %</i>							
moisture	73.9	73.5	73.8	74.1	74.1	0.15	0.06
crude protein	21.0	20.9	21.3	21.4	20.8	0.11	0.18
ether extract	4.62 <sup>b</sup>	4.65 <sup>b</sup>	5.06 <sup>a</sup>	5.22 <sup>a</sup>	5.24 <sup>a</sup>	0.08	0.001
ash	1.11	1.07	1.11	1.09	1.10	0.01	0.09
pH	5.5	5.5	5.6	5.6	5.6	0.03	0.06
<i>Colour of LD muscle</i>							
lightness, L* <sup>2</sup>	40.8 <sup>b</sup>	40.9 <sup>b</sup>	41.6 <sup>ab</sup>	42.3 <sup>a</sup>	42.2 <sup>a</sup>	0.19	0.001
redness, a* <sup>2</sup>	7.26 <sup>d</sup>	7.26 <sup>d</sup>	7.97 <sup>c</sup>	8.33 <sup>b</sup>	9.09 <sup>a</sup>	0.08	0.001
yellowness, b* <sup>2</sup>	5.18 <sup>bc</sup>	5.04 <sup>c</sup>	5.40 <sup>bc</sup>	5.53 <sup>b</sup>	6.07 <sup>a</sup>	0.09	0.001

<sup>1</sup> explanation see Table 2; <sup>2</sup> L - black (0) to white (100) scale; a - red (+) to green (-) colour scale; b - yellow (+) to blue (-) colour scale

<sup>a,b,c,d</sup> within rows, values with different superscript letters are different (P<0.05)

of the LD muscle increased with increasing inclusion of ECM. The L\* values increased from 40.8 in ECM0 to 42.3 in ECM75 and 42.2 in ECM100. Similarly, the a\* value of ECM100 (9.09) was higher than in ECM0 (7.26). However, the b\* values were highest in pigs fed ECM100 (6.07) and ECM75 (5.53) and lowest in pigs fed ECM25 (5.04).

Table 6. Effect of ensiled catfish by-products on fatty acid composition of *Longisimus dorsis* (LD) muscle in finishing pigs, % of total fatty acids

Fatty acid	Diet <sup>1</sup>					SE	P
	ECM0	ECM25	ECM50	ECM75	ECM100		
C12:0	0.13	0.13	0.13	0.12	0.12	0.00	0.69
C14:0	1.60	1.57	1.66	1.62	1.58	0.03	0.14
C16:0	28.2	27.6	27.4	27.1	27.5	0.27	0.10
C18:0	13.3	13.5	13.4	13.8	13.6	0.12	0.11
C16:1, n-9	3.51	3.57	3.53	3.56	3.52	0.03	0.53
C18:1, n-9	33.1	32.7	33.1	32.6	33.0	0.26	0.41
C20:1	0.62 <sup>b</sup>	0.65 <sup>ab</sup>	0.68 <sup>ab</sup>	0.69 <sup>a</sup>	0.70 <sup>a</sup>	0.01	0.001
C18:2, n-6	12.0 <sup>b</sup>	12.4 <sup>ab</sup>	12.6 <sup>ab</sup>	12.8 <sup>a</sup>	12.9 <sup>a</sup>	0.15	0.001
C18:3, n-3	2.37 <sup>c</sup>	2.42 <sup>b</sup>	2.44 <sup>b</sup>	2.48 <sup>a</sup>	2.51 <sup>a</sup>	0.01	0.001
C20:4, n-6	0.36	0.36	0.39	0.36	0.38	0.01	0.12
C20:5, n-3 EPA	0.76	0.77	0.76	0.76	0.77	0.00	0.85
C20:2, n-6	0.51 <sup>a</sup>	0.51 <sup>a</sup>	0.49 <sup>ab</sup>	0.44 <sup>c</sup>	0.46 <sup>bc</sup>	0.01	0.001
C22:5, n-3 DPA	0.91 <sup>b</sup>	0.92 <sup>b</sup>	0.97 <sup>a</sup>	0.97 <sup>a</sup>	0.97 <sup>a</sup>	0.01	0.001
C22:6, n-3 DHA	1.23 <sup>b</sup>	1.21 <sup>b</sup>	1.32 <sup>a</sup>	1.33 <sup>a</sup>	1.33 <sup>a</sup>	0.00	0.01
SFA <sup>2</sup>	43.3	42.8	42.6	42.7	42.8	0.31	0.59
MUFA <sup>2</sup>	37.2	36.9	37.3	36.8	37.2	0.37	0.61
PUFA <sup>2</sup>	18.2 <sup>c</sup>	18.6 <sup>bc</sup>	18.9 <sup>ab</sup>	19.1 <sup>ab</sup>	19.3 <sup>a</sup>	0.15	0.00
PUFA/SFA	0.42 <sup>b</sup>	0.43 <sup>ab</sup>	0.44 <sup>a</sup>	0.45 <sup>a</sup>	0.45 <sup>a</sup>	0.00	0.00

<sup>1</sup> explanation see Table 2; <sup>2</sup> SFA - saturated fatty acids; MUFA - mono-unsaturated fatty acids; PUFA - polyunsaturated fatty acids

<sup>a,b,c</sup> within rows, values with different superscript letters are different (P<0.05)

*Fatty acid composition of Longissimus dorsi (LD) muscle*

There was no significant difference among diets ( $P>0.05$ ) in saturated (SFA) and monounsaturated fatty acids (MUFA) in the LD muscle (Table 6). However, polyunsaturated fatty acids (PUFA), such as linoleic (C18:2, n-6),  $\alpha$ -linolenic (C18:3, n-3), C22:5, n-3 (DPA) and C22:6, n-3 (DHA), increased with higher inclusion of ECM in the diet, with the highest total PUFA in ECM100 (19.3%) and lowest value in ECM0 (18.2%) ( $P<0.05$ ).

## DISCUSSION

Tra catfish by-product composition varies according to by-product input material and the procedure for fat extraction, and the CBP input material, which was mainly head and bone by-products, had lower CP and DM contents than in fish meal. The study of Thuy et al. (2010) showed that CBP can be successfully ensiled with 20 to 40% of sugar cane molasses, and can be kept for around 2 months without affecting quality, and this was confirmed in the present study. Ensiling involved boiling and grinding the catfish by-product and adding sugar cane molasses to get the pH below 4.5, at which growth of spoilage bacteria is prevented. The increasing DM and decreasing CP contents in ECM compared with the CBP were due to the inclusion of sugar cane molasses (20% in wet weight) which is higher in DM and lower in CP content than CBP. The higher the ECM replacement the higher crude fat contents in the diet, which can be explained by the higher EE in CBP than in the fish meal used, which was produced from small, whole marine fish. Moreover, all diets were formulated to contain similar CP and ME to avoid the effect of different levels of nitrogen and energy. Hsia and Lu (2004) showed that under moderately high environmental temperatures (around 30°C), the weight gain of pigs increased with increasing dietary protein and energy contents.

The inclusion of ECM in the diets slightly reduced the average daily feed intake (ADFI), probably due to differences in palatability. In an earlier study with ensiled catfish by-product, after 4 weeks of ensiling the concentration of acetic acid (21% of total organic acids) was high (Thuy et al., 2010) and Brooks et al. (2001) showed that a high level of acetic acid in fermented liquid feed is undesirable because it can reduce the palatability. In addition the high fat content of the diets with high inclusion levels of ECM could have reduced feed intake, as Michael (2001) showed that daily intake of diets with high levels of fat was reduced.

Although there was a small but significant decrease in intake of the high ECM diets, average daily gain (ADG) of pigs fed ECM100 were 11% higher than in ECM0. This can be explained by the higher fat content in ECM100, which mainly came from catfish oil, which has been shown to improve the efficiency of energy utilization in pigs maintained at high ambient temperatures (Stahly, 1984). This is in agreement with previous research from Green et al. (1988), who found that animals fed on oily fish silage grew significantly faster than those given no fish silage, and increasing the level of oily fish silage in the diet also resulted in an improvement in feed conversion ratio. Similarly, Øverland et al. (1999) showed that a high fat diet (10% added fat) gave a significantly higher ADG, lower total feed intake and better feed efficiency compared with a low fat diet (1.5% added fat) and in constant ME content diets. In addition, fish silage is considered to be an excellent protein source, with a high biological value (Vidotti et al., 2003), because during silage processing, proteins are hydrolysed to free amino acids, thus increasing their availability for protein biosynthesis. Moreover, the studies of Urlings et al. (1993), Jensen and Mikkelsen (1998) and Scholten et al. (1999) showed that fermented feed resulted in improved growth performance and reduced mortality and morbidity in growing-finishing pigs because of enhanced nutrient availability and reduced growth and shedding of pathogenic bacteria due to the low pH, which is a result of the high concentration of organic acids (Van Winsen et al., 2001). Similarly results from Lallo et al. (1997) showed that poultry offal ensiled with sugar cane molasses can replace up to 30% of commercial feeds for growing pigs without affecting growth performance and health.

Feed conversion ratio (FCR) of pigs fed the high ECM diets was improved as a result of lower feed intake and higher growth rate. An additional reason for the lower FCR could be that the catfish by-product was heated before ensiling, which could have improved diet digestibility, as was confirmed by Urlings et al. (1993), who found that mild heating applied before the fermentation of poultry by-products probably contributed to the better growth and the reduced FCR in pigs.

The supplementation of catfish by-product silage did not affect hot carcass and dressing percentage. Kjos et al. (1999) reported that the inclusion of defatted fish silage at the level of 50 g/kg diet, corresponding to 9% of the total protein, had no negative effects on the dressing percentage or sensory quality of pig meat. In the present study, backfat thickness and EE contents in LD increased with higher ECM inclusion in the diet, which was also found by Stahly and Cromwell (1979) who showed that dietary fat supplementation increased carcass backfat thickness in pigs raised at high ambient temperatures. Urlings et al. (1993) also showed that feeding pigs with fermented poultry by-product which was heated before fermentation also increased backfat thickness, and Kim et al. (2006) reported that

addition of fermented persimmon shell to the diet increased the EE content of the LD muscle.

Chemical analysis of LD indicated that there were no differences in moisture, CP and ash, among diets, but the meat from pigs fed ECM100 and ECM75 had higher  $a^*$  and  $b^*$  values than those given ECM0 and ECM25. The cause of the higher  $a^*$  and  $b^*$  values could probably be linked to the higher concentration of C16:0 and C18:0 in the LD fat, which makes the lipid less translucent and therefore brightens the colour of the pork (Teye et al., 2006). Also the lower pH in ECM0 is an indicator of lower colour value in LD, because the lower the pH the paler the meat colour. Moreover, Kouba (2006) reported that a high degree of tissue unsaturation can result in darker meat colour, because tissue unsaturation can cause a more rapid conversion of the red muscle pigment myoglobin to brown metmyoglobin.

Fat and fatty acids are important because of their effects on human health, and fatty acid composition is a major factor in the nutritional value of meat. A ratio of polyunsaturated fatty acids to saturated fatty acids of 0.4 or above is considered suitable for human consumption (Department of Health, 1994). The pig is unable to synthesize essential fatty acids such as linoleic and linolenic acid, and they must be supplied in the diet, and the fatty acid composition of pig meat is mostly controlled by diet (Kristinsson et al., 2001). The fat in ECM is mainly from catfish oil which is a rich source of essential polyunsaturated fatty acids in both the omega-3 and omega-6 families. Ho and Paul (2009) showed that the high absolute contents of DHA (C22:6, n-3) and EPA (C20:5, n-3) in Tra catfish makes it a potentially valuable source of omega-3 fatty acids. Linoleic acid (8.4%) is the major PUFA in Tra catfish, followed by DHA (4.7%). Thus, the higher the inclusion rate of ECM in the diet, the higher the DHA, EPA, DPA and other polyunsaturated fatty acids in LD. This is in agreement with Lauridsen et al. (1999), Bryhni et al. (2002) and Hallenstvedt et al. (2010), who showed that feeding fish oil to pigs did not affect the sensory quality of loin, but increased the level of DHA, EPA and DPA in muscle. Although fish meal normally contains high levels of PUFA (Jonsdottir et al., 2003), the fish meal used in the present experiment was made from small marine fish which had a lower PUFA content than in catfish by-product silage.

The feed costs per kg liveweight gain were much lower in ECM100 and ECM75 (18,300 and 19,600 VND/kg gain, respectively) compared with ECM25 and ECM0 (23,900 and 24,900 VND/kg gain, respectively). So, 100% replacement of fish meal by ensiled catfish by-product reduced feed cost per kg gain to around 72 of the 100% fish meal diet.

## CONCLUSIONS

Replacing fish meal by ensiled catfish by-product improved the performance and meat quality of finishing pigs, but resulted in an increase in backfat thickness. However, because of the reduced feed costs, complete replacement of fish meal would still be profitable for pig producers in the Mekong Delta.

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