The Effect of High Environmental Temperature and Nutrient Density on Pig Performance, Conformation and Carcass Characteristics under Restricted Feeding System

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ABSTRACT : An experiment was conducted to examine the effect of a high environmental temperature on the performance, conformation, and carcass characteristics of pigs and the influence of diet. Thirty-six three-way crossed castrated male pigs with average initial body weight of 50.4 kg were used in the experiment. The pig were allocated to the following treatments: two environmental temperatures (20 and 30°C)×three dietary energy levels (2,980, 3,300 and 3,600 kcal/kg)×three protein levels (12.8, 15.2 and 17.2%). Daily weight gain was lighter ($p<0.01$) and feed: gain ratio lower ($p<0.05$) in pigs at 30°C than for pigs at 20°C. The pigs at 30°C were significantly taller with deeper bodies ($p<0.05$) and significantly longer ($p<0.05$) both vertically horizontally in the planum nasal when kept at 30°C. The width of body and the circumference of the neck were greater ($p<0.05$) at 20°C. The lean meat of the loin, middle section, ham, and hind section were significantly greater ($p<0.05$) in pigs kept at 30°C and the belly was significantly heavier. The total unsaturated free fatty acids were significantly higher ($p<0.05$) in the body fat of pigs kept at 20°C than in that of pigs at 30°C. The results indicated that when pigs are given very restricted same amounts of feed, they may need less energy to maintain their body temperature under moderately high environmental temperature (30°C); consequently, their performance is better than that of pigs under optimum environmental temperature. The results showed very clearly that weight gain of pigs increased with increasing of dietary protein and energy content. The increasing of dietary protein content seemed more significant when content increasing to 17.2% compared with the 12.8 and 15.2% protein content treatments. The increasing of dietary energy content was more significant when content increasing to 3,600 compared with the other low energy content treatments. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 2 : 250-258)***

Key Words : Fattening Pigs, Temperature, Energy, Protein, Performance, Carcass Composition

INTRODUCTION

It is well known that food intake and weight gain of growing and finishing pigs decrease with increasing environmental temperature (Hazen and Mangold, 1960; Kazarian and Hoefer, 1960; Smith and Tonks, 1966; Morrison et al., 1966; Hale and Johnson, 1970; Andreasi et al., 1971; Morrison and Mount, 1971; Tonks, Smith and Bruce, 1972; Steinbach, 1976; Straub et al., 1976; Stahly and Cromwell, 1979; Stahly et al., 1979; Morrison and Heitman, 1983; Hsia and Lu, 1987, 1988, 1989a,b; Hsia, 1990; Nienaber et al., 1990; Hsia, 1998; Quiniou et al., 2000). The performance and carcass quality of pigs can be influenced directly by food intake, so that when pigs are fed ad labium in a high environmental temperature, the change in performance and carcass quality may be a simple consequence of the reduced food intake and not due to directly environmental factors. From a theoretical point of view, pigs can dissipate heat more easily when they have a large body surface area (Kleiber, 1961). A more slender conformation in an animal usually represents a higher total surface area than a more round conformation (Kleiber, 1961). Several reports indicate that young pigs develop a more slender conformation when kept at a high environmental temperature (Weaver and Ingram, 1969; Ingram, 1977; Dauncey et al., 1983). However, there is no comparable information for finishing pigs. The free fatty acids (FFA) contents in the carcasses of pigs may also be influenced by high environmental temperature (Fuller et al., 1974; MacGrath et al., 1968). Since nutrient intake also plays an important role in determining performance, conformation, and carcass quality, the present experiment was designed to investigate the effect of high environmental temperature on growing and finishing pigs and the modification of these effects by diet, especially protein and energy.

MATERIAL AND METHODS

Thirty-six three-way cross [Landrace×(Yorkshire×uroc)] castrated male pigs with an average initial body weight of 50.4 kg were used in the experiment. The pigs were distributed according to the following factorial design

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Received May 21, 2003; Accepted October 21, 2003

Table 1. Composition of experimental diets

Energy (kcal DE)	2,980			3,300			3,600		
Protein (%)	12.8	15.2	17.2	12.8	15.2	17.2	12.8	15.2	17.2
Ingredient, %									
Corn meal, %	69.38	63.96	58.57	80.42	74.99	69.57	79.36	73.77	68.17
Soybean meal, %	16.21	21.75	27.21	14.17	19.72	25.24	14.33	19.94	25.51
Limestone pulverized, %	0.34	0.39	0.43	0.38	0.43	0.48	0.38	0.43	0.47
Dicalcium phosphate, %	1.42	1.30	1.19	1.34	1.22	1.11	1.35	1.23	1.12
Salt, %	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Rice hull meal, %	12.00	12.00	12.00	3.00	3.00	3.00			
L-lysine HCl, %	0.05						0.09	0.03	
Soybean oil, %							3.99	4.00	4.13
Vitamin premix (1), %	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix (2), %	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Calculated nutrient composition									
Digestible energy (kcal/kg)	2,987	2,983	2,976	3,309	3,304	3,298	3,600	3,600	3,600
Crude protein, %	13.16	15.15	17.15	13.21	15.20	17.19	13.19	15.19	17.19
Lysine, %	0.64	0.74	0.89	0.64	0.74	0.85	0.64	0.74	0.86
Calcium, %	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Phosphorous, %	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Analyzed nutrient composition									
Crude protein, %	12.85	15.32	17.61	12.72	15.17	16.17	12.80	15.06	16.73
Calcium, %	0.76	0.78	0.81	0.73	0.77	0.73	0.75	0.82	0.73
Phosphorus, %	0.55	0.56	0.56	0.54	0.56	0.54	0.54	0.57	0.54

Each kg of premix contained vitamin A, 4,000,000 IU; vitamin D, 600,000 IU; vitamin E, 20 g; vitamin K, 2 g; vitamin B_2, 0.02 g a pantothenic acid, 12 g; niacin, 40 g; folic acid, 0.4 g; biotin, 0.01 g; choline chloride, 50.

Each kg of premix container Zn, 100 g; Cu, 20 g; Fe, 140 g; I, 0.2 g; Mn, 4 g; Se, 0.1 g.

Table 2. Effect of environmental temperature and nutrient density on the performance of finishing pigs under restricted feeding: main effects

	Environmental temperature (°C)		SE	Dietary protein content (%)			SE	Dietary energy content (kcal)			SE
	20	30		12.8	15.2	17.2		2,980	3,300	3,600	
Daily food intake (g)	1,741	1,732	36.5	1,729	1,710	1,771	46.0	1,724	1,747	1,740	50.2
Daily weight gain (g)	388^{B}	453^{A}	19.8	399^{a}	405^{ab}	457^{b}	24.9	367^{a}	417^{a}	476^{b}	27.1
Feed/gain ratio	4.49^{A}	3.82^{B}	0.21	4.33	4.22	3.88	0.26	4.70^{a}	4.19^{ab}	3.66^{b}	0.28

Means in the same item of the same row with different superscripts are significantly different ($p<0.05$; $p<0.01$). a, b; A, B

treatments: two environmental temperatures×three energy levels×three protein levels. The temperatures of two climatic chambers were set at 20°C and 30°C. The three digestible energy levels were 2,980, 3,300 and 3,600 (kcal/kg). The three protein levels were 12.8, 15.2 and 17.2 (%). Feed formulations used in the experiment are given in Table 1. The pigs were kept in individual pens (2.0 m×0.9 m). The pens contained a self feeder and automatic water bowl. The weighed feed was provided according to a scale of 60 g/kg $W^{0.75}$ per day formula, in which W is body weight. Pigs were weighed every week. The body conformation of pigs was measured immediately after the last weighing before they were sent to the slaughterhouse.

The conformation measurements are defined as follows

- Length 1: From the tip of the nose to the root of the tail
- Length 2: From the midline of the root of the ear to the root of the tail
- Height: From the ground to the top of the back along the front leg
- Depth: From the ventral midline to the top of the back behind the front leg
- Height-depth: Height minus depth
- Width: Between the two sides of the shoulders
- Trunk circumference: The circumference around the trunk behind the front leg
- Circumference of the neck: The circumference of the neck behind the ear
- Mouth length: The length between the tip of the mouth and the angle of the mandible
- Vertical length of define.
- Horizontal length of planum nasal
- Width of cheek

Carcass measurements were based on the Japanese style cut. The pigs were weighed immediately before transportation (LBT). This was the final body weight of the pigs. The pigs arrived at the slaughterhouse after 4.5 h transportation. Only water was provided. Pigs were weighed the next morning before slaughter (LWBS).

Table 3. Interaction between environmental temperature and dietary energy density on the performance of finishing pigs with restricted feeding

Environmental temperature	20°C			30°C			SE
Energy content	2,980	3,300	3,600	2,980	3,300	3,600	
Daily food intake (g)	1,702	1,730	1,792	1,746	1,763	1,688	107
Daily weight gain (g)	315^b	367^b	481^a	420^{ab}	467^a	471^a	36
Feed/gain ratio	5.40^a	4.71^{ab}	3.73^b	4.16^b	3.78^b	3.58^b	0.38

Means in the same row with different superscripts are significantly different (p<0.05).

Table 4. Effect of environmental temperature and nutrient density on the body conformation

	Environmental temperature (°C)		SE	Protein level (%)			SE	Energy level (kcal)			SE
	20	30		12.8	15.2	17.2		2,980	3,300	3,600	
Body length 1.	115.9	117.5	1.43	117.7	116.8	115.6	1.62	114.0^b	116.8^{ab}	119.3^a	1.80
Body length 2.	143.1	143.5	1.3	143.4	143.1	143.4	1.43	140.8^B	142.8^B	146.2^A	1.59
Body height	73.5^B	76.2^A	0.91	75.3^{ab}	76.0^b	73.3^a	1.04	73.4^b	74.5^{ab}	76.6^a	1.16
Body depth	37.6^B	39.9^A	0.72	38.9	38.2	39.2	0.82	39.0	37.8	39.4	0.91
Body height-body depth	35.9	36.6	1.15	36.4^{ab}	37.8^a	34.1^b	1.31	34.4	36.7	37.3	1.46
Body width	24.7^a	23.2^b	0.60	24.2	24.1	23.5	0.68	24.5	24.4	22.8	0.75
Circle length of neck	79.9^a	78.4^b	0.81	78.8	79.3	79.3	0.93	79.0	77.9	80.6	1.03
Circle length of chest	105.0	105.1	1.06	105.0	106.0	104.6	1.12	105.2	105.3	105.3	1.35
Length of mouth	26.7	27.4	0.57	26.9	27.3	27.0	0.65	27.3	27.1	27.1	0.73
Vertical length of planum nasale	7.0	7.4	0.18	7.2	7.1	7.2	0.20	7.3	7.1	7.2	0.22
Horizontal length of planum nasale	8.3	8.7	0.19	8.4	8.7	8.4	0.22	8.6	8.5	8.5	0.25
Width of cheek	17.1	16.1	0.45	16.3	16.8	16.8	0.52	16.8	16.8	16.7	0.58

Means in the same item of the same row with different superscripts are significantly different (p<0.05; p<0.01). Unit: cm. a, b; A, B.

After bleeding, all internal organs (viscera) were removed and the primary carcass weight (PCW) was taken. The killing out percentage was obtained as (PCW/LWBS)×100%.

The weight of carcass excluding the front leg below the knee, the hind leg below the hock, the head in front of the atlas and the skin is defined as the secondary carcass weight. Back fat thickness was measured by ultrasonic machine (Scanoprobe 731C, Ithaca Co.) at the following three points: (1) the point between fourth and fifth rib, (2) last rib, and (3) last lumbar vertebra. The measurements were taken 3-5 cm from the mid-line of the back. The back fat thickness of the carcass was measured at the following four points: first rib, 4th rib, last rib and last lumbar vertebra.

Carcass length (1) is defined as the length from the front part of the first atlas to aitchbone and carcass length (2) as the length from the tip of first rib to the aitchbone.

Meat color was scored at the scale: 1=serious PSE (pale, soft, and exudative), 2=slight PSE, 3 and 4=normal, 5=slight DFD (dark, firm and dry), 6=serious DFD.

The fat thickness at points P_1, P_2 and P_3 (Whittemore, 1993) were measured at points 4.5, 6.5 and 8 cm away from the midline of the back between the fourth and fifth ribs.

Carcasses were cut 24 h after slaughter and storage at 5°C. The carcass was cut into the following parts: front section, middle section, hind section, belly, and neck. The lean meat, fat and bone of the first three parts were separated and weighed. The front section of lean meat included Boston butt, picnic shoulder and foreleg shank; the middle included tenderloin and loin; the hind section included ham and hind leg. The lean meat and fat in the belly and neck were not separated.

The fat used for free fatty acid analysis was sampled from three sites: back fat, ham fat, and leaf fat. The fat was enclosed in plastic bags and stored at -20°C until analyzed. The fatty acid contents of the fat samples were analyzed by gas chromatography using the methods of AOAC (1984).

The result of each measurement was analyzed by least square analysis of variance using the GLM procedure of SAS. The significant test was conducted by Duncan's multiple range test.

RESULTS

As the food was provided according to body weight, there were no differences in food intake at different temperatures. The daily weight gain was higher for pigs at 30°C than for pigs at 20°C (p<0.01). The daily weight gain also increased with the increases in both the protein and energy content of the diet (Table 2). There was a significant interaction between environmental temperature and dietary energy (p<0.05) (Table 3). The feed: gain ratio was

Table 5. Effect of environmental temperature on carcass measurements

Temperature (°C)	20	30	SE	Treatment (°C)	20	30	SE
Weight loss (kg)	6.25	6.28	0.87	Lean meat (kg)			
Carcass percentage (%)	85.43	85.88	0.82	Boston butt	4.32[a]	4.20	0.08
Backfat thickness of live pig (cm)				Picnic shoulder	9.77	9.43[b]	0.14
4th to 5th rib	2.03	2.00	0.1	Foreleg shank	0.45	0.45	0.01
Last rib	1.02	0.99	0.07	Total of fore section	14.54[a]	14.08[b]	0.17
Last lumbar vertebra	1.44	1.45	0.12	Tenderloin	1.05	1.06	0.04
Mean	1.51	1.49	0.08	Loin	7.42[b]	7.71[a]	0.15
Backfat thickness of carcass (cm)				Total of middle section	8.48[b]	8.77[a]	0.14
1st rib	2.22	2.34	0.11	Ham	13.84[b]	14.29[a]	0.25
4th rib	1.75	1.88	0.13	Hindleg shank	0.76	0.75	0.02
Last rib	1.02	0.92	0.07	Total of hind section	14.60	15.03	0.25
Last lumbar vertebra	0.83	0.89	0.07	Total	37.62	37.89	0.47
Mean				Belly (kg)	6.17b	6.48[a]	0.13
(1st rib+last rib+last lumbar vertebra)/3	1.37[b]	1.51[a]	0.06	Neck (kg)	0.52	0.49	0.03
(4th rib+last rib+last lumbar vertebra)/3	1.20[b]	1.36[a]	0.07	Fat (kg)			
P_1 (cm)	1.20	1.30	0.15	Total fore section	1.24	1.21	0.11
P_2 (cm)	1.00	1.02	0.11	Total of middle section	3.07[a]	2.50[b]	0.28
P_3 (cm)	0.92	0.97	0.09	Total of hind section	2.10	2.01	0.17
$(P_1+P_2+P_3)/3$ (cm)	1.05	1.07	0.11	Leaf fat	0.66	0.78	0.06
Carcass length (cm) Atlas to aitch bone	99.2[b]	102.3[a]	1.15	Total	7.05	6.50	0.46
1st rib to aitch bone	82.25[b]	84.85[a]	1.03	Bone (kg)			
Loin eye area (cm^2)	22.15	20.88	1.44	Total of fore section	3.30	3.35	0.06
Meat color	3.29	3.21	0.24	Total of middle section	3.09	3.08	0.07
				Total of hind section	2.70	2.77	0.05
				Total	9.08	9.20	0.13

Means in the same item of the same row with different superscripts are significantly different ($p<0.05$).

significantly lower for pigs at 30°C than at 20°C and was also lower with the higher energy or higher protein diets compared with low energy or protein (Table 2).

The results concerning conformation are shown in Table 4. Pigs kept at 30°C seemed to be longer than those at 20°C but this effect was not significant ($p>0.05$). Pigs at 30°C were significantly taller and deeper ($p<0.05$) than those at 20°C. Pigs kept at 30°C also had longer planum nasal. However, the width of body and the circumference of the neck were greater at 20°C than at 30°C. There were no significant ($p>0.05$) effects of protein on conformation except body height ($p<0.05$). However, the higher the energy content of the food, the longer were the pigs ($p<0.05$). The other measurements on conformation of pigs were not significantly different among the three levels of energy content of feed provided except the circle length of neck ($p>0.05$).

The effects of environmental temperature on back fat thickness are shown in Table 5. There were no significant differences in back fat thickness due to temperature. However, there was a tendency for the back fat to be thicker at 20°C when measured on the live animal, but in the carcass there was the opposite tendency. The average back fat thickness of three points (first or fourth rib, last rib and last lumbar vertebra) was significantly ($p<0.05$) thicker for pigs kept at 30°C but back fat at P_1, P_2, P_3 was not significantly different at the two environmental temperatures, without showing the same tendency as the other four measurements. The carcasses of pigs kept at 30°C were significantly longer than those kept at 20°C ($p<0.05$).

The lean meat of the shoulder and in the whole fore section was significantly greater ($p<0.05$) in pigs kept at 20°C compared with those at 30°C but the lean meat contents of loin, middle section, ham, and hind section were significantly greater ($p<0.05$) in pigs kept at 30°C compared with those at 20°C. The total lean content also tended to be higher in the carcass as of pigs kept at the higher environmental temperature but did not reach significance ($p>0.05$). The belly weight of carcass was significantly heavier for the pigs kept at the high environmental temperature ($p<0.05$). The weight of fat in different sections (except the leaf fat) all tended to be greater in pigs kept at 20°C compared with those at 30°C, but only for the middle section did reach this significance ($p<0.05$). There were no significant differences in bone weight of pigs at the two environmental temperatures, but there was a tendency for bone to be heavier in pigs at the higher environmental temperature.

Table 6 shows that the back fat of the live pigs was thicker when a low energy diet was provided, especially when measured above fourth and fifth rib ($p<0.05$). The back fat thickness of the carcass was thinner for the pigs with a medium energy diet, especially measured above the

Table 6. Effect of different energy levels in diets on carcass measurements of pigs under restricted feeding

Treatment	Digestible energy (kcal)			SE	Treatment	Digestible energy (kcal)			SE
	2,980	3,300	3,600			2,980	3,300	3,600	
Weight loss (kg)	5.73	6.57	6.50	0.99	Lean meat (kg)				
Carcass percentage (%)	85.62	85.61	85.73	0.94	Boston butt	4.29	4.15	4.34	0.09
Backfat thickness of live pigs (cm)					Picnic shoulder	9.49	9.80	9.52	0.16
4^{th} to 5^{th} rib	2.15^{a}	2.05^{ab}	1.84^{b}	0.11	Foreleg shank	0.45	0.45	0.45	0.02
Last rib	1.09	1.02	0.92	0.08	Total of fore section	14.23	14.40	14.31	0.20
Last lumbar vertebra	1.55	1.38	1.40	0.13	Tenderloin	1.00^{b}	1.11^{a}	1.06^{ab}	0.04
Mean	1.61	1.49	1.39	0.09	Lion	7.44	7.55	7.70	0.19
Backfat thickness of carcass (cm)					Total of middle section	8.44	8.66	8.77	0.20
1^{st} rib	2.43^{a}	2.11^{b}	2.29^{ab}	0.12	Ham	13.49^{B}	13.98^{B}	14.73^{A}	0.29
4^{th} rib	1.91	1.70	1.84	0.14	Hindleg shank	0.75	0.75	0.75	0.02
Last rib	0.95	0.88	1.08	0.08	Total of hind section	14.24^{b}	14.73^{b}	15.48^{a}	0.29
Last lumbar vertebra	0.92	0.79	0.87	0.08	Total	36.92^{b}	37.80^{b}	38.55^{a}	0.54
1^{st} rib+last rib+last lumbar vertebra/	1.54^{a}	1.35^{b}	1.44^{ab}	0.07	Belly (kg)	6.29	6.35	6.34	0.15
4^{th} rib+final rib+last lumbar vertebra/	1.36	1.19	1.29	0.08	Neck (kg)	0.52	0.47	0.52	0.04
P_1	1.40	1.23	1.12	0.17	Fat (kg)				
P_2	1.18^{a}	1.03^{ab}	0.81^{b}	0.12	Total fore section	1.45^{a}	1.18	1.04	0.13
P_3	1.01	1.00	0.82	0.10	Total of middle section	3.14	2.76	2.45	0.32
$P_1+P_2+P_3/3$	1.22^{a}	107^{ab}	0.90^{b}	0.12	Total of hind section	2.24	1.89	2.08	0.20
Carcass length (cm)					Leaf fat	0.83^{a}	0.71^{ab}	0.61^{b}	0.08
Atlas to aitch bone	100.99	99.86	101.37	1.31	Total	7.66^{a}	6.55^{ab}	6.13^{b}	0.57
1^{st} rib to aitch bone	83.99	83.20	83.46	1.17	Bone (kg)				
Loin eye area (cm^2)	21.12	20.71	22.71	1.64	Total of fore section	3.30	3.39	3.29	0.07
Meat color	3.33	3.23	3.19	0.27	Total of middle section	3.10	3.11	3.04	0.08
					Total of hind section	2.70	2.77	2.72	0.05
					Total	9.10	9.27	9.05	0.14

Means in the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$). a, b; A, B.2.70

point of the fourth and first ribs. The back fat at P_1, P_2, P_3 were all thicker in the pigs given the low energy diet, especially for the P_2 and the average ($p<0.05$). With the increase in diet energy content, the lean meat content of tenderloin, ham, total of hind section, and total lean meat increased significantly ($p<0.05$). Separated fat increased with the increase of diet energy content. The bone was significantly heavier ($p<0.05$) when the medium energy diet was provided.

Table 7 shows the effect of dietary protein level on the carcass measurements of pigs. Although most measurements did not show a significant effect of primary protein some tendencies can be seen in Table 7. With the increase of dietary protein level carcass length, loin eye area, Boston butt, tenderloin, loin, total of middle section, total lean meat, neck and leaf fat tended to increase and weight loss, back fat thickness of live pigs, P_1, P_2, P_3 $(P_1+P_2+P_3)/3$, and meat color and all fat measured except leaf fat tended to decrease. The back fat thickness of carcass was greater for the pigs with the medium level of protein, except for the measurement on the first rib. Tables 8 and 9 show the significant interactions between any two of the three factors: environmental temperature, energy content of diet, or protein content of diet. Back fat thickness decreased with increased dietary energy content at the high environmental temperature; however, compared with that of the pigs with a low and high energy diet, the back fat thickness of pig was thinner with the medium energy diet. The lean meat of ham, hind leg shank, and total of hind section increased with the increase of diet energy content when pigs were kept at the high environmental temperature. The increase in lean meat in the ham and in the total hind section was shown when pigs were kept at 20°C. The lean meat content of hind leg shank even decreased with the increasing energy content of diet under optimum environmental temperature.

The weight of Boston butt increased with dietary protein level only in pigs kept at 20°C; at 30°C there was no effect of protein. The fat of total of middle section decreased with the increase of diet protein content; however, the drop was more dramatic for pigs under optimum environmental temperature. The leaf fat of pigs decreased with the increase of diet protein; this decrease was sharper for pigs under high environmental temperature. The weight of bone increased with the increase of protein level; this effect occurred mainly in pigs kept at 20°C.

The weight of bone was greater for the medium energy content diet treatment when diet protein was low, but this difference changed when middle and high protein diets were provided.

The free fatty acid contents of fat from three different carcass sites are shown in Table 10 and 11. The contents of palmitic acid (C:16) ($p<0.001$) and stearic acid (C:18)

Table 7. Effect of different dietary protein levels on carcass measurements

Treatment	Crude protein %			SE	Treatment	Crude protein			SE
	12.8	15.2	17.2			12.8	15.2	17.2	
Weight loss (kg)	6.74	6.24	5.81	1.09	Lean meat (kg)				
Carcass percentage (%)	85.38	85.72	85.87	1.06	Boston butt	4.20	4.19	4.4	0.10
Backfat thickness of live pigs (cm)					Picnic shoulder	9.88^a	9.58^{ab}	9.35^b	0.18
4^{th} to 5^{th} rib	1.08	1.98	1.99	0.12	Foreleg shank	0.46	0.45	0.45	0.02
Last rib	1.00	1.03	1.00	0.09	Total of fore section	14.53	14.21	14.20	0.23
Last lumbar vertebra	1.52	1.42	1.38	0.15	Tenderloin	1.03	1.05	0.10	0.05
Mean	1.55	1.49	1.46	0.10	Loin	7.35	7.57	7.78	0.22
Backfat thickness of carcass (cm)					Total of middle section	8.38	8.62	8.88	0.22
1^{st} rib	2.29	2.26	2.28	0.14	Ham	13.88	14.19	14.12	0.33
4^{th} rib	1.83	1.87	1.76	0.17	Hindleg shank	0.76	0.76	0.75	0.02
Last rib	0.89	1.04	0.98	0.10	Total of hind section	14.63	14.95	14.87	0.34
Last lumbar vertebra	0.89	0.91	0.78	0.09	Total	37.54	37.78	37.95	0.62
Mean					Belly (kg)	6.27	6.35	6.34	0.17
1^{st} rib+last rib+last lumbar vertebra/	1.40	1.49	1.43	0.08	Neck (kg)	0.47	0.50	0.55	0.04
4^{th} rib+final rib+last lumbar vertebra/	1.24	1.36	1.22	0.10	Fat (kg)				
P_1	1.41	1.20	1.13	0.20	Total of fore section	1.34	1.26	1.07	0.15
P_2	1.12	0.99	0.91	0.14	Total of middle section	3.25	2.79	2.32	0.37
P_3	0.97	0.95	0.91	0.11	Total of hind section	2.17	2.16	1.83	0.23
$P_1 + P_2 + P_3 /3$	1.13	1.04	1.02	0.14	Leaf fat	0.66	0.74	0.75	0.09
Carcass length (cm)					Total	7.42^a	9.94^{ab}	5.98^b	0.66
Atlas to aitch bone	99.55	101.36	101.32	1.51	Bone (kg)				
1^{st} rib to aitch bone	82.59	83.83	84.23	1.35	Total of fore section	3.17^B	3.29^B	3.52^A	0.08
Loin eye area (cm^2)	20.08	21.67	22.79	1.88	Total of middle section	2.96^b	3.06^{ab}	3.22^a	0.09
Meat color	3.48	3.24	3.03	0.31	Total of hind section	2.61^B	2.76^A	2.83^A	0.06
					Total	8.75^C	9.11^B	9.56^A	0.16

Means in the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$). a, b; A, B, C.

($p<0.001$) were significantly higher in pigs kept at 30°C. On the other hand, the content of linoleic acid (C:18:2) ($p<0.05$) and total unsaturated free fatty acids ($p<0.001$) were significantly higher in pigs kept at 20°C. There were no significant differences in free fatty acids when diets with different amounts of protein diet were provided. The contents of all fatty acids except n-pentadecanoic acid (C15), margaric acid, and arachidic acid were significantly influenced by dietary energy content ($p<0.05$). The contents of myristoleic acid ($p<0.01$), palmitic acid (C:16) ($p<0.001$), palmitoleic acid (C16:1) ($p<0.05$), and stearic acid (C:18) ($p<0.01$)of fat sampled from test pigs were significantly decreased by high diet any energy content. The highest content of these free fatty acids was found in the fat of pigs with a medium energy content diet. Linoleic, linolenic and eicosadienoic acid were highest in the fat of pigs given the highest energy diet. The highest content of total unsaturated free fatty acid was in the carcasses of pigs given the highest energy diet. Pentadecanoic acid, margaric acid, linolenic acid and arachidic acid contents were not significantly different among the different parts of the body; however, other free fatty acids were significantly different in different parts of the body. The total unsaturated free fatty acid (UFFA) content of leaf fat was the lowest ($p<0.001$) compared with the total UFFA content of back fat and belly fat.

DISCUSSION

Most experimental results show that pigs gain less when kept in a high environmental temperature than in moderate environmental temperatures. However, in the present experiment pigs gained faster in the higher environmental temperature. The difference is due to the highly restricted feeding used in the present experiment. At low environmental temperatures when fed ad lib pigs may eat more than they need to maintain their body temperature (Fuller, 1969); and consequently grow faster at the lower environmental temperature. Indirect evidence to explain why pigs grow faster in a cold environment is that the food intake of pigs increases sharply within a range of mild cold (Hsia and Lu, 1987). The pigs in the present experiment were given restricted feeding ($60\times W^{0.75}$) and as a result grew more slowly due to their greater loss of heat needed to maintain body temperature than did the pigs raised in the higher environmental temperature. In a preliminary experiment it was found that some pigs with a body weight over 80 kg could not consume more than $60\times W^{0.75}$ at 30°C, consequently the chosen feeding scale, who designed to ensure equal intake. The significant interaction between environmental temperature and energy content of diet under restricted feeding may be due to higher energy need of pigs for maintenance of body temperature at 20°C; at the same

Table 8. Environmental and dietary energy content of diet on live pigs measurements

Temperature (°C)	20			30			SE
Energy (kcal)	2,980	3,300	3,600	2,980	3,300	3,600	
Backfat thickness of live pig (cm)							
4th to 5th rib	2.04^{A}	1.98^{A}	2.07^{A}	2.26^{A}	2.13^{A}	1.16^{B}	0.16
Last rib	1.07^{a}	0.93^{a}	1.07^{a}	1.11^{a}	1.11^{a}	0.76^{b}	0.19
Mean	1.53^{a}	1.45^{a}	1.55^{a}	1.68^{a}	1.54^{a}	1.24^{b}	0.12
Backfat thickness of carcass (cm)							
1st rib	2.24^{bc}	1.95^{b}	2.45^{ac}	2.62^{a}	2.27^{a}	2.13^{bc}	0.18
4th rib	1.78^{A}	1.37^{B}	2.10^{A}	2.04^{A}	2.03^{A}	1.58^{A}	0.21
Last rib	0.96^{b}	0.86^{b}	1.25^{a}	0.94^{b}	0.91^{b}	0.90^{b}	0.12
Mean							
(1st rib+last rib+last lumbar vertebra)/3	1.40^{ABC}	1.17^{C}	1.53^{AB}	1.68^{A}	1.52^{AB}	1.34^{BC}	0.20
(4th rib+last rib+last lumbar vertebra)/3	1.24^{AB}	0.95^{B}	1.40^{A}	1.48^{A}	1.42^{A}	1.17^{AB}	0.11
P_3 (cm)	0.94^{ab}	0.88^{ab}	0.94^{ab}	1.07^{a}	1.13^{a}	0.71^{b}	0.12

Means in the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$). a, b, c: A, B, C.

Table 9. Influence of environmental and dietary protein level on carcass measurements

Temperature (°C)	20			30			SE
Protein	12.8	15.2	17.2	12.8	15.2	17.2	
Backfat thickness of carcass (cm)							
1st rib	2.04^{b}	2.34^{ab}	2.27^{ab}	2.54^{a}	2.19^{ab}	2.30^{ab}	0.19
Lean meat (kg)							
Boston butt	4.12^{b}	4.28^{ab}	4.56^{a}	4.28^{ab}	4.09^{b}	4.24^{b}	0.02
Bone (kg)							
Total of fore section	3.02^{C}	3.24^{B}	3.63^{A}	3.33^{B}	3.33^{B}	3.40^{AB}	0.22
Total	8.46^{C}	9.01^{BC}	9.78^{A}	9.03^{BC}	9.21^{A}	9.35^{AB}	0.22

Means in the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$). a, b; A, B, C.

Table 10. Effect of environmental temperature and nutrient density on the fatty acid composition body fat

	Environmental temperature		SE	Protein level			SE	Energy level (kcal)			SE
	20°C	30°C		12.8%	15.2%	17.2%		2,980	3,300	3,600	
C:14	1.15	1.20	0.03	0.13	0.19	1.21	0.04	0.19^{A}	0.26^{A}	1.07^{B}	0.04
C:15	0.10	0.08	0.04	0.06	0.10	0.11	0.05	0.07	0.13	0.08	0.05
C:16	21.87^{Y}	23.27^{X}	0.27	22.41	22.34	22.96	0.33	22.93^{X}	23.53^{X}	21.26^{Y}	0.33
C:16:1	2.26	2.22	0.08	2.19^{ab}	2.13^{b}	2.40^{a}	0.10	2.55^{X}	2.36^{X}	1.80^{Y}	0.10
C:17	0.35	0.33	0.03	0.35	0.36	0.32	0.03	0.36	0.35	0.32	0.03
C:18	12.97^{Y}	14.51^{X}	0.432	13.81	13.90	13.51	0.53	13.80^{A}	14.64^{A}	12.78^{B}	0.53
C:18:1	37.35^{a}	36.16^{b}	0.45	37.49	35.82	36.94	0.55	38.07^{X}	38.64^{X}	33.55^{Y}	0.55
C:18:2	20.9^{a}	19.39^{b}	0.66	19.76	21.16	19.51	0.81	18.55^{Y}	16.53^{Z}	25.34^{X}	0.81
C:18:3	2.00	1.88	0.17	1.75	1.91	2.15	0.21	1.54^{Y}	1.66^{YZ}	2.62^{X}	0.21
C:20	0.26	0.22	0.02	0.23^{ab}	0.27^{a}	0.22^{b}	0.03	0.23	0.27	0.22	0.03
C:20:2	0.79	0.74	0.08	0.75	0.82	0.67	0.10	0.71^{Y}	0.67^{Y}	0.85^{X}	0.10
Total unsaturated fatty acids	63.39^{X}	60.39^{Y}	0.69	61.94	61.84	61.67	0.85	61.42^{Y}	59.86^{X}	64.16^{X}	0.85

Means in the same item of the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$, $p<0.001$).

Unit: %, a, b; A, B; x, y, z.

time, the pigs given the low energy diet consumed less total energy, so differences in weight gain among three levels of energy are greatest at the low environmental temperature. On the other hand, pigs need less energy for maintenance in a high environmental temperature so that differences in weight gain among the three dietary energy levels are small. Similar findings were reported by Hsia and Lu (1988).

Body length, carcass length, height, and depth were all greater for pigs at 30°C than at 20°C. In order to dissipate more heat at high environmental temperature, pigs need a big body surface area. Pigs with a slender conformation usually have a larger surface area than pigs with a round conformation. The development of vertical and horizontal length of the planum nasal may be due to the higher respiration rate of pigs under high environmental temperature. However, the reason for the positive relation between energy content of diet and body length is not clear and needs further study.

There was no significant difference in back fat thickness between pigs at high or low environmental temperatures.

Table 11. Fat acid content of different part of body

	Back fat	Belly fat	Leaf fat	SE
C:14	1.09^{b}	1.19^{a}	1.25^{a}	0.04
C:15	0.06^{c}	0.09^{b}	0.12^{a}	0.05
C:16	21.17^{z}	22.47^{y}	24.07^{x}	0.33
C:16:1	2.35^{x}	2.57^{x}	1.79^{y}	0.10
C:17	0.33	0.33	0.37	0.03
C:18	12.19^{y}	12.44^{y}	16.59^{x}	0.53
C:18:1	37.91^{x}	39.65^{x}	31.88^{y}	0.55
C:18:2	20.80^{A}	18.61^{B}	21.02^{A}	0.81
C:18:3	2.9	1.76	1.96	0.21
C:20	0.21^{b}	0.21^{c}	0.28^{a}	0.03
C:20:2	0.85^{x}	0.73^{y}	0.66^{y}	0.10
Total unsaturated fatty acids	64.81^{x}	63.32^{x}	57.31^{y}	0.85

Means in the same item of the same row with different superscripts are significantly different ($p<0.05$, $p<0.01$, $p<0.001$).
Unit: %, a. b, c: A, B: x. y, z.

whether measured at the live pigs or carcasses. However, the tendency was for average back fat thickness to be greater in live pigs at the low environment temperature and greater for carcass at the higher environmental temperature. This may be due to the thicker skin of the pigs under low environmental temperature. The average back fat thickness of the three points of carcass was significantly greater in pigs kept at 30°C than in pigs at 20°C. This may be another piece of evidence to show that at 30°C pigs used less energy to maintain their body temperature than at 20°C and deposited more as fat. That the lean content was higher for pigs at the high environmental temperature may be due to more energy being available for the synthesis of lean meat than in pigs under low environmental temperature.

Other interesting results are: (1) the lean meat of picnic shoulder and total of fore section were heavier for pigs under low environmental temperature, and (2) the belly weight of carcass was heavier for pigs under high environmental temperature. This phenomenon may be due to the growth sequence for the body of pigs (Davies, 1974). It is also interesting to know that the carcass fat of restricted feeding pigs kept in a high environmental temperature had lower unsaturated fat acid. This result is similar to the results of MacGrath et al. (1968). The low unsaturated fatty acid of carcass fat, may be related to the low secretion of reproductive hormone, which consequently may cause damage to some aspects of reproductive performance. This is because unsaturated fatty acids are the precursors of prostaglandins (Hadley, 1988). Wood (1984) reported that low food intake (i.e. low energy intake) may cause high unsaturated fatty acid content in pigs. The reason for high unsaturated content fatty acid in the fat from pigs kept in a low environmental temperature may be because the pigs spent more energy to maintain their body temperature; consequently, they had less energy for fat deposition. This hypothesis needs further study in the future.

The results of this experiment suggest that the pigs under high environmental temperature may need less energy for maintenance. In consequence, their performance, conformation, carcass quality, unsaturated fatty acids can be influenced by temperature, energy and protein.

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