3-2008

# Effects of deep-bedded finishing system on market pig performance, composition and pork quality

B. S. Patton
*Iowa State University*

Elisabeth J. Huff-Lonergan
*Iowa State University*, elonerga@iastate.edu

Mark S. Honeyman
*Iowa State University*, honeyman@iastate.edu

J. D. Crouse
*United States Department of Agriculture*

Brian J. Kerr
*United States Department of Agriculture*

***See next page for additional authors***

# Effects of deep-bedded finishing system on market pig performance, composition and pork quality

**Abstract**
The purpose of this study was to compare effects of finishing environment on growth performance, pork quality and lipid composition of pork. Environments compared were standard confinement (CON) and deep-bedded semi-outdoor systems. The deep-bedded method employed in the current study was the use of hoop structures. Hoops are large, tent-like shelters with cornstalks or straw for bedding. Gilts ranging in weight from 59 to 71 kg were randomly assigned to treatments of Hoop ($n = 50$) and CON ($n = 18$) environments. Gilts were fed a two-phase dietary sequence, *ad libitum* for 45 days. Six gilts per treatment were selected for carcass composition and quality evaluation. The experiment was replicated a total of five times. Pigs raised in the Hoop environment gained significantly less and required significantly more feed for growth than pigs raised in the CON environment. Carcasses from CON-finished pigs were significantly fatter at the 10th rib, which lowered carcass percentage fat-free lean(FFL) and they also had greater loin marbling scores compared with carcasses from Hoop-finished pigs ($P < 0.05$). Significant replication effects were noted on beginning weight, live weight, carcass weight, percentage FFL, backfat, lipid content and adipose firmness. Carcasses from Hoop pigs had lower proportions of palmitic acid ($P < 0.05$), and higher proportions of oleic and linoleic acid ($P < 0.05$) in the inner layer of adipose tissue. The proportion of saturated fatty acid was lower, and that of mono- and poly-unsaturated fatty acid was higher in the inner layer of the adipose tissue of Hoop pigs. Variations in fatty acid composition and lipid deposition may have been caused by environmental temperature, since decreases in environmental temperature accompanied compositional variation of the adipose, leading to higher proportions of monounsaturated fatty acid and lower proportions of saturated and polyunsaturated fatty acid in adipose tissue, regardless of treatment. Volatile profile analysis revealed that adipose tissue of Hoop pigs had significantly higher amounts of 3-butanal and heptanal compared with CON pigs, which may be related to the amount of oleic and linoleic acids composing the adipose tissue. These data indicate finishing pigs in hoop structures allows for exposure to fluctuating temperatures, which may influence the growth of pigs, as well as fatty acid composition and firmness of pork products.

**Keywords**
pork quality, pig production

**Disciplines**
Agriculture | Animal Sciences | Meat Science

**Comments**
This article is from *Animal* 2 (2008): 459–470, doi:10.1017/S1751731107001292.

*Animal* (2008), **2:3**, pp 459–470 © The Animal Consortium 2008
doi: 10.1017/S1751731107001292

animal

# Effects of deep-bedded finishing system on market pig performance, composition and pork quality

B. S. Patton[1], E. Huff-Lonergan[1], M. S. Honeyman[1], J. D. Crouse[2], B. J. Kerr[2] and S. M. Lonergan[1†]

[1]*Department of Animal Science, Iowa State University, Ames, IA 50011, USA;* [2]*USDA-ARS, Swine Odor and Manure Management Research Unit, Ames, IA 50011, USA*

(Received 10 April 2007; Accepted 17 October 2007)

*The purpose of this study was to compare effects of finishing environment on growth performance, pork quality and lipid composition of pork. Environments compared were standard confinement (CON) and deep-bedded semi-outdoor systems. The deep-bedded method employed in the current study was the use of hoop structures. Hoops are large, tent-like shelters with cornstalks or straw for bedding. Gilts ranging in weight from 59 to 71 kg were randomly assigned to treatments of Hoop (*n *= 50) and CON (*n *= 18) environments. Gilts were fed a two-phase dietary sequence,* ad libitum *for 45 days. Six gilts per treatment were selected for carcass composition and quality evaluation. The experiment was replicated a total of five times. Pigs raised in the Hoop environment gained significantly less and required significantly more feed for growth than pigs raised in the CON environment. Carcasses from CON-finished pigs were significantly fatter at the 10th rib, which lowered carcass percentage fat-free lean(FFL) and they also had greater loin marbling scores compared with carcasses from Hoop-finished pigs (*$P < 0.05$*). Significant replication effects were noted on beginning weight, live weight, carcass weight, percentage FFL, backfat, lipid content and adipose firmness. Carcasses from Hoop pigs had lower proportions of palmitic acid (*$P < 0.05$*), and higher proportions of oleic and linoleic acid (*$P < 0.05$*) in the inner layer of adipose tissue. The proportion of saturated fatty acid was lower, and that of mono- and poly-unsaturated fatty acid was higher in the inner layer of the adipose tissue of Hoop pigs. Variations in fatty acid composition and lipid deposition may have been caused by environmental temperature, since decreases in environmental temperature accompanied compositional variation of the adipose, leading to higher proportions of monounsaturated fatty acid and lower proportions of saturated and polyunsaturated fatty acid in adipose tissue, regardless of treatment. Volatile profile analysis revealed that adipose tissue of Hoop pigs had significantly higher amounts of 3-butanal and heptanal compared with CON pigs, which may be related to the amount of oleic and linoleic acids composing the adipose tissue. These data indicate finishing pigs in hoop structures allows for exposure to fluctuating temperatures, which may influence the growth of pigs, as well as fatty acid composition and firmness of pork products.*

**Keywords:** pork quality, pig production

## Introduction

A recent trend in pork production is the incorporation of alternative production methods. This trend is primarily driven by the lower cost of production (Thornton, 1988), and growing consumer interest in alternatively produced pork. In addition, some consumers are willing to pay more for pork products from pigs grown in outdoor systems (Dransfield *et al*., 2005). Opportunities for niche marketing accompanied with lower investment costs have caused some producers to switch from standard confinement (CON) systems to semi-outdoor, alternative systems (Honeyman, 1996). Extensive systems such as outdoor, free-range and deep-bedded semi-outdoor systems are the alternative systems utilised in the pig industry (Miao *et al*., 2004). Deep-bedded hoop structures (also referred to as hoop barns or simply hoops) are tent-like structures consisting of metal pipe arches, or trusses, covered by a polyethylene fabric tarp attached to concrete or wooden sidewalls. Pigs are kept inside the hoop with most of the floor area covered by bedding such as straw or cornstalks (Honeyman *et al*., 2001).

Several items differ between hoop structures and standard confinement systems, including the use of straw for

† E-mail: slonerga@iastate.edu

bedding and subjection of animals to a greater variety of seasonal weather changes. In addition, using deep-bedded structures is an environmental enrichment strategy that has been shown to stimulate foraging and/or explorative behaviour (De Jong *et al.*, 1998; O'Connell *et al.*, 2004). Housing pigs in alternative environments also supports increasing spontaneous exercise and exploratory behaviour (Barton-Gade and Blaagjerg, 1989; Gentry *et al.*, 2002b; Morrison *et al.*, 2003a), which may lead to changes in stress susceptibility, thereby influencing growth performance and ultimate pork quality (Klont *et al.*, 2001; Morrison *et al.*, 2003b). Few studies have compared growth characteristics from confinement systems to deep-bedded systems (Gentry *et al.*, 2002a; Honeyman and Harmon, 2003). Substantial variation in growth performance and pork quality has been noted in opposing seasons, as well as between confinement and deep-bedded systems (Lebret *et al.*, 2002; Honeyman and Harmon, 2003). Seasonal alterations in fatty acid profiles (Cava *et al.*, 2000; Bee *et al.*, 2004), flavour attributes of fresh pork, including intensity and pork flavour (Gentry *et al.*, 2002b), and overall flavour acceptability (Enfalt *et al.*, 1997) have also been noted between pigs finished in deep-bedded and outdoor systems compared with indoor systems.

No research has been conducted comparing pork quality and fatty acid composition specifically between deep-bedded hoop systems and confinement systems. Increased physical activity, less consistent environmental temperature and the use of straw-bedding differ from hoops to standard confinement environments. This study was undertaken to determine the extent to which finishing environment influences pig growth performance, pork quality and fatty acid composition of the *longissimus* muscle and adipose tissue.

## Material and methods

### *Animals*

Use of animals for the described experiments was approved by the Iowa State University Institutional Animal Care and Use Committee. At 4 months of age, 68 gilts were weighed into allotment blocks by weight. From those weight allocation blocks, gilts ranging in weight from 59 to 71 kg were randomly assigned to treatments of either hoop (Hoop, $n = 50$) or confinement (CON, $n = 18$). Stocking density in each treatment environment was 0.70 $m^2$ per pig. Gilts assigned to Hoop treatment were transported to the Iowa State University Western Research Farm, Castana, IA, USA, while gilts allocated to the CON treatment were moved into finishing pens at the ISU Swine Nutrition Farm, Ames, IA, USA. Gilts were *ad libitum* fed a two-phase diet (Table 1) for a period of 45 days. At 45 days, gilts were weighed and allocated into pre-slaughter groups stratified by weight. One gilt was randomly chosen to represent each weight group for a total of six pigs from each treatment group. All pigs were transported 200 km prior to delivery to the Iowa State University Meat Laboratory for processing to alleviate the confounding effect of travel on one group of pigs. These studies were replicated a total of five times.

**Table 1** *Description of nutritional rations fed to gilts during the finishing period, as-is basis*

| | Finisher phase (kg) | |
|---|---|---|
| | 91 to 101 kg | 101 to 113 kg |
| Ingredient (%) | | |
| Maize | 81.95 | 83.95 |
| Soya-bean meal | 12.00 | 10.00 |
| Soya-bean hulls | 2.50 | 2.50 |
| Vitamin + mineral pre-mix[†] | 2.50 | 2.50 |
| Fat | 1.00 | 1.00 |
| L-lysine HCl | 0.05 | 0.05 |
| Total | 100.00 | 100.00 |
| Calculated composition (%total)[‡] | | |
| Crude protein | 12.99 | 12.21 |
| Crude fibre | 3.33 | 3.32 |
| Crude fat | 4.63 | 4.65 |
| Lysine | 0.76 | 0.71 |
| Threonine | 0.47 | 0.44 |
| Tryptophan | 0.13 | 0.12 |
| Sulphur amino acids | 0.34 | 0.31 |
| Calcium | 0.65 | 0.64 |
| Phosphorus, total | 0.59 | 0.58 |
| Metabolisable energy (kcal/kg) | 1520 | 1520 |

[†]Vitamin + mineral premix contained phytase.
[‡]Calculated composition based on NRC (1998) values.

Initial weight, 21- and 45-day weight, and pre-transport, and slaughter weight were obtained for each pig. Average daily gain (ADG, g/day), feed conversion (gain : feed), and shrink (%) during transport and lairage were calculated for each pig, and percentage shrink was calculated: [(farm weight − slaughter weight)/farm weight] × 100. Feed was removed 18 h prior to slaughter. Gilts were randomly assigned to a process order at the ISU Meat Laboratory. After electrical stunning, and exsanguination via jugular depletion, carcasses were eviscerated, washed and chilled. Carcasses were placed in a 0°C cooler and chilled for 24 h. Temperature and pH measurements were taken by a penetration probe at 1, 6 and 24 h *post mortem* on right-side loins using a Hanna 9025 pH/ORP meter (Hanna Instruments, Woonsocket, RI, USA). The pH probe was calibrated with temperature at each time period using two buffers (pH 4.2 and pH 7.1), and was calibrated after each carcass. For measurements taken under refrigeration temperatures, buffer was cooled to ambient temperature prior to calibration.

### *Sample collection*

After 24 h, carcasses were ribbed between the 10th and the 11th rib interface for carcass composition and pork quality evaluation. Two 20-g samples of adipose tissue from the blade end of the loin were obtained for fatty acid analysis and fat firmness measurement. Four subsequent 2.54-cm chops were obtained for Star Probe analysis; the first two chops were assigned an ageing period of 24 h and the second two were assigned an ageing period of 120 h.

Three subsequent 2.54-cm chops were obtained for objective colour and drip loss analysis. Sirloin ends of pork loin were obtained for purge analysis. All samples were vacuum-packaged and held until analysis was conducted.

*Carcass composition and pork quality*

A trained panel ($n = 2$) used the National Pork Board (1 = pale, 6 = dark) standards to determine a colour score for each exposed loin eye at the 10th rib (National Pork Board, 2000). Firmness and wetness were evaluated on a three-point scale (1 = soft and wet, 3 = firm and dry; National Pork Board, 2000). Marbling values were based on National Pork Board standards correlated to the concentration of intramuscular lipid (National Pork Board, 2000). Backfat measurements at the 10th rib and last rib off the midline were obtained using a pig backfat probe. *Longissimus* area was measured using carcass grid. Percentage fat-free lean (FFL) was calculated using the National Pork Board percentage FFL calculation (National Pork Board, 2000).

Four 2.54-cm chops from right-side loins were stored in a vacuum bag at 4°C for 24 or 120 h *post mortem*. After ageing, chops were frozen in a −20°C blast freezer until needed for Star Probe analysis. Chops were then thawed at 4°C, weighed and cooked in a convection oven (140°C) until an internal end-point temperature of 72°C, flipping once at a mid-cook cycle temperature of 35°C. Pre- and post-cooked weights were recorded and used to calculate cooking loss percentage. After cooking, chops were cooled at 4°C overnight prior to measurement. Chops were allowed to equilibrate at room temperature for 2 h prior to Star Probe analysis. An objective, instrumental measure of tenderness was evaluated on two chops per ageing period per pig using a circular, five-point Star Probe attached to a TA-XT2 Texture Analyser (Texture Technologies, Scarsdale, NY). The Star Probe was 9 mm in diameter with 6 mm between each point. The angle from the end of each point to the centre is 48°. A 10-kg load cell was used with a cross-head speed of 3.3 mm/s (Lonergan *et al*., 2007). Force (kg) required to puncture and compress the chop to 20% of sample height was recorded, and the mean of four measurements per chop was used for statistical analysis.

Hunter *L**(light–dark), *a**(red–green) and *b**(yellow–blue) values were determined at 1 day *post mortem* on 2.54-cm-thick chops. Samples were allowed to bloom for 1 h at room temperature and were analysed on a calibrated Hunter Labscan colorimeter (Hunter Associates Laboratories Inc., Reston, VA, USA). A CIE D/65 10° standard observer and a 2.54 cm viewing port were used to obtain three colour measurements on each of three chops. All nine colour measurements were used to determine an average colour score for each loin (Lonergan *et al*., 2001).

Drip loss was determined using 2.54-cm-thick boneless chops (two per loin) (Gardner *et al*., 2006). Chops were towel dried to remove excess surface moisture, weighed and stored in a sealed plastic bag held under atmospheric conditions at 4°C. The liquid lost as drip was removed from each bag and measured after 120 h of storage. Purge loss was measured on the sirloin after 120 h of storage at 4°C in a vacuum bag. Samples were towel dried and weighed in a similar fashion to drip loss chops. Purge and drip loss were recorded as a percentage of the original weight of the sirloin by {[(initial chop/sirloin weight) − (final chop/sirloin weight)]/initial weight} × 100.

*Total lipid and fatty acid analysis*

The inner layer of adipose tissue was chosen for adipose analysis as it has been shown to be the most susceptible to depositional changes during finishing (Leymaster and Mersmann, 1991; Warnants *et al*., 1996). Lean samples were cut directly underneath the sample taken isolated adipose tissue analysis. Total lipid analysis was carried out by the method of Folch *et al*. (1957). For each tissue sample, an amount of Folch extract containing 2.5 mg total lipid was placed into a 20 ml methylation tube. Fatty acid methyl esters were prepared according to the method of Morrison and Smith (1964) and were separated according to Jo and Ahn (2000). Analysis of fatty acid composition was performed with a HP 6890 gas chromatograph (Hewlett-Packard Co., Palo Alto, CA, USA) equipped with an autosampler, a flame ionisation detector and an SP-2560 fused silica capillary column (100 m × 0.25 mm × 0.2-μm film thickness). Peak areas and percentages were calculated using HP ChemStation™ software (Hewlett-Packard Co.). Fatty acid methyl esters were identified by comparison with retention times of standards (Sigma-Aldrich, St Louis, MO, USA). Fatty acid values and total lipids were expressed as percentages of adipose or lean tissue sample.

*Adipose tissue firmness*

Adipose samples were cut into 5 × 3-cm squares and analysed for firmness using a method modified from Nishioka and Irie (2005). Samples were evaluated using a TA-XT2 Texture Analyser (Texture Technologies, Scarsdale, NY, USA) with a 0.25″-diameter ball-shaped probe. Sample height was noted by the testing machine, and the probe was driven downward at 2 mm/s to a depth of 20% of the sample height. Force exerted (kg) and sample height (cm) were recorded for three separate positions on the square, and were averaged by sample for statistical analysis.

*Volatile profile analysis*

Approximately 20 g of subcutaneous adipose tissue and 20 g of lean was excised from the blade end of the *longissimus dorsi*. Samples were packaged and sealed under vacuum pressure and kept at −20°C until further analysis. Volatile organic chemicals were analysed using a Solatek 72 Multimatrix-Vial auto sampler/sample concentrator 3100 (Tekmar-Dohrmann, Mason, OH, USA) connected to a GC/MS (Model 6890/5973; Hewlett-Packard Co.) according to the method of Ahn *et al*. (2001). Samples (3 g) were minced and placed in a 40 ml sample vial, flushed with helium gas (2.8 kg/cm$^2$) for 3 s, and then capped airtight with a Teflon*fluorocarbon resin/silicone septum (I-Chem Co.,

Rockwood, TN, USA). The maximum waiting time for a sample to be in a loading tray (4°C) for analysis was less than 2 h to minimise oxidative changes. Meat samples were purged with helium (40 ml/min) for 14 min at 80°C. Volatiles were trapped using a Tenax/charcoal/silica column (Tekmar-Dohrmann) and desorbed for 2 min at 225°C, focused in a cryofocusing module (−80°C), and then thermally desorbed into a column for 60 s at 225°C. For acids, phenols and indoles, an HP-Wax column (60 m, 0.25 mm i.d., 0.25 μm nominal) was used. For sulphur compounds, an HP-624 column (7.5 m, 0.25 mm i.d., 1.4 μm nominal) an HP-1 column (60 m, 0.25 mm i.d., 0.25 μm nominal), and an HP-Wax column (7.5 m, 0.25 mm i.d., 0.25 μm nominal) were connected using zero dead-volume column connectors (J and W Scientific, Folsom, CA, USA). Ramped oven temperature was used to improve volatile separation. The initial oven temperature of 0°C was held for 1.5 min. Then, the oven temperature was increased to 15°C at 2.5°C/min, increased to 45°C at 5°C/min, increased to 110°C at 20°C/min, and then increased to 210°C at 10°C/min and held for 2.25 min at that temperature. Constant column pressure at 154 945 Pa was maintained. The ionisation potential of the mass spectrometry was 70 eV, and the scan range was 19.1 to 350 *m/z*. The identification of volatiles was achieved using the Wiley library (Hewlett-Packard Co.). The area of each peak was integrated using ChemStation™ software and the total peak area (total ion counts $\times 10^6$) was reported as an indicator of volatiles generated from the samples. Data are reported as ion counts.

*Statistical analysis*

Gilt performance, pork quality, and adipose and tissue fatty acid composition data were analysed using general linear model (GLM) procedures of Statistical Analysis Systems (SAS, Institute, Cary, NC, USA). Experimental model included environmental treatment (Hoop or CON), replication, and interactive effects of treatment and replication as independent variables. The experiment was replicated five times. Pairwise comparisons of means were carried out using Tukey's test with an $\alpha = 0.01$.

## Results

*Growth performance*

Initial weight and slaughter weight were not influenced by treatment (Table 2). Pigs finished in Hoop gained less per day, but had a more efficient feed efficiency than CON-finished pigs ($P < 0.01$). Hoop-finished pigs exhibited less shrink during transport and lairage (2.32% *v.* 4.48%) compared with CON pigs. Hot carcass weights differed between the two treatments ($P < 0.05$), though there were no significant differences in dressing percentage at slaughter. No treatment differences in loin eye area were detected, but carcasses from CON-finished pigs were fatter at the 10th rib ($P < 0.05$) and had lower calculated FFL percentages than Hoop-finished pigs. Replication differences were noted in beginning weight, live weight, carcass weight, FFL and backfat thickness at the 10th rib as well as at the last rib. These effects were not noted in growth characteristics such as ADG and feed efficiency.

*Pork quality*

Differences between the two environments on pork quality were limited to lipid attributes (Table 3). Carcasses from CON pigs had higher levels of marbling in the loin compared with Hoop pigs ($P < 0.01$). There were no differences in the temperature or pH decline between Hoop- and CON-finished pigs. There were no significant differences in National Pork Board colour, firmness or wetness of the loin. No differences were observed in objective colour measurements, percentage drip or purge loss between the two treatment groups. Star Probe texture measurements taken

**Table 2** *Effect of finishing environment on pig performance and carcass composition*[†]

| Variable | Environment | | s.e. | Significance[§] | | |
|---|---|---|---|---|---|---|
| | Hoop[‡] | CON[‡] | | ENV | Rep | ENV × Rep |
| Initial weight (kg) | 73.82 | 71.40 | 5.25 | NS | ** | ** |
| Average daily gain (ADG) (kg/day) | 0.81 | 1.07 | 0.09 | *** | NS | NS |
| Feed efficiency (G : F)[¶] | 0.52 | 0.42 | 0.09 | *** | NS | NS |
| Slaughter weight (kg) | 106.92 | 110.41 | 5.64 | NS | *** | ** |
| Shrink (%) | 2.32 | 4.48 | 0.36 | *** | *** | ** |
| Carcass weight (kg) | 79.15 | 82.75 | 4.34 | ** | *** | ** |
| Dressing (%) | 74.65 | 74.90 | 0.37 | NS | NS | NS |
| Backfat 10th rib (mm) | 13.72 | 15.24 | 0.03 | ** | ** | ** |
| Backfat last rib (mm) | 19.02 | 20.32 | 0.09 | NS | ** | *** |
| Loin eye area ($cm^2$) | 44.71 | 44.70 | 0.21 | NS | ** | NS |
| FFL (%)[‖] | 56.87 | 55.50 | 0.52 | *** | *** | *** |

[†]Presented as least squares means.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $**P < 0.05$; $***P < 0.01$; NS: $P > 0.05$; ENV = environmental significance, Hoop *v.* CON; Rep = replication group of experiment significance; ENV × Rep = treatment-by-group interaction significance.
[¶]G : F calculated by daily weight gain/daily feed consumed.
[‖]Fat-free lean (FFL) percentage calculated using National Pork Board % FFL equation (National Pork Board, 2000).

**Table 3** *Effect of finishing environment on pork quality attributes*[†]

| Variable | Environment | | s.e. | Significance[§] | | |
|---|---|---|---|---|---|---|
| | Hoop[‡] | CON[‡] | | ENV | Rep | ENV × Rep |
| Temperature | | | | | | |
| 1 h | 36.49 | 36.82 | 0.50 | NS | NS | NS |
| 6 h | 9.05 | 9.77 | 0.22 | NS | NS | NS |
| 24 h | 1.39 | 1.32 | 0.62 | NS | NS | NS |
| pH | | | | | | |
| 1 h[¶] | 6.21 | 6.18 | 0.52 | NS | NS | NS |
| 6 h | 5.61 | 5.62 | 0.42 | NS | NS | NS |
| 24 h | 5.32 | 5.40 | 0.53 | NS | NS | NS |
| Colour[‖] | 1.92 | 2.07 | 0.12 | NS | NS | NS |
| Marbling[¥] | 1.42 | 1.78 | 0.12 | *** | NS | NS |
| Firmness[#] | 1.90 | 1.88 | 0.06 | NS | NS | NS |
| Wetness[#] | 1.83 | 1.89 | 0.07 | NS | NS | NS |
| Hunter[††] | | | | | | |
| *L** | 54.48 | 54.40 | 0.64 | NS | ** | NS |
| *a** | 8.06 | 8.26 | 0.24 | NS | ** | NS |
| *b** | 14.19 | 14.27 | 0.35 | NS | *** | NS |
| Drip loss (%)[‡‡] | 3.68 | 4.64 | 0.92 | NS | NS | NS |
| Star Probe | | | | | | |
| 24 h (kg)[§§] | 6.69 | 6.77 | 1.2 | NS | NS | NS |
| 120 h (kg) | 6.96 | 6.92 | 1.1 | NS | NS | NS |
| Cooking loss | | | | | | |
| 24 h (%)[¶¶] | 32.55 | 31.34 | 1.3 | NS | NS | NS |
| 120 h (%) | 29.89 | 31.28 | 1.2 | NS | NS | NS |

[†]Presented as least squares means.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$; ENV = environmental significance, Hoop *v.* CON; Rep = replication group of experiment significance; ENV × Rep = treatment-by-replication interaction significance.
[¶]pH was measured at the 10th and 11th rib interface of the *Longissimus* muscle.
[‖]Colour scores range from 1 to 6, 1 = pale, pinkish-grey and 6 = dark, purplish-red.
[¥]Marbling scores range from 1 to 10, 1 = devoid and 10 = moderately abundant or greater.
[#]Firmness and wetness scores range from 1 to 5, with 1 = very soft and watery and 5 = very firm and dry.
[††]Hunter *L** values range from 1 to 100 with 1 = pure black and 100 = pure white. Hunter *a** values represent the amount of red to green colours and a higher value indicates a redder colour.
[‡‡]Drip and purge loss calculated as [(initial chop/sirloin weight) – (final chop/sirloin weight)]/initial chop weight × 100.
[§§]Star Probe texture evaluated at 24 and 120 h ageing periods using TA-XT2 Texture Analyser with probe driven downward at 2 mm/s to 20% of sample height. Peak force exerted (kg) is presented.
[¶¶]Cooking loss calculated as (raw chop weight – cooked chop weight)/(raw chop weight) × 100.

at 24 and 120 h of ageing did not differ between Hoop- and CON-finished pigs. Significant replication effects were noted only for objective loin colour measurements.

*Adipose composition and firmness*

Hoop-finished pigs had lower proportions of palmitic acid and higher deposition of oleic and linoleic acids in the inner layer of adipose tissue compared with CON pigs (Table 4). These differences led to overall differences in proportions of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and total polyunsaturated fatty acids (PUFA) in the adipose tissue, where total SFA was lower and total PUFA was higher in Hoop-finished pigs. There was a significant replication effect noted for the individual fatty acids within the inner layer of adipose tissue, with the exception of myristic acid, margaric acid, heptadecanoic acid and docahexaenoic acid (DHA).

Adipose tissue firmness was similar between treatments (Table 6). In an effort to ascertain whether concentrations of individual fatty acids affect the firmness of adipose tissue, Pearson correlation coefficients were calculated for each fatty acid on the firmness measurement of force (Table 7). Saturated fatty acids, such as palmitic and stearic, were significantly ($P < 0.01$) correlated with adipose firmness. Therefore, as saturation increased, the samples were firmer. Unsaturated acids, such as palmitoleic, oleic, *trans*-vaccenic and linoleic acids, were negatively ($P < 0.01$) correlated to force. A negative ($P < 0.01$) correlation ($-0.24$) was reported from percentage of MUFA in the adipose tissue and adipose tissue firmness. There were no significant ($P > 0.01$) correlations between the proportion of polyunsaturated lipid and firmness within these samples.

*Longissimus fatty acid composition*

The fatty acid composition of the lean tissue was similar to the adipose tissue composition for each treatment (Table 5). *Longissimus* muscle from Hoop-finished pigs had lower levels of palmitic acid, and higher levels of oleic and linoleic acid compared with *longissimus* muscle from CON-finished pigs. Differences were also seen between Hoop- and CON-finished pigs in total SFA, MUFA and PUFA, where Hoop pigs had significantly higher levels of SFA and PUFA in lean tissue. There were similar replication effects on the lean fatty acid composition as noted in adipose tissue, where fluctuations occurred in every fatty acid except for stearic acid. Figure 1a–f depicts the changes in those fatty acids that had an environmental effect over the five replications of the experiment in adipose tissue as well as in the lean. Oleic acid dramatically increased in Hoop-finished pigs over the five replications in adipose tissues, where it decreased in the same fashion in CON-finished pigs. There was a clear tendency for total MUFA to increase in the tissues of Hoop-finished pigs as replications increased. This trend coincides with decreasing environmental temperature.

*Volatile organic profile*

Common volatiles were defined as those that were observed in each treatment and each replication, unique volatiles were those observed in only one treatment. There were limited variations in the common volatile organic profile between Hoop and CON treatments in lean and adipose tissue (Tables 8 and 9). The lean tissue of Hoop-finished pigs had less concentration of octamethyl cyclotrisiloxane, a common hydrocarbon found in fresh pork (Ho *et al.*, 1994). Adipose tissue of Hoop pigs had higher amounts of 3-butanal and heptanal, which are both products of lipid oxidation (Ho *et al.*, 1994). Overall, the lean tissue had higher amounts of volatile organic compounds than adipose tissue. Table 10 denotes the frequency of

**Table 4** *Effects of finishing environment on fatty acid composition and total lipid concentration of adipose tissue*[†]

| | | Environment | | | Significance[§] | | |
|---|---|---|---|---|---|---|---|
| Fatty acid | Formula | Hoop[‡] | CON[‡] | s.e. | ENV | Rep | ENV × Rep |
| Myristic acid | C14:0 | 1.88 | 2.94 | 0.55 | NS | NS | NS |
| Palmitic acid | C16:0 | 19.16 | 32.0 | 0.50 | *** | ** | ** |
| Palmitoleic acid | C16:1 n-7 | 5.50 | 6.00 | 0.51 | NS | *** | ** |
| Margaric acid | C17:0 | 0.93 | 0.84 | 0.11 | NS | NS | NS |
| Heptadecanoic acid | C17:1 n-10 | 0.73 | 1.01 | 0.32 | NS | NS | NS |
| Stearic acid | C18:0 | 11.11 | 12.28 | 0.81 | NS | *** | ** |
| Oleic acid | C18:1 n-9 | 39.96 | 26.52 | 1.32 | *** | *** | *** |
| *trans*-Vaccenic acid | C18:1 n-7 | 2.21 | 1.50 | 0.42 | NS | *** | ** |
| Linoleic acid | C18:2 n-6 | 15.38 | 13.14 | 0.81 | *** | *** | ** |
| α-Linolenic acid | C18:3 n-3 | 0.84 | 0.80 | 0.18 | NS | *** | ** |
| Arachidic acid | C20:0 | 0.67 | 1.52 | 0.46 | NS | *** | ** |
| Arachidonic acid | C20:4 n-6 | 0.63 | 0.58 | 0.12 | NS | ** | ** |
| Eicosapentaenoic acid | C20:5 n-3 | 0.46 | 0.34 | 0.16 | NS | *** | ** |
| Behinic acid | C22:0 | 0.31 | 0.22 | 0.10 | NS | *** | ** |
| Docosapentaenoic acid | C22:5 n-3 | 0.18 | 0.21 | 0.07 | NS | *** | ** |
| Docosahexaenoic acid | C22:6 n-3 | 0.05 | 0.10 | 0.04 | NS | NS | *** |
| Total saturated | | 34.06 | 49.80 | 1.28 | *** | *** | ** |
| Total MUFA | | 48.4 | 35.03 | 1.22 | *** | *** | ** |
| Total PUFA | | 17.54 | 15.17 | 0.85 | *** | *** | *** |
| % Lipid in adipose | | 81.55 | 83.60 | 1.68 | NS | *** | NS |

Abbreviations are: MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
[†]Analysis conducted on inner layer of backfat tissue. Presented as least squares means of percentage of total lipid.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$; ENV = environmental significance, Hoop *v.* CON; Rep = replication group of experiment significance; ENV × Rep = treatment-by-replication interaction significance.

**Table 5** *Effects of finishing environment on fatty acid composition and total lipid concentration of* Longissimus dorsi *muscle*[†]

| | | Environment | | | Significance[§] | | |
|---|---|---|---|---|---|---|---|
| Fatty acid | Formula | Hoop[‡] | CON[‡] | s.e. | ENV | Rep | ENV × Rep |
| Myristic acid | C14:0 | 6.70 | 6.70 | 0.59 | NS | *** | NS |
| Palmitic acid | C16:0 | 21.15 | 27.60 | 0.64 | ** | *** | NS |
| Palmitoleic acid | C16:1 n-7 | 4.08 | 4.11 | 0.26 | NS | *** | NS |
| Margaric acid | C17:0 | 0.90 | 0.95 | 0.14 | NS | *** | NS |
| Heptadecanoic acid | C17:1 n-10 | 0.92 | 1.00 | .21 | NS | *** | NS |
| Stearic acid | C18:0 | 11.45 | 11.20 | 0.35 | NS | NS | NS |
| Oleic acid | C18:1 n-9 | 28.41 | 25.90 | 0.54 | ** | *** | NS |
| *trans*-Vaccenic acid | C18:1 n-7 | 3.83 | 4.10 | 0.36 | NS | *** | NS |
| Linoleic acid | C18:2 n-6 | 16.69 | 13.12 | 0.70 | *** | *** | NS |
| Arachidonic acid | C20:4 n-6 | 5.87 | 5.32 | 0.37 | NS | *** | NS |
| Total saturated | | 40.19 | 41.05 | 0.98 | *** | *** | *** |
| Total MUFA | | 37.24 | 38.50 | 1.35 | *** | *** | ** |
| Total PUFA | | 22.57 | 20.44 | 0.97 | *** | *** | NS |

Abbreviations are: MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
[†]Presented as least squares means of the percentage of total lipid in the lean tissue.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$; ENV = environmental significance, Hoop *v.* CON; Rep = replication group of experiment significance; ENV × Rep = treatment-by-replication interaction significance.

unique volatile organic compounds that were observed in lean tissue. Pigs fed in the CON environment had higher deposition of alcohols and sulphides, whereas Hoop pigs had higher observed frequencies of ketones, hydrocarbons, acids and aldehydes than the lean tissue. Mimicking the common volatile profile, the unique volatile profile of the adipose tissue was more limited than the lean tissue, with less total volatiles comprising the profile (Table 11). Subcutaneous adipose from Hoop pigs had higher observed frequencies of alkanes, alcohols and sulphides.

**Table 6** *Effects of finishing environment on adipose tissue quality*

| Variable | Environment | | s.e. | Significance‡ | | |
|---|---|---|---|---|---|---|
| | Hoop† | CON† | | ENV | Rep | ENV × Rep |
| Force (kg)§ | 9.57 | 8.77 | 0.85 | NS | *** | ** |
| Height (cm)¶ | 9.81 | 9.81 | 0.92 | NS | NS | NS |

†Hoop = hoop-finished pigs; CON = confinement-finished pigs.
‡Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$; ENV = environmental significance, Hoop *v.* CON; Rep = replication group of experiment significance; ENV × Rep = treatment-by-replication interaction significance.
§Measured as peak force (kg) exerted to compress to 20% of sample height with 0.25″ diameter probe at 2 mm/s.
¶Height of fat sample measured from inner layer to outer layer.

**Table 7** *Pearson correlation coefficients – fatty acids and average and low temperatures† and fat firmness of adipose tissue‡*

| Fatty acid | Formula | Temperature (°C) | | Firmness |
|---|---|---|---|---|
| | | AVG§ | LOW§ | Force (kg) |
| Myristic acid | C14:0 | 0.06 | 0.01 | 0.06 |
| Palmitic acid | C16:0 | 0.70*** | 0.56*** | 0.22** |
| Palmitoleic acid | C16:1 n-7 | −0.79*** | −0.58*** | −0.22** |
| Margaric acid | C17:0 | 0.06 | 0.01 | 0.09 |
| Heptadecanoic acid | C17:1 n-10 | −0.10 | 0.08 | −0.10 |
| Stearic acid | C18:0 | 0.44*** | 0.34*** | 0.17* |
| Oleic acid | C18:1 n-9 | −0.21** | −0.18** | −0.23** |
| *Trans*-Vaccenic acid | C18:1 n-7 | −0.28*** | −0.27*** | −0.27** |
| Linoleic acid | C18:2 n-6 | 0.22** | 0.11 | −0.12 |
| α-Linolenic acid | C18:3 n-3 | 0.22** | 0.14 | 0.06 |
| Arachidic acid | C20:0 | −0.23** | −0.13 | 0.15* |
| Arachidonic acid | C20:4 n-6 | −0.23** | −0.19** | −0.05 |
| Eicosapentaenoic acid | C20:5 n-3 | −0.22** | −0.17* | −0.09 |
| Behinic acid | C22:0 | −0.04 | −0.02 | 0.03 |
| Docosapentaenoic acid | C22:5 n-3 | 0.03 | 0.01 | −0.02 |
| Docosahexaenoic acid | C22:6 n-3 | 0.02 | 0.04 | 0.03 |
| Total saturated | | 0.65*** | 0.50*** | 0.23** |
| Total MUFA | | −0.66*** | −0.48*** | −0.24** |
| Total PUFA | | −0.18* | −0.07 | 0.09 |

Abbreviations are: MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
†Temperatures taken in 1-min increments using HOBO® LCD Temperature Loggers (Onset Computer Corporation. Bourne, MA, USA) placed at three different areas within the hoop structure and two different places within the confinement pens.
‡Firmness measured as peak force (kg) exerted to compress to 20% of sample height with 0.25″ diameter probe at 2 mm/s.
§Data presented as correlation coefficient: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

## Discussion

Few studies have been conducted comparing alternative environments to confinement systems on pig performance and carcass composition. Honeyman and Harmon (2003) examined the use of hoop structures for finishing pigs compared with an unbedded confinement system and determined that pigs finished in hoops had a higher ADG and lower feed efficiency than pigs finished in confinement. These results are similar with the current study, with the exception of feed efficiency. In the current study, Hoop-finished pigs had a higher feed efficiency than CON-finished pigs. Overall, Hoop-finished pigs ate less, grew slower and had less fat at the 10th rib than pigs finished in confinement (Table 2). In addition, carcasses from Hoop-finished pigs had a higher percentage of calculated FFL (56.9% *v.* 55.5%) compared with CON-finished pigs. Several other studies have noted lower levels of backfat in pigs finished outdoors or semi-outdoor systems compared with indoor-finished pigs (Warriss *et al.*, 1983; Enfalt *et al.*, 1997; Gentry *et al.*, 2002a). One commonality between these studies is that the pigs were finished in fall or winter months. Interestingly, the opposite trend is seen when pigs are finished in alternative environments during the summer months. Honeyman and Harmon (2003) reported that pigs finished in hoop structures during the summer months had greater amounts of backfat at the 10th rib than CON-finished pigs, and noted no difference in backfat measurements between Hoop- and CON-finished pigs during the winter months. Therefore, it appears that differences in feed intake and backfat deposition are related to ambient temperature.

In the current study, replications spanned the months of August to November, 2004. The thermoneutral zone for pigs ranges from 17.2°C to 22°C. Within the thermoneutral zone, pigs are able to maintain heat production approximately constant for a given energy intake (Bruce and Clark, 1979). Consequently, with the temperature fluctuations noted in this experiment (Figure 2), both Hoop- and CON-finished pigs were exposed to temperature fluctuations above and below their thermoneutral target, with the more extreme exposure being in the Hoop-finished pigs. Generally, pigs exposed to colder temperatures will have increased levels of feed intake with a decrease in feed utilisation for lean gain due to maintenance requirement of the animal for body heat (Quiniou *et al.*, 2000). Interestingly, there were no replication effects on ADG or feed efficiency on either treatment group. Therefore, as temperatures decreased in each treatment (Figure 2), there were no significant effects on ADG or feed efficiency of the pigs. However, there were replication effects, and treatment-by-replication interactions noted for live weight, carcass weight, backfat deposition at the 10th and last rib, as well as percentage FFL. With no change in feed intake, it is probable that the effect of ambient temperature may play a role in metabolism, specifically in fat deposition and lean gain.

Grandin (2003) considered that environmental enrichment (access to toys, outdoor rearing, etc.) reduced excitability in hogs, which in turn allowed easier handling and less stress prior to slaughter. One of the hypotheses of the current study was that deep-bedded semi-outdoor finishing environments may reduce stress susceptibility and behaviours that have been noted to lead to aberrant pork quality (Sather *et al.*, 1997; Klont *et al.*, 2001). In the current experiment, the effect of finishing environment had minor influence on pork quality attributes, with the main difference between the two finishing treatments being an increase in marbling within the loin in CON-finished pigs.

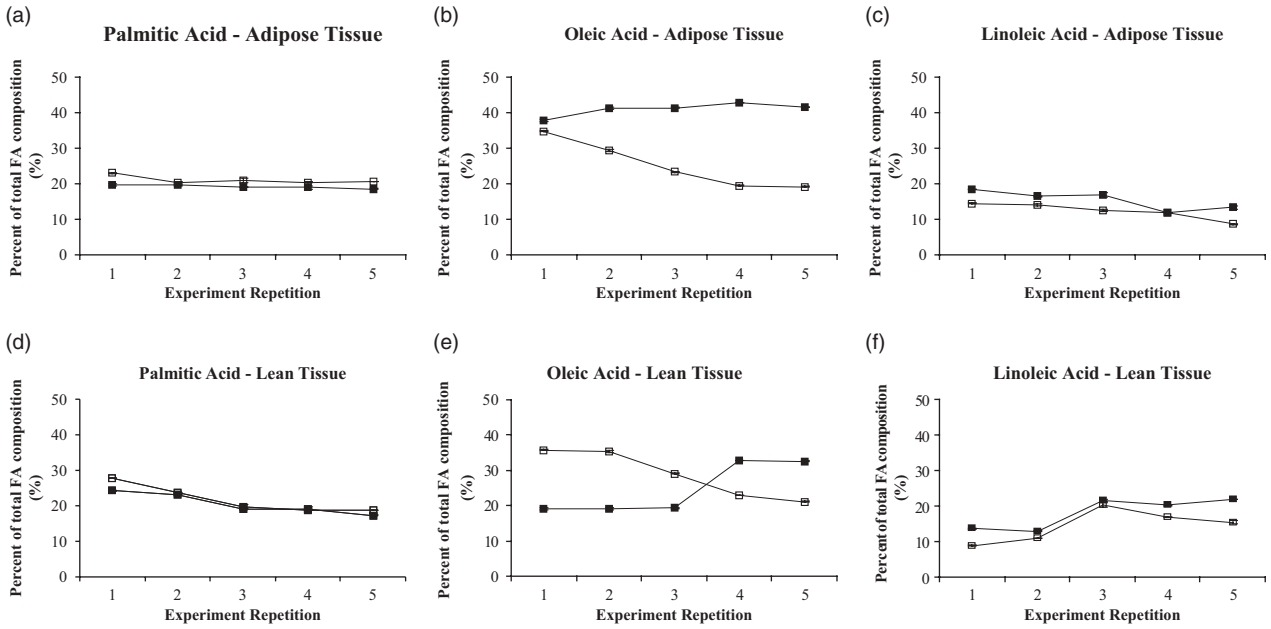


**Figure 1** The effects of finishing environment on lipid composition in lean and adipose tissue. Changes in the concentration of palmitic, oleic and linoleic acids were compared between Hoop- and confinement (CON)-finished pigs over the five repetitions of the experiment. a = palmitic acid, adipose tissue, b = oleic acid, adipose tissue, c = linoleic acid, adipose tissue, d = palmitic acid, lean tissue, e = palmitic acid, lean tissue, f = linoleic acid, lean tissue. For all graphs, □ = CON and ■ = Hoop.

**Table 8** *Effect of finishing environment on the volatile organic profile of lean (*Longissimus dorsi*) – common volatiles*[†]

| Volatile family | Volatile | Hoop[‡] | Significance[§] CON[‡] | s.e. | ENV[¶] |
|---|---|---|---|---|---|
| Alcohols | 1-butanol | 1.20 | 1.27 | 0.23 | NS |
| | 2-butanol | 1.91 | 1.38 | 0.77 | NS |
| | 2-propanol | 4.25 | 3.13 | 0.39 | NS |
| | 3-pentanol | 29.81 | 31.89 | 10.14 | NS |
| | Ethanol | 1.24 | 1.38 | 0.02 | NS |
| | Methanol | 11.39 | 15.17 | 1.87 | NS |
| Ketone | 2-propanone | 0.50 | 0.62 | 0.20 | NS |
| Hydrocarbons | Propane | 1.02 | 1.58 | 0.70 | NS |
| | Pentane | 2.00 | 1.98 | 0.52 | NS |
| | Cyclopentane | 2.02 | 0.96 | 0.61 | NS |
| | Hexane | 4.53 | 3.75 | 0.92 | NS |
| | Hexamethyl Cyclotrisiloxane | 0.45 | 0.52 | 0.03 | NS |
| | Heptane | 1.10 | 1.54 | 0.90 | NS |
| | Octane | 5.97 | 5.66 | 0.65 | NS |
| | Octamethyl Cyclotrisiloxane | 0.14 | 0.56 | 0.14 | ** |
| | Decane | 0.86 | 0.40 | 0.28 | NS |
| | Octene | 0.77 | 0.74 | 0.16 | NS |
| Aldehydes | Pentanal | 0.28 | 0.31 | 0.16 | NS |
| | Hexanal | 2.25 | 1.67 | 0.30 | NS |
| | Heptanal | 0.64 | 0.67 | 0.20 | NS |
| | Acetaldehyde | 26.04 | 21.11 | 7.61 | NS |
| Ether | Tetrahydrofuran | 1.97 | 2.55 | 2.09 | NS |

[†]Common volatiles observed in all samples. Least square means of total ion counts for each volatile compound.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$.
[¶]Environemental significance, hoop *v.* confinement.

**Table 9** *Effect of finishing environment on volatile organic profile of adipose – common volatiles*[†]

| Volatile family | Volatile | Hoop[‡] | Significance[§] CON[‡] | s.e. | EVN[¶] |
|---|---|---|---|---|---|
| Alcohols | 1-butanol | 0.87 | 1.00 | 0.51 | NS |
| | 2-propanol | 1.94 | 1.72 | 0.92 | NS |
| | Ethanol | 21.30 | 27.97 | 1.81 | NS |
| Ketones | 2-propanone | 1.10 | 1.63 | 1.18 | NS |
| Hydrocarbons | Pentane | 10.15 | 12.04 | 7.57 | NS |
| | Hexane | 8.12 | 11.04 | 6.39 | NS |
| | Heptane | 4.78 | 3.96 | 1.40 | NS |
| | Hexamethyl Cyclotrisiloxane | 0.35 | 0.30 | 0.16 | NS |
| | Octane | 16.41 | 10.67 | 3.94 | NS |
| | Decane | 1.74 | 5.14 | 2.44 | NS |
| | Octene | 1.05 | 2.08 | 1.20 | NS |
| Aldehydes | 3-butanal | 1.26 | 0.94 | 0.64 | ** |
| | Hexanal | 1.28 | 1.12 | 0.72 | NS |
| | Heptanal | 1.22 | 0.15 | 1.11 | ** |
| | Acetaldehyde | 16.24 | 11.79 | 1.79 | NS |

[†]Common volatiles observed in all samples. Least square means of total ion counts for each volatile compound.
[‡]Hoop = hoop-finished pigs; CON = confinement-finished pigs.
[§]Significance: $^{**}P < 0.05$; $^{***}P < 0.01$; NS: $P > 0.05$.
[¶]Environemental significance, hoop *v.* confinement.

Fatty acid profiles of the lean and adipose tissue were affected by environmental treatment (Table 5). Hoop-finished pigs had greater deposition of linoleic and oleic acid, and lower deposition of palmitic acid in both their lean and adipose tissues. These differences corresponded to significant alterations between environments within the adipose tissue, with lipid from adipose in Hoop pigs being significantly less saturated than confinement pigs. Main factors affecting fatty acid composition are diet, fatness, age/body weight, gender, breed, environmental temperature depot site, maintenance and hormones (Wood and

Enser, 1997; Nürnberg *et al*., 1998). With the exception of four fatty acids (myristic acid, margaric acid, heptadecanoic acid and DHA), fatty acids varied by replication and were affected by an interactive effect of treatment and replication. This suggests that individual fatty acids were being deposited at different levels from replication to replication, and were also differing within the two treatments. One characteristic differing from replication to replication was ambient temperature (Figure 2). The replication differences in ambient temperature were more pronounced in hoop systems compared with confinements. Fluctuations in ambient temperature due to alternative production systems have been shown to influence fatty acid composition in pigs (Lefaucheur *et al*., 1991; Lebret *et al*., 2002; Bee *et al*., 2004). Overall, outdoor-produced pigs have been shown to deposit more PUFA than their confinement counterparts (Bee *et al*., 2004). Specifically, decreasing environmental temperature affected the fatty acid composition of the back fat, leading to higher MUFA and lower SFA and PUFA contents of cold-exposed pigs.

The three fatty acids representing the largest variation from environment and replication to replication in this experiment were palmitic, oleic and linoleic acid (Figure 1a–f). These observations were interesting in that temperatures did not vary as dramatically in confinement as in hoop systems. The large deviation in oleic acid created significant difference in MUFA, and a significant difference in PUFA between

**Table 10** *Effect of finishing environment on volatile organic profile of lean (*Longissimus dorsi*) –unique compounds*[†]

| Volatile family | Volatile | Environment[‡] | |
|---|---|---|---|
| | | Hoop[§] | CON[§] |
| Diene | 1,3-pentadiene | 6.0 | 22.0 |
| Alcohols | 2-butenol | 6.0 | 28.0 |
| | 3-butanol | 6.0 | 0.0 |
| | 1-pentanol | 6.0 | 0.0 |
| | 1-hexanol | 6.0 | 6.0 |
| | 1-octenol | 6.0 | 0.0 |
| Ketones | 2-butanone | 22.0 | 6.0 |
| | 2-pentanone | 0 | 6.0 |
| | Cyclohexanone | 6.0 | 6.0 |
| | 2-heptanone | 6.0 | 0.0 |
| Hydrocarbons | Cyclobutane | 11.0 | 0.0 |
| | 2-propene | 0.0 | 6.0 |
| | Cyclohexane | 6.0 | 0.0 |
| | 2-heptene | 22.0 | 11.0 |
| | Cycloheptane | 6.0 | 0.0 |
| | Undecane | 17.0 | 11.0 |
| | Dodecane | 6.0 | 0.0 |
| | Tridecane | 6.0 | 6.0 |
| | Tetradecane | 6.0 | 0.0 |
| | Hexadecane | 0.0 | 6.0 |
| | Eicosane | 6.0 | 6.0 |
| Acids | Propanoic acid | 22.0 | 11.0 |
| | Formic acid | 22.0 | 22.0 |
| | Acetic acid | 28.0 | 17.0 |
| Nitriles | Acetonitrile | 28.0 | 28.0 |
| Sulphides | Carbon disulphide | 28.0 | 39.0 |
| | Dimethyl disulphide | 6.0 | 0.0 |
| Aldehydes | Propanal | 6.0 | 6.0 |
| | 4-Pentenal | 6.0 | 0.0 |
| | 2-Hexanal | 6.0 | 0.0 |
| | Octanal | 6.0 | 0.0 |
| | Nonanal | 6.0 | 0.0 |

[†]Unique compounds not observed evenly in all lean muscle samples throughout experiment.
[‡]Presented as frequency (%) of observation within environment over five replications.
[§]Hoop = hoop-finished pigs; CON = confinement-finished pigs.

**Table 11** *Effect of finishing environment on volatile organic profile of adipose tissue – unique compounds*[†]

| Volatile family | Volatile | Environment[‡] | |
|---|---|---|---|
| | | Hoop[§] | CON[§] |
| Diene | 1,3-pentadiene | 0.09 | 0.00 |
| Alcohol | 3-pentanol | 0.09 | 0.00 |
| Sulphide | Carbon disulphide | 0.36 | 0.30 |
| Alkanes | Cyclopentane | 0.18 | 0.00 |
| | Eicosane | 0.09 | 0.10 |
| | Hexadecane | 0.18 | 0.20 |
| | Nonane | 0.36 | 0.10 |
| Acid | Propanoic acid | 0.18 | 0.10 |
| Ether | Tetrahydrofuran | 0.00 | 0.10 |

[†]Unique compounds not observed evenly in adipose tissue throughout experiment.
[‡]Presented as frequency (%) of observation within environment over five replications.
[§]Hoop = hoop-finished pigs; CON = confinement-finished pigs.

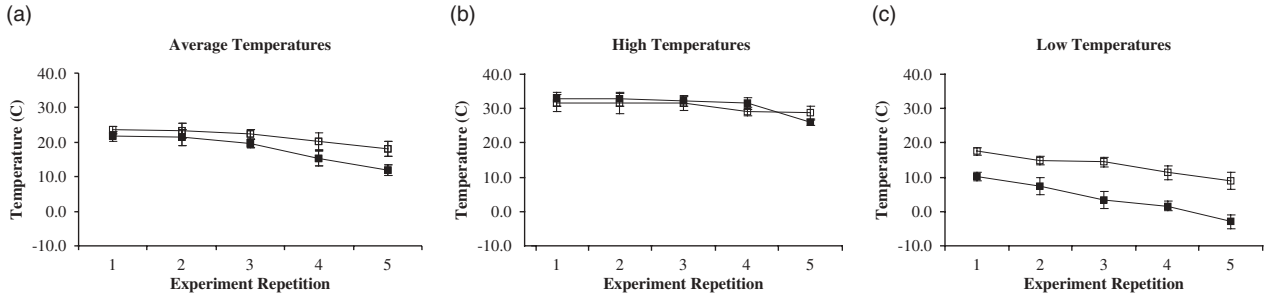


**Figure 2** Ambient temperature fluctuations. Fluctuations in average, high and low temperatures (°C) were recorded over the five repetitions of the experiment. Temperatures were recorded every min using a HOBO Pro Series™ temperature recorder (Ben Meadows Company, Janesville, WI, USA). Temperatures are recorded as averages of triplicate measures taken throughout the systems. For all graphs, □ = CON and ■ = Hoop.

treatment groups. In an effort to discern these deviations, Pearson correlation coefficients were analysed for each individual fatty acid against daily average and low temperatures taken throughout the experimental replication (Table 7). The proportions of palmitic and stearic acid were significantly correlated with average and low temperatures. Unsaturated fatty acids such as palmitoleic, oleic, linoleic and arachidonic acids were all negatively correlated with average and low temperatures. These relationships resulted in a strong positive correlation between total saturation and low temperature. A strong negative correlation between proportion of MUFAs and low temperature was also observed. These data verify that fluctuations in ambient temperature below the thermoneutral zone for pigs accompanied an increased proportion of monounsaturated lipid in the adipose tissue of pigs. Bee *et al*. (2004) reported that higher PUFA content was compensated by both a lower saturated and MUFA content in the outer layer of backfat tissue from outdoor reared pigs. In that study, pigs were finished during winter months in an intensive outdoor system with igloos for shelter. The ambient temperatures of the outdoor system averaged 5°C to 27°C. One possible reason Bee *et al*. (2004) did not observe the increase in monounsaturation as in the current study is that the temperatures were colder in the current study. Figure 2 reports an average low temperature of −2.9°C. If low temperatures drive the deposition of MUFA, then it seems probable that more MUFA would be deposited in the current experiment. Bee *et al*. (2004) measured the outer layer, as the current experiment was conducted on the inner layer. These two layers differ significantly in deposition and metabolic behaviour, which is another reason as to why the increase in the proportion of monounsaturated lipid was not observed in that study (Bee *et al*., 2002).

One component of meat quality influenced by fatty acids is fat tissue firmness. Higher levels of unsaturation will lead to softer, less-firm fat (Wood *et al*., 2004). Soft fat is a major issue related to fat quality. Problems from soft fat arise during cutting, grinding and slicing operations and can result in lower processing yields and reduced value. There were significant replication effects on the firmness of the tissue, as well as environment-by-replication interactions. When CON and Hoop temperatures were similar, fatty acid profile and firmness was similar. However, when CON and Hoop temperatures varied, fatty acid composition and firmness varied as well. The correlations provided in Table 7 are apparent indicators of total saturation and increasing firmness. In a recent review by Wood *et al*. (2004), it was reported that the concentrations of stearic and linoleic acids are the best predictors of firmness of adipose tissue itself, the former being softer and the latter being firmer. This was not the case in the current experiment.

Although environment did not affect fat firmness in this experiment, it is likely that replication differences in fat firmness are the result of proportions of monounsaturated lipid in the adipose tissue. The negative correlation of MUFA to fat firmness indicates that, in this experiment, percentage of monunsaturation is a more apparent driver of adipose tissue firmness than polyunsaturation.

Hansen *et al*. (1994) suggested that deep-bedded pigs housed intensively without continuous bedding change may increase the risk of pork taint, negatively affecting pork flavour. Specific compounds relating to meat taint in that experiment (Hansen *et al*., 1994) were skatole and indole, which are directly related to bore taint and stored in the adipose tissue (Rius and García-Regueiro, 2001). Other compounds negatively identified with flavour are aldehydes, furans and sulphides (Mottram, 1991; Ho *et al*., 1994).

There were limited differences in common volatiles between treatments in the current study (Tables 8 and 9). Adipose tissue of Hoop pigs had significantly higher amounts of 3-butanal and heptanal compared with CON pigs. These two aldehydes are produced primarily by autoxidation of lipids, and are related to the amount of oleic and linoleic acids composing the adipose tissue (Grueb and Gatfield, 1989). It is not surprising that these compounds were associated with Hoop pigs granting previous discussion of the amounts of oleic and linoleic acid being much higher in Hoop pigs. Tables 10 and 11 provide insight into environmental effects of certain volatile organic compounds. Given the observed frequencies, it seems that tissues from Hoop-finished pigs had higher amounts of alcohols, acids and sulphides compared with CON-finished pigs. Without performing similar profile analysis of bedded materials, it cannot be stated that these frequencies were changed due to exposure to excreta.

An experiment by Schiffman *et al*. (2001) reported that 1,3-pentadiene, 2-butenol, 2-butanol, 1-hexanol, cyclobutane, 2-heptene, propanoic and formic acid, carbon and dimethyl disulphide, propanal, 2-pentanal and 2-hexanal contribute to excreta emissions from pig production facilities. When comparing these compounds to unique compounds observed in this experiment, they are very similar. Therefore, variations in volatile organic profiles between Hoop and CON pigs may be explained by the increased exposure to emissions in hoops (Edwards, 2005).

*Conclusions*

Variations in finishing environment had specific effects on pork adipose attributes. Hoop-finished pigs had lower backfat deposition and higher degree of unsaturation in the inner layer of adipose tissue and in lean tissue. Replication effects and treatment-by-replication interactions caused variations within growth subsequently affecting fatty acid composition and adipose tissue firmness. The specific role of ambient temperature fluctuation on these attributes needs to be further evaluated within these systems. Seasonal variations in lipid deposition, fatty acid composition and firmness are not yet understood and need to be critically investigated.

**Acknowledgements**

Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the

USDA and does not imply approval to the exclusion of other products that may be suitable. This project was supported by Hatch Act and State of Iowa funds, USDA Special Grants and the Leopold Center for Sustainable Agriculture. The authors recognise the significant efforts of the Iowa State University Western Research Farm and the Iowa State University Swine Nutrition Farm for animal care. The authors also recognise the technical support provided by Randall Petersohn and the Iowa State University Meat Laboratory.

## References

Ahn DU, Nam KC, Du M and Jo C 2001. Volatile production in irradiated normal, pale soft exudative (PSE), and dark firm dry (DFD) pork under different packaging and storage conditions. Meat Science 57, 419–426.

Barton-Gade P and Blaagjerg LO 1989. Preliminary observations on the behaviour and meat quality of free range pigs. In Proceedings. 35th International Congress of Meat Science Technology, Copenhagen, Denmark, pp. 1002–1005.

Bee G, Gebert S and Messikommer R 2002. Effect of dietary energy supply and fat source on the fatty acid pattern of adipose and lean tissues and lipogenesis in the pig. Journal of Animal Science 80, 1564–1574.

Bee G, Guex G and Herzog W 2004. Free-range rearing of pigs during the winter: adaptations in muscle fiber characteristics and effects on adipose tissue composition and meat quality traits. Journal of Animal Science 82, 1206–1218.

Bruce JM and Clark JJ 1979. Models of heat production and critical temperature for growing pigs. Animal Production 28, 353–369.

Cava R, Ventanas J, Ruiz J, Andres AI and Antequera T 2000. Sensory characteristics of Iberian ham: influence of rearing system and muscle location. Food Science and Technology International 6, 235–242.

De Jong IC, Ekkel ED, Van de Burgwal JA, Lambooij E, Korte SM, Ruis M, Koolhaas JM and Blokhuis HJ 1998. Effects of straw bedding on physiological responses to stressors and behavior in growing pigs. Physiology and Behavior 64, 303–310.

Dransfield E, Ngapo TM, Nielsen NA, Bredahl L, Sjoden PO, Magnusson M, Campo MM and Nute GR 2005. Consumer choice and suggested price for pork as influenced by its appearance, taste and information concerning country of origin and organic pig production. Meat Science 69, 61–70.

Edwards SA 2005. Product quality attributes associated with outdoor pig production. Livestock Production Science 94, 5–14.

Enfalt AC, Lundstrom K, Hansson I, Lundeheim N and Nystrom PE 1997. Effects of outdoor rearing and sire breed (Duroc or Yorkshire) on carcass composition and sensory and technological meat quality. Meat Science 45, 1–15.

Folch J, Lees M and Stanley G 1957. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry 226, 497–509.

Gardner MA, Huff-Lonergan E, Rowe LJ, Schultz-Kaster CM and Lonergan SM 2006. Influence of harvest processes on pork loin and ham quality. Journal of Animal Science 84, 178–184.

Gentry JG, McGlone JJ, Blanton Jr JR and Miller MF 2002a. Alternative housing systems for pigs: influences on growth composition, and pork quality. Journal of Animal Science 80, 1781–1790.

Gentry JG, McGlone JJ, Miller MF and Blanton JR 2002b. Diverse birth and rearing environment effects on pig growth and meat quality. Journal of Animal Science 80, 1707–1715.

Grandin T 2003. Transferring results of behavioral research to industry to improve animal welfare on the farm, ranch and the slaughter plant. Applied Animal Behaviour Science 81, 215–228.

Grueb H and Gatfield JL 1989. Generation of flavor components. In Flavor chemistry of lipid foods (ed. D Min and TH Smouse), pp. 367–375. American Oil Chemists' Society, Champaign, IL.

Hansen LL, Larsen AE, Jensen BB, Hansen-Møller J and Barton-Gade P 1994. Influence of stocking rate and faeces deposition in the pen at different temperatures on skatole concentration (boar taint) in subcutaneous fat. Animal Production 59, 99–110.

Ho CT, Oh YC and Bae-Lee M 1994. The flavor of pork. In Flavor of meat and meat products (ed. F Shahidi), vol. 1, pp. 38–51. Blackie Academic and Professional, New York.

Honeyman MS 1996. Sustainability issues of US swine production. Journal of Animal Science 74, 1410–1417.

Honeyman MS and Harmon JD 2003. Performance of finishing pigs in hoop structures and confinement during winter and summer. Journal of Animal Science 81, 1663–1670.

Honeyman MS, Harmon JD, Kliebenstein JB and Richard TL 2001. Feasibility of hoop structures for market swine in Iowa: pig performance, pig environment, and budget analysis. Applied Engineering in Agriculture 17, 869–874.

Jo C and Ahn DU 2000. Volatiles and oxidative changes in irradiated pork sausage with different fatty acid composition and tocopherol content. Journal of Food Science 65, 270–275.

Klont RE, Hulsegge B, Hoving-Bolink AH, Gerritzen MA, Kurt E, Winkelman-Goedhart HA, De Jong IC and Kranen RW 2001. Relationships between behavioral and meat quality characteristics of pigs raised under barren and enriched housing conditions. Journal of Animal Science 79, 2835–2843.

Lebret B, Massabie P, Granier R, Juin H, Mourot J and Chevillon P 2002. Influence of outdoor rearing and indoor temperature on growth performance, carcass, adipose tissue and muscle traits in pigs, and on the technological and eating quality of dry-cured hams. Meat Science 62, 447–455.

Lefaucheur L, Ledividich J, Mourot J, Monin G, Ecolan P and Krauss D 1991. Influence of environmental temperature on growth, muscle and adipose metabolism, and meat quality in swine. Journal of Animal Science 69, 2844–2854.

Leymaster KA and Mersmann HJ 1991. Effect of limited feed-intake on growth subcutaneous adipose-tissue layers and on carcass composition in swine. Journal of Animal Science 69, 2837–2843.

Lonergan SM, Huff-Lonergan E, Rowe LJ, Kuhlers DL and Jungst SB 2001. Selection for lean growth efficiency in Duroc pigs influences pork quality. Journal of Animal Science 79, 2075–2085.

Lonergan SM, Stalder KJ, Huff-Lonergan E, Knight TJ, Goodwin RN, Prusa KJ and Beitz DC 2007. Influence of lipid content on pork sensory quality within pH classification. Journal of Animal Science 85, 1074–1079.

Miao ZH, Glatz PC and Ru YJ 2004. Review of production, husbandry and sustainability of free-range pig production systems. Asian-Australasian Journal of Animal Science 17, 1615–1634.

Morrison W and Smith L 1964. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. Journal of Lipid Research 5, 600–608.

Morrison RS, Hemsworth PH, Cronin GM and Campbell RG 2003a. The social and feeding behaviour of growing pigs in deep-litter, large group housing systems. Applied Animal Behaviour Science 82, 173–188.

Morrison RS, Hemsworth PH, Cronin GM and Campbell RG 2003b. The effect of restricting pen space and feeder availability on the behaviour and growth performance of entire male growing pigs in a deep-litter, large group housing system. Applied Animal Behaviour Science 83, 163–176.

Mottram DS 1991. Meat. In Volatile compounds in foods and beverages (ed. H Maarse and M Dekker), pp. 107–177. Culinary and Hospitality Industry Publications Services, New York.

National Pork Board 2000. In Pork composition and quality assessment procedures (ed. EP Berg), pp. 17–32. NPB, Des Moines, IA.

Nishioka T and Irie M 2005. Evaluation method for firmness and stickiness of porcine perirenal fat. Meat Science 70, 399–404.

Nürnberg K, Wegner J and Ender K 1998. Factors influencing fat composition in muscle and adipose tissue of farm animals. Livestock Production Science 56, 145–156.

O'Connell NE, Beattie VE and Moss BW 2004. Influence of social status on the welfare of growing pigs housed in barren and enriched environments. Animal Welfare 13, 425–431.

Quiniou N, Dubois S and Noblet J 2000. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. Livestock Production Science 63, 245–253.

Rius MA and García-Regueiro JA 2001. Skatole and indole concentrations in *Longissimus dorsi* and fat samples of pigs. Meat Science 59, 285–291.

Sather AP, Jones SDM, Schaefer AL, Colyn J and Roberston W 1997. Feedlot performance, carcass composition and meat quality of free-range reared pigs. Canadian Journal of Animal Science 77, 225–232.

Schiffman SS, Bennett JL and Raymer JH 2001. Quantification of odors and odorants from swine operations in North Carolina. Agricultural and Forest Meteorology 108, 213–240.

Thornton K 1988. Outdoor pig production. Farming Press, Ipswich, UK.

Warnants N, VanOeckel M and Boucque CV 1996. Incorporation of dietary polyunsaturated fatty acids in pork tissues and its implications for the quality of the end products. Meat Science 44, 125–144.

Warriss PD, Kestin SC and Robinson JM 1983. A note on the influence of rearing environment on meat quality in pigs. Meat Science 9, 271–279.

Wood JD and Enser M 1997. Factors influencing fatty acids in meat and the role of antioxidants in improving meat quality. British Journal of Nutrition 78, S49–S60.

Wood JD, Richardson RI, Nute GR, Fisher AV, Campo MM, Kasapidou E, Sheard PR and Enser M 2004. Effects of fatty acids on meat quality: a review. Meat Science 66, 21–32.