EFFECTS OF RACTOPAMINE HCl, L-CARNITINE AND DRIED DISTILLERS GRAINS WITH SOLUBLES ON GROWTH, CARCASS TRAITS, LOIN AND JOWL FAT QUALITY OF FINISHING PIGS, AND ENERGY AND PROTEIN SOURCES IN NURSERY DIETS

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Abstract

Six experiments using 3,862 pigs were conducted to evaluate effects of ractopamine HCl (RAC) feeding programs, dietary L-Carnitine and dried distillers grains with solubles (DDGS) on growth, carcass traits, loin and jowl fat quality of pigs, and energy and protein sources in nursery diets. In Exp. 1 and 2, RAC-fed pigs had greater (P<0.05) ADG, G:F and HCW compared with the control. Within RAC treatments, there were no differences in growth. Pigs fed step-up RAC had increased (P<0.01) percentage lean, fat-free lean index and loin depth but decreased (P<0.01) backfat than the control or constant treatment. In Exp. 2, pigs fed step-up RAC program had greater (P<0.05) ADG and G:F than the constant treatment. Pigs fed constant RAC had greater (P=0.002) carcass yield than controls. There were no overall differences in other carcass traits among treatments. In Exp. 3, dietary L-Carnitine improved (P<0.02) ADG and final BW. A DDGS × L-Carnitine interaction (quadratic, P<0.01) was observed for G:F. Pigs not fed DDGS had similar G:F, but in DDGS diets pigs fed 50 ppm L-Carnitine had worse G:F than those fed 100 ppm. Pigs fed L-Carnitine had greater (P<0.02) HCW compared with those not fed L-Carnitine. Increasing L-Carnitine up to 100 ppm increased HCW (quadratic, P<0.03) and backfat (quadratic, P<0.04), with the maximum response at 50 ppm dietary L-Carnitine. Increasing L-Carnitine increased (linear, P<0.04) purge loss of loin. Feeding DDGS increased (P<0.001) linoleic acid and iodine value of jowl fat compared with feeding no DDGS. However, feeding L-Carnitine did not change jowl fatty acid composition. In Exp. 4, 5 and 6, nursery pigs fed choice white grease (CWG) had improved (P<0.02) G:F than pigs fed a control diet or an alcohol based energy source. Also, pigs fed CWG had greater (P<0.04) ADG in Exp. 4 and 6 and had reduced (P<0.01) ADFI in Exp. 5. The alcohol based energy source improved (P<0.04) ADG and ADFI with no change in G:F in Exp. 4; but did not affect growth in Exp. 5 and 6. In Exp. 6, pigs fed AV-E Digest had equal performance as nursery pigs fed other specialty proteins.

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Chapter 1 - Evaluation of Ractopamine HCl Feeding Programs on Growth Performance and Carcass Characteristics of Finishing Pigs

ABSTRACT

Two experiments were conducted to evaluate the effects of ractopamine HCl (RAC) feeding programs on growth performance and carcass traits of finishing pigs. In Exp. 1, a total of 1,099 pigs (PIC 337 × C22, initially 94.4 kg) were used in a 28-d trial with 26 pigs per pen and 14 pens per treatment. Pigs were randomly allotted to 1 of 3 treatments including a basal diet with no RAC fed for 28 d (control), no RAC from d 0 to 7 and 5 mg/kg RAC from d 7 to 28 (constant) and 5 mg/kg RAC from d 0 to 14 and 7.5 mg/kg from d 14 to 28 (step-up). The RAC and control diets contained 0.95% and 0.70% SID lysine, respectively. Overall (d 0 to 28), pigs fed RAC had improved ($P < 0.01$) ADG and G:F compared with control pigs, but there were no differences among the two RAC feeding programs. Pigs fed RAC tended to have increased carcass yield ($P < 0.10$) and HCW ($P < 0.05$) compared with control pigs. Pigs fed step-up RAC over 28 d had increased ($P < 0.01$) percentage lean, fat-free lean index and loin depth and decreased ($P < 0.01$) backfat compared with pigs fed the control diet or the 21 d constant RAC treatment. In Exp. 2, a total of 934 barrows and gilts (PIC 337 × 1050, initially 109 kg) were used in a 26-d trial with pens of pigs randomly allotted to 1 of 4 treatments. Each treatment had 10 pens with a similar number of barrows and gilts in each pen. Treatments included a basal diet with no RAC for 26 d (control), 7.5 mg/kg RAC for 26 d (constant), 5 mg/kg RAC from d 0 to 14 and 10 mg/kg for d 14 to 26 (step-up), and RAC

concentration increased daily from 5 mg/kg on d 0 to 10 mg/kg on 26 d by using the FEEDPro (Feedlogic Corp., Willmar, MN) system (curve). All diets contained 1% SID lysine. Overall (d 0 to 26), pigs fed RAC had increased ($P < 0.001$) ADG and G:F compared with control pigs. Pigs fed the step-up RAC program had increased ADG ($P < 0.05$) and G:F ($P = 0.02$) than those fed the constant RAC program. Pigs fed diets containing RAC had heavier ($P < 0.001$) HCW when compared with control pigs. Pigs fed constant RAC had greater ($P = 0.002$) carcass yield than control pigs. There were no differences in carcass traits among RAC treatments. In conclusion, feeding RAC improved growth performance regardless of feeding method with pigs fed step-up programs having increased response as compared to constant RAC program as measured by better carcass traits in Exp. 1 and greater ADG and G:F in Exp. 2.

Key words: feeding program, finishing pig, growth, ractopamine HCl

INTRODUCTION

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) has been widely used to improve growth and carcass characteristics of late-finishing pigs. The greatest growth responses to RAC occur during the initial feeding period; however, these responses decline over time (Williams et al., 1994). The cause of the reduced performance to RAC over time is thought to be down-regulation of beta receptors (Spurlock et al., 1994; Mills, 2002). Several studies suggested that a step-up RAC feeding program might alleviate the down-regulation of beta adrenergic receptors (Herr et al., 2001; Armstrong et al., 2005). Furthermore, recent automatic feeding systems, such as FEEDPro system (Feedlogic Corp., Willmar, MN), have capability to blend and deliver different ratios of 2 diets (Sulabo et al., 2010; Frobose et al., 2011). With the application of automatic feeding system in swine facilities, pigs can be fed following a curve by slowly increasing the RAC dosage over time or via a step-up program. We hypothesized that gradually increasing RAC dosage on a daily basis may provide for an improved growth and carcass traits compared to constant or step-up feeding program.

Therefore, the objective of this study was to evaluate the effects of different RAC feeding programs on growth performance and carcass traits of finishing pigs.

MATERIALS AND METHODS

All experimental procedures were approved by the Kansas State University Animal Care and Use Committee.

Both experiments were conducted in a commercial research finishing barn in southwestern Minnesota. The barn was naturally ventilated and double curtain sided.

Pens had completely slatted flooring and deep pits for manure storage. Each pen (3 m × 5.5 m) was equipped with a 5-hole, stainless steel, dry self-feeder and a cup waterer for ad libitum access to feed and water. The barn had an automated feeding system (FEEDPro; Feedlogic Corp., Willmar, MN) capable of delivering and measuring feed added on an individual pen basis.

Experiment 1

A total of 1,099 pigs (PIC 337 × C22, Hendersonville, TN, initially 94.4 kg BW) were used in a 28-d experiment. There were 26 pigs per pen and 14 pens per treatment. Pens were ranked by average pig weight, and then allotted to 1 of 3 experimental treatments in a randomized design. Treatments included (1) a basal diet with no RAC for 28 d (control), (2) control diet from d 0 to 7 and 5 mg/kg RAC from d 7 to 28 (constant), and (3) 5 mg/kg RAC from d 0 to 14 and 7.5 mg/kg from d 14 to 28 (step-up; Table 1). The control diet was formulated to 0.70% standardized ileal digestible (SID) lysine and the RAC diets were formulated to contain 0.95% SID lysine as per findings of Webster et al. (2007). The increase in dietary Lys was accomplished by increasing the soybean meal and L-lysine HCl content of the diet. All other nutrients were formulated to meet or exceed all requirement estimates suggested by NRC (1998). Average daily gain, ADFI, and G:F were determined by weighing pigs and measuring feed disappearance every 7 d.

On d 14 of the experiment, the 3 heaviest pigs (determined visually) from each pen were removed and sold according to the normal marketing procedure of the farm. These removed pigs were not included in carcass data analysis but were included in the growth performance data. At the end of experiment (d 28), all pigs were tattooed with a specific pen identity in order to attribute carcass data back to the individual pen. All pigs

were transported approximately 1 h to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and data collection. Carcass yield, HCW, backfat, percentage lean, and loin depth were collected with pen as the experimental unit. Lean percentage was provide from the packing plant by using a proprietary equation. Fat-free lean index was calculated using the equation: 50.767 + (0.035 × HCW) – (8.979 × backfat) (NPPC, 2000).

Experiment 2

A total of 934 barrows and gilts (PIC 337 × 1050, Hendersonville, TN, initially 109 kg BW) were used in a 26-d experiment. There were 22 to 24 pigs per pen and 10 pens per treatment. Pens were ranked by average pig weight, and then allotted to 1 of 4 experimental treatments in a randomized design. Pigs had ad libitum access to feed and water. Treatments included a basal diet with no RAC for 26 d (control), 7.5 mg/kg RAC for 26 d (constant), 5 mg/kg RAC from d 0 to 14 and 10 mg/kg from d 14 to 26 (step-up), and RAC dosage increased daily from 5 mg/kg on d 0 to 10 mg/kg on 26 d by using the FEEDPro system (curve; Table 2). All diets were formulated to contain 1% SID lysine and other nutrients were the same. Diets were formulated to meet or exceed all requirement estimates suggested by NRC (1998). Average daily gain, ADFI, and G:F were determined by weighing pigs and measuring feed disappearance every 7 d.

In this study, the 9 heaviest pigs (determined visually) were topped from each pen on d 14 of trial. The remaining pigs, except cull (6 with umbilical rupture, 2 with tail bites, and 2 lame pigs) and light pigs (BW less than 90.8 kg; 4 pigs) that didn't meet the minimum acceptable packing plant specifications, were marketed on d 26. All pigs were tattooed with a specific pen identity in order to attribute carcass data back to the

individual pen. All pigs were transported approximately 1 h to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and data collection similar to Exp. 1.

Statistical Analysis

For Exp. 1 and 2, all data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Backfat, loin depth, and percentage lean were adjusted to a common HCW. Differences between treatments were determined by using least square means ($P < 0.05$).

RESULTS

Experiment 1

From d 0 to 7, pigs fed the step-up RAC feeding program (the only group fed RAC during wk 1) had improved ($P < 0.04$) ADG, ADFI and G:F compared with pigs fed diets without RAC (Table 3). Due to feeding the same control diet during this period, pigs fed the constant RAC program had similar ADG and ADFI as the control group as expected. However, surprisingly, pigs fed the constant RAC program had higher G:F ($P < 0.001$) than those fed the control diet. From d 7 to 14, regardless of feeding program, pigs fed RAC diets had greater ($P < 0.001$) ADG and G:F compared with pigs fed the control diet. Pigs fed the step-up RAC feeding program (5 mg/kg) had lower ($P < 0.001$) ADFI than the control group. Compared with the step-up RAC feeding program, pigs fed the constant RAC feeding program (5 mg/kg) had greater ($P < 0.002$) ADG and ADFI. From d 0 to 14, pigs fed RAC diets had better ($P < 0.01$) ADG and G:F than control pigs. Pigs on the step-up RAC feeding program had better ($P < 0.05$) G:F compared to those fed the constant feeding program.

From d 14 to 28, all pigs fed RAC diets had greater ADG and G:F than the control pigs. Pigs fed step-up RAC (7.5 mg/kg during this period) diet had decreased ($P < 0.01$) ADFI compared with pigs fed the control diet. Pigs fed the constant RAC feeding program (5 mg/kg) had greater ($P < 0.05$) ADG and ADFI than that of pigs fed the step-up RAC feeding program.

Because pigs fed the constant RAC feeding program were not fed RAC diet until d 7, the performance from d 7 to 28 was evaluated. There were improvements in ADG ($P < 0.01$) and G:F ($P < 0.05$) observed from feeding RAC, compared with pigs fed the control diet. Compared with the pigs fed the constant RAC feeding program, pigs fed step-up RAC had decreased ($P < 0.01$) ADG and ADFI but similar G:F. Overall (d 0 to 28), pigs fed RAC diets had improved ($P < 0.05$) ADG and G:F than that of the control pigs. There were no differences in growth performance between the two RAC feeding programs.

Ractopamine intake was greater ($P < 0.01$) for pigs fed the step-up RAC program compared with pigs fed the constant RAC level.

For carcass traits, both RAC feeding programs resulted in greater ($P < 0.03$) HCW compared with pigs fed the control diet (Table 4). Feeding RAC tended ($P < 0.10$) to increase carcass yield compared to the control pigs. Pigs fed step-up RAC feeding program had increased ($P < 0.01$) percentage lean, fat-free lean index and loin depth but decreased ($P < 0.01$) backfat than pigs fed control diet or constant RAC diet.

Experiment 2

From d 0 to 14, pigs fed diets containing RAC had improved ($P < 0.001$) ADG and G:F compared to control pigs (Table 5). In addition, pigs fed constant or step-up

RAC feeding programs had greater ($P < 0.04$) ADFI than the control fed pigs. No significant differences in growth performance were observed among the RAC feeding programs. Pigs fed the constant feeding program had higher ($P < 0.001$) daily RAC intake compared with the step-up or curve treatment during this period.

From d 14 to 26, regardless of feeding program, pigs fed diets containing RAC had greater ($P < 0.001$) ADG and G:F than control-fed pigs. However, differences in growth performance were observed among RAC treatments. Pigs fed the step-up RAC program (10 mg/kg during this period) had greater ($P < 0.005$) ADG and G:F compared with those fed the constant RAC program (7.5 mg/kg), with pigs fed the curve RAC program intermediate. Pigs on the step-up or curve feeding program had higher ($P < 0.001$) daily RAC intake than pigs fed the constant RAC diet.

Overall (d 0 to 26), pigs fed RAC had improved ($P < 0.001$) ADG and G:F compared with control pigs. Additionally, pigs fed the step-up RAC program had greater ADG ($P = 0.01$) and G:F ($P = 0.02$) than those fed the constant RAC program. No differences in growth were observed between pigs fed the RAC step-up and curve treatments. Pigs fed all three RAC treatments had similar average daily RAC intake for the overall trial.

For carcass characteristics, regardless of feeding methods, pigs fed diets containing RAC had heavier ($P < 0.04$) HCW, yield, and loin depth than control pigs when marketed on d 14 (Table 6). No differences in carcass traits were observed among RAC-fed pigs on d 14.

Pigs marketed on d 26 had greater ($P < 0.003$) HCW when fed RAC diets compared with pigs fed the control diet. Pigs fed the constant RAC diet had greater ($P <$

0.01) carcass yield compared with pigs not fed RAC. There were no differences in carcass traits among RAC treatments.

Combining the carcass data of d 14 and d 26 marketing groups, all RAC-fed pigs had greater ($P < 0.003$) HCW than that of control pigs. Additionally, pigs fed the constant RAC program had greater ($P < 0.002$) carcass yield compared with control pigs. There were no differences in carcass traits among the 3 RAC feeding programs.

DISCUSSION

Several studies have demonstrated that dietary RAC is an effective compound for stimulating growth performance of pigs (See et al., 2004; Armstrong et al., 2005; Apple et al., 2007). In the current study, both experiments indicated a positive growth response to feeding RAC immediately after a 7-d feeding period, and this improvement was maintained through 28-d experimental period regardless of RAC feeding programs. Williams et al. (1994) observed that the improvement in ADG from feeding RAC was maintained for 49 d, but this positive response declined linearly after 21-d feeding of a constant concentration of RAC. Down-regulation of beta adrenergic receptors in adipose tissue might contribute to these decreased responses to long duration of feeding constant RAC level (Spurlock et al., 1994). In Exp. 2 of the current study, there were no differences in ADG and G:F observed among RAC feeding programs during first 14 d, although pigs received different concentrations of dietary RAC.

While many research trials have been done to determine the optimum dosage (constant or step-up) of RAC, the findings are inconsistent. Armstrong et al. (2004) and Apple et al. (2007) suggested that dietary concentration of RAC did not affect the magnitude of improvement in ADG. Also, studies suggest that there are similar growth

responses among feeding methods during the first 2 wk, but pigs fed a step-up RAC feeding program had better ADG and G:F compared with the constant RAC treatment after 14-d feeding (Herr et al., 2001; Armstrong et al., 2005). However, in contrast to those results, See et al. (2004) reported that pigs fed a step-up RAC program had similar growth performance with pigs fed a constant RAC program. This inconsistency in research findings was confirmed in the current studies as differences in growth were observed among feeding programs during last period of both experiments (14 and 12-d, respectively. Compared to the constant feeding level, pigs fed a higher level of RAC in the last period had lower ADG and ADFI in Exp.1, but in Exp.2 they had improved ADG and G:F. The decreased performance in the last 14 d with the step-up RAC program compared with the constant RAC program in Exp. 1 was probably because pigs on the constant program were on week 2 and 3 of RAC feeding as compared with weeks 3 and 4 for the step-up program. Previous research has demonstrated that the response to RAC declines with time on feed, regardless of dose (Kelly et al., 2003). When pigs were fed RAC for the same total duration in Exp. 2, pigs on the step-up program had improved growth performance when the higher dose was fed during the last 12 d of the trial..

The curve feeding program is similar to the step-up feeding method with the introduction of the low dietary RAC level in early feeding phase and then increased RAC level in later phase. It was hypothesized that slowly increasing RAC feeding level of the curve RAC treatment could maintain the maximum growth response to feeding RAC in current study. However, the growth response to the curve feeding program in Exp. 2 was not greater than the constant or step-up RAC feeding methods. It is possible that the

difference in daily RAC intake between the curve and step-up program were not great enough to demonstrate a growth response.

Feeding dietary RAC has consistently resulted in greater HCW compared with pigs fed no RAC diets (Apple et al., 2007). These findings were also found in our trials, where pigs fed RAC, regardless of program, were heavier than pigs fed control diets. However, when comparing between constant and step-up RAC feeding methods, HCW was similar, which is in agreement with the results of the present trials (Herr et al., 2001; See et al., 2004; Armstrong et al., 2005).

Carcass yield was found to improve for pigs fed RAC in a meta-analysis by 0.2 and 0.6 percentage units in pigs fed 5 and 10 mg/kg RAC diet, respectively; while feeding 20 mg/kg RAC increased carcass yield by approximately 1 percentage unit compared to pigs fed no RAC (Apple et al., 2007). Several studies reported that pigs fed step-up or constant RAC diets had increased carcass yield compared with the control pigs (Herr et al., 2001; See et al., 2004; Armstrong et al., 2005). Likewise, improved or tendencies for improved yield were reported in the present studies for RAC fed pigs compared to controls.

It was initially hypothesized that RAC increased nutrients available for protein accretion and increased lipolysis in adipose tissue (Adeola et al., 1990; Watkins et al., 1990). Thus, feeding RAC was expected to change carcass composition such as reduced backfat. However, variation in the response to backfat has been reported as research has found both reductions (Herr et al., 2001; See et al., 2004) and no change (Armstrong et al., 2004; Armstrong et al., 2005; Kutzler et al., 2011) when comparing RAC or control fed pigs. This might be explained by rapid down-regulation of beta-adrenoceptor in

adipose tissue that may cause small or insignificant adipose tissue response to dietary RAC (Liu et al., 1994; Spurlock et al., 1994). In the current study, there was a reduction in backfat of pigs fed step-up RAC diet in Exp. 1, but no difference was observed for backfat among treatments in Exp. 2. For loin depth, there were increases observed for pigs fed step-up RAC treatment in Exp. 1, and pigs marketed on d 14 when fed the constant RAC diet compared with control pigs in Exp. 2 of the present studies. Herr et al. (2001) and Armstrong et al. (2005) reported that both step-up and constant RAC treatments had greater loin depth compared with the control. In addition, Armstrong et al. (2005) reported that the step-up feeding programs during 35 d resulted in greater loin depth than the constant treatment that had less total RAC intake. Also, greater loin depth was observed from pigs fed step-up feeding program compared with the constant treatment in Exp. 1. Because of the longer feeding period, total RAC intake of the step-up treatment in Exp. 1 was greater than that of the constant treatment, which may contribute to the improvement in loin depth of the step-up treatment. In Exp. 2 of current study, total RAC intake was similar among RAC feeding programs and, as a result, carcass traits were similar among RAC-fed pigs. Previous research observed that constant and step-up feeding programs had similar loin depth when having similar total RAC intake (Herr et al., 2001).

Because of the backfat and loin depth responses, pigs fed the step-up RAC feeding program in Exp. 1 had increased percentage lean and FFLI compared with the control and constant RAC fed pigs. Previous studies reported that both constant and step-up RAC feeding methods increased percentage lean with no differences between RAC feeding methods (Herr et al., 2001; See et al., 2004). Again, the difference in total RAC

intake in Exp. 1 may have attributed to the difference in carcass traits between the constant and step-up RAC treatments. Pigs had similar total RAC intake for constant and step-up feeding programs in the Herr et al. (2001) and See et al. (2004)'s studies. Also, in Exp. 2 of our study, percentage lean of all RAC-fed pigs were not different when pigs had similar total RAC intake.

The improvement in carcass traits (percent lean, backfat, and loin depth) found in Exp. 1, but not Exp. 2 also may have been partially attributed to differences in diet formulation between experiments. Several studies that found RAC-fed pigs to have similar percentage lean to pigs fed diets containing equal digestible lysine and energy to all pigs (Fernández-Dueñas et al., 2008; Kulzler et al., 2011). This supports our lack of carcass lean response for pigs fed RAC in Exp. 2 where all diets were formulated to contain 1.0% SID lysine. Previous study reported that increasing digestible lysine level in RAC diets from 0.51% to 1.06% linearly increased protein accretion (Webster et al., 2007). In Exp. 1 of current study, RAC diets were formulated to contain 0.95% SID lysine compared to control diet containing 0.70% SID lysine. This difference in Lys content may have contributed to the difference in percentage lean measured in Exp. 1. The difference in methods used in the two experiments demonstrate that although carcass traits may be influenced, growth responses and carcass weight advantages can be found using either diet formulation approach for control diets when conducting RAC studies.

In conclusion, regardless of feeding method, pigs fed diets containing RAC had improved growth performance compared with those fed the control diet. When fed for the same duration (Exp. 2), pigs fed the RAC step-up program had improved performance during the second half of the feeding period (d 14 to 28) and overall compared with a

constant RAC level. Refining the step-up further by increasing RAC level each day (curve) did not further improve performance.

LITERATURE CITED

Adeola, O., E. A. Darko, P. He and L. G. Young. 1990. Manipulation of porcine carcass composition by ractopamine. J. Anim. Sci. 68:3633-3641.

Apple, J. K., P. J. Rincker, F. K. McKeith, S. N. Carr, T. A. Armstrong and P. D. Mazat. 2007. Review: Meta-analysis of the ractopamine response in finishing swine. Prof. Anim. Sci. 23:179-196.

Armstrong, T. A., D. J. Ivers, J. R. Wagner, D. B. Anderson, W. C. Weldon and E. P. Berg. 2004. The effect of dietary ractopamine concentration and duration of feeding on growth performance, carcass characteristics, and meat quality of finishing pigs. J. Anim. Sci. 82:3245-3253.

Armstrong, T. A., B. T. Kremer, T. A. Marsteller and D. Mechler. 2005. Effects of ractopamine step-up use programs on finishing pigs fed under commercial conditions. Journal of Swine Health and Production 13:66-71.

Fernández-Dueñas, D. M., A. J. Myers, S. M. Scramlin, C. W. Parks, S. N. Carr, J. Killefer and F. K. McKeith. 2008. Carcass, meat quality, and sensory characteristics of heavy body weight pigs fed ractopamine hydrochloride (Paylean). J. Anim. Sci. 86:3544-3550.

Frobose, H.L., J. M. DeRouchey, D. Ryder, M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2011. The effects of feed budgeting, complete diet blending, and corn supplement blending on finishing pig growth performance in a commercial environment. Anim. Sci. 89 (E-Suppl. 2):206 (Abstr.).

Herr, C. T., A. P. Schinckel, L. E. Watkins, B. Weldon and B. T. Richert. 2001. Optimal Paylean sequence (step-up/step-down) when fed to late-finishing swine. http://www.ansc.purdue.edu/swine/swineday/sday01/7.pdf. Accessed Sept. 27, 2011.

Kelly, J. A., M. D. Tokach, S. S. Dritz. 2003. Weekly growth and carcass response to feeding ractopamine (Paylean®). Pages 51-58 in Proc. Am. Assoc. Swine Vet., Perry, IA.

Kutzler, L. W., S. F. Holmer, D. D. Boler, S. N. Carr, M. J. Ritter, C. W. Parks, F. K. McKeith and J. Killefer. 2011. Comparison of varying doses and durations of ractopamine hydrochloride on late-finishing pig carcass characteristics and meat quality. J. Anim. Sci. 89:2176-2188.

Liu, C. Y., A. L. Grant, K. H. Kim, S. Q. Ji, D. L. Hancock, D. B. Anderson and S. E. Mills. 1994. Limitations of ractopamine to affect adipose tissue metabolism in swine. J. Anim. Sci. 72:62-67.

Mills, S. E. 2002. Biological basis of the ractopamine response. J. Anim. Sci. 80:E28-E32.

National Pork Producers Council. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Counc., Des Moines, IA.

NRC. 1998. Nutrient Requirement of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

See, M. T., T. A. Armstrong and W. C. Weldon. 2004. Effect of a ractopamine feeding program on growth performance and carcass composition in finishing pigs. J. Anim. Sci. 82:2474-2480.

Spurlock, M. E., J. C. Cusumano, S. Q. Ji, D. B. Anderson, C. K. Smith, D. L. Hancock and S. E. Mills. 1994. The effect of ractopamine on beta-adrenoceptor density and affinity in porcine adipose and skeletal muscle tissue. J. Anim. Sci. 72:75-80.

Sulabo, R. C., G. Papadopoulos, J. R. Bergstrom, J. M. DeRouchey, D. Ryder, M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2010. Evaluation of feed budgeting, complete diet blending, and corn-supplement blending on finishing pig performance. J. Anim. Sci. 88 (Suppl. 3): (Abstr.).

Watkins, L. E., D. J. Jones, D. H. Mowrey, D. B. Anderson and E. L. Veenhuizen. 1990. The effect of various levels of ractopamine hydrochloride on the performance and carcass characteristics of finishing swine. J. Anim. Sci. 68:3588-3595.

Webster, M. J., R. D. Goodband, M. D. Tokach, J. L. Nelssen, S. S. Dritz J. A. Unruh, K. R. Brown, D. E. Real, J. M. DeRouchey, J. C. Woodworth, C. N. Groesbeck and T. A. Marsteller. 2007. Interactive effects between ractopamine HCl and dietary lysine on finishing pig growth performance, carcass characteristics, pork quality and tissue accretion. Prof. Anim. Sci. 23:597-611.

Williams, N. H., T. R. Cline, A. P. Schinckel and D. J. Jones. 1994. The impact of ractopamine, energy intake, and dietary fat on finisher pig growth performance and carcass merit. J. Anim. Sci. 72:3152-3162.

Table 1.1 Diet composition (as-fed basis, Exp. 1)

Item	Control	Ractopamine HCl[1]
Ingredient, %		
Corn	75.04	66.73
Soybean meal (46.5% CP)	11.19	19.36
Dried distillers grains with solubles	10.00	10.00
Choice white grease	2.00	2.00
Limestone	0.95	0.95
Salt	0.35	0.35
Vitamin and trace mineral premix[2]	0.10	0.10
L-Lys HCl	0.33	0.40
L-Thr	0.03	0.08
Phytase[3]	0.02	0.02
Total	100.0	100.0
Calculated analysis		
Standard ileal digestible (SID) amino acids, %		
Lys	0.70	0.95
Ile:lys	68	64
Leu:lys	187	158
Met:lys	33	28
Met & cys:lys	67	57
Thr:lys	65	65
Trp:lys	17	17
Val:lys	83	75
Total lys, %	0.81	1.08
ME, Mcal/kg	3.45	3.45
SID lysine:ME, g/Mcal	2.02	2.75
Ca, %	0.42	0.45
Available P, %	0.22	0.22

[1] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) 20 g/kg, replaced corn to provide: 5 mg/kg RAC for d 7 to 28 d (constant), 5 mg/kg RAC for d 0 to 14 and 7.5 mg/kg for d 14 to 26 (step-up).

[2] Provided per kg of complete diet: 4,509 IU vitamin A; 701 IU vitamin $D_{3;}$ 24 IU vitamin E; 1.4 mg vitamin K; 12 mg pantothenic acid; 18 mg niacin; 3 mg vitamin B_2 and 15 mg vitamin B_{12}, 40 mg Mn from manganese oxide, 90 mg Fe from iron sulfate, 100 mg Zn from zinc oxide, 10 mg Cu from copper sulfate, 0.5 mg I from Ethylenediamin dihydroiodide, and 0.3 mg Se from sodium selenite.

[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 0.12% available P.

Table 1.2 Composition of basal diet (as-fed basis, Exp. 2)[1]

Item	
Ingredient, %	
Corn	62.40
Soybean meal (46.5% CP)	20.60
Dried distillers grains with solubles	15.00
Limestone	1.03
Salt	0.35
Vitamin and trace mineral premix[2]	0.09
L-Thr	0.06
Biolys[3]	0.475
Phytase[4]	0.005
Total	100.00
Calculated analysis	
Standard ileal digestible (SID) amino acids, %	
Lys	1.00
Ile:lys	66
Leu:lys	164
Met:lys	29
Met & cys:lys	59
Thre:lys	65
Trp:lys	17.5
Val:lys	78
Total lys, %	1.14
ME, Mcal/kg	3.36
SID lysine:ME, g/Mcal	2.97
CP, %	19.4
Ca, %	0.48
Available P, %	0.21

[1] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) 20 g/kg, replaced corn to provide the control diet (no RAC), 7.5 mg/kg RAC for 26 d (constant), 5 mg/kg RAC for d 0 to 14 and 10 mg/kg for d 14 to 26 (step-up), and RAC concentration increased daily from 5 mg/kg on d 0 to 10 mg/kg on 26 d (curve).

[2] Provided per kg of complete diet: 4,509 IU vitamin A; 701 IU vitamin $D_{3;}$ 24 IU vitamin E; 1.4 mg vitamin K; 12 mg pantothenic acid; 18 mg niacin; 3 mg vitamin B_2 and 15 mg vitamin B_{12}, 40 mg Mn from manganese oxide, 90 mg Fe from iron sulfate, 100 mg Zn from zinc oxide, 10 mg Cu from copper sulfate, 0.5 mg I from Ethylenediamin dihydroiodide, and 0.3 mg Se from sodium selenite.

[3] Biolys contains 50.7% L-lys.

[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 0.12% available P.

Table 1.3 Effect of ractopamine HCl feeding program on growth performance of finishing pigs (Exp. 1)[1]

	Feeding program[2]			
Item	Control	Constant	Step-up	SEM
d 0 to 7				
ADG, kg	0.91[a]	0.97[a]	1.13[b]	0.029
ADFI, kg	2.77[a]	2.74[a]	2.91[b]	0.047
G:F	0.328[a]	0.354[b]	0.389[c]	0.0088
d 7 to 14				
ADG, kg	0.85[a]	1.12[b]	1.01[c]	0.023
ADFI, kg	2.79[a]	2.82[a]	2.55[b]	0.046
G:F	0.306[a]	0.398[b]	0.399[b]	0.0084
d 0 to 14				
ADG, kg	0.88[a]	1.05[b]	1.07[b]	0.016
ADFI, kg	2.78	2.78	2.73	0.041
G:F	0.317[a]	0.376[b]	0.394[c]	0.0039
d 14 to 28				
ADG, kg	0.70[a]	0.84[b]	0.77[c]	0.020
ADFI, kg	2.59[a]	2.56[a]	2.44[b]	0.039
G:F	0.271[a]	0.329[b]	0.315[b]	0.0057
d 7 to 28				
ADG, kg	0.76[a]	0.94[b]	0.86[c]	0.016
ADFI, kg	2.66[a]	2.65[a]	2.48[b]	0.039
G:F	0.284[a]	0.356[b]	0.347[b]	0.0049
d 0 to 28				
ADG, kg	0.80[a]	0.95[b]	0.93[b]	0.015
ADFI, kg	2.69	2.68	2.60	0.037
G:F	0.296[a]	0.356[b]	0.359[b]	0.0038
BW, kg[3]				
d 0	94.4	94.4	94.4	1.64
d 7	100.8	101.1	102.5	1.62
d 14 (before topping)	106.7	109.0	109.7	1.65
d 14 (top pigs)	120.5	122.9	123.4	1.31
d 14 (after topping)	104.9	107.2	107.9	1.74
d 21	110.2	113.9	114.1	1.69
d 28	114.8	119.0	118.7	1.81
RAC intake[4], mg/d	0	9.96[a]	16.04[b]	0.173

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

[1] A total of 1,099 pigs (PIC 337 × C22, Hendersonville, TN, initially 94.4 kg BW) were used with 26 pigs per pen and 14 pens per treatment.

[2] Control = no RAC for 28 d; Constant = no RAC on d 0 to 7 and 5 mg/kg RAC on d 7 to 28; and Step-up = 5 mg/kg RAC on d 0 to 14 and 7.5 mg/kg RAC on d 14 to 28.

[3] BW was obtained at research farm before shipping to processor.

[4] RAC intake was calculated based on ADFI and RAC concentration of each week.

Table 1.4 Effect of ractopamine HCl feeding program on carcass traits of finishing pigs (Exp. 1)[1]

	Feeding program[2]			
Item	Control	Constant	Step-up	SEM
HCW, kg	87.0[a]	91.6[b]	90.4[b]	1.50
Yield, %	75.4	76.1	76.0	0.33
Lean[3], %	55.1[a]	55.8[a]	57.1[b]	0.40
Loin depth[3], cm	5.97[a]	6.30[a]	6.54[b]	0.122
Backfat[3], cm	1.71[a]	1.74[a]	1.58[b]	0.054
Fat-free lean index[3]	50.0[a]	50.2[a]	50.9[b]	0.24

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

[1] A total of 690 pigs (PIC 337 × C22, Hendersonville, TN, initially 94.4 kg BW) were used for obtaining carcass data.

[2] Control = no RAC for 28 d; Constant = no RAC on d 0 to 7 and 5 mg/kg RAC on d 7 to 28; and Step-up = 5 mg/kg RAC on d 0 to 14 and 7.5 mg/kg RAC on d 14 to 28.

[3] Values are adjusted to a common HCW.

Table 1.5 Effect of ractopamine HCl feeding program on growth performance of finishing pigs (Exp. 2)[1]

	Feeding program[2]				
Item	Control	Constant	Step-up	Curve	SEM
d 0 to14					
ADG, kg	0.83[a]	1.06[b]	1.08[b]	1.09[b]	0.027
ADFI, kg	2.45[a]	2.60[b]	2.61[b]	2.49[ab]	0.049
G:F	0.339[a]	0.408[b]	0.417[b]	0.437[b]	0.0115
RAC intake[3], mg/d	0	19.5[a]	13.0[b]	15.5[c]	0.28
d 14 to 26					
ADG, kg	0.89[a]	1.00[b]	1.16[c]	1.09[bc]	0.320
ADFI, kg	2.97	2.79	2.84	2.93	0.067
G:F	0.299[a]	0.358[b]	0.410[c]	0.372[b]	0.0122
RAC intake, mg/d	0	20.9[a]	28.5[b]	25.6[c]	0.56
d 0 to 26					
ADG, kg	0.85[a]	1.04[b]	1.11[c]	1.09[bc]	0.019
ADFI, kg	2.63	2.67	2.69	2.64	0.047
G:F	0.324[a]	0.389[b]	0.416[c]	0.413[bc]	0.0078
RAC intake, mg/d	0	20.2[a]	20.2[a]	20.1[a]	0.34
BW[4], kg					
d 0	109.0	109.1	109.1	109.1	1.13
d 14 (before topping)	120.7[a]	123.9[b]	124.2[b]	124.4[b]	1.08
d 26	126.1[a]	131.1[b]	133.8[b]	132.9[b]	1.34

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

[1] A total of 934 pigs (PIC 337 × 1050, Hendersonville, TN, initially 109 kg BW) were used with 22 to 24 pigs per pen and 10 pens per treatment. Nine pigs were marketed per pen on d 14 of the experiment.

[2] Control = no RAC for 26 d; Constant = 7.5 mg/kg RAC for 26 d; Step-up = 5 mg/kg RAC from d 0 to 14 and 10 mg/kg from d 14 to 26; Curve = RAC concentration increased daily from 5 mg/kg on d 0 to 10 mg/kg on 26 d by using the FEEDPro system.

[3] RAC intake was calculated based on ADFI and dietary RAC concentrations.

[4] BW was obtained at research farm before shipping to processor.

Table 1.6 Effect of ractopamine HCl feeding program on carcass traits of finishing pigs (Exp. 2)[1]

	Feeding program[2]				
Item	Control	Constant	Step-up	Curve	SEM
d 14 marketing					
Live wt[3], kg	123.0	126.0	124.9	125.6	1.05
HCW, kg	91.4[a]	94.7[b]	93.5[b]	94.0[b]	0.79
Yield[4], %	74.4[a]	75.1[b]	74.9[ab]	74.8[ab]	0.25
Backfat[5], cm	1.70	1.69	1.74	1.68	0.044
Loin depth[5], cm	5.58[a]	6.06[b]	5.68[ab]	5.70[ab]	0.143
Lean[5], %	55.2	55.8	55.0	55.5	0.35
d 26 marketing[6]					
Live wt[3], kg	122.3[a]	127.1[b]	127.7[b]	127.6[b]	1.15
HCW, kg	90.8[a]	95.9[b]	95.4[b]	95.4[b]	1.00
Yield[4], %	74.3[a]	75.4[b]	74.7[ab]	74.8[ab]	0.31
Backfat[5], cm	1.59	1.45	1.52	1.55	0.055
Loin depth[5], cm	6.49	6.53	6.52	6.72	0.093
Lean[5], %	56.9	57.0	56.7	57.0	0.58
Combined marketing data[7]					
Live wt[3], kg	122.6[a]	126.7[b]	126.6[b]	126.8[b]	0.97
HCW, kg	91.1[a]	95.4[b]	94.7[b]	94.9[b]	0.81
Yield[4], %	74.3[a]	75.3[b]	74.8[ab]	74.8[ab]	0.22
Backfat[5], cm	1.63	1.55	1.61	1.61	0.037
Loin depth[5], cm	6.15	6.33	6.18	6.32	0.093
Lean[5], %	56.3	56.5	56.0	56.4	0.37

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

[1] A total of 904 pigs (PIC 337 × 1050, Hendersonville, TN, initially 109 kg BW) were used for obtaining carcass data.

[2] Control = no RAC for 26 d; Constant = 7.5 mg/kg RAC for 26 d; Step-up = 5 mg/kg RAC for d 0 to 14 and 10 mg/kg for d 14 to 26; Curve = RAC concentration increased daily from 5 mg/kg on d 0 to 10 mg/kg on 26 d by using the FEEDPro system.

[3] Live wt was obtained at packing plant.

[4] Percentage yield was calculated by dividing HCW by live wt obtained at the packing plant.

[5] Values are adjusted to a common carcass weight.

[6] All pigs were marketed, except 14 cull or light pigs that included 4 pigs from control treatment, 5 pigs from RAC constant treatment, 3 pigs from RAC step-up treatment and 2 pigs from RAC curve treatment.

[7] Overall marketing data combines data from marketing group on d 14 and d 26.

Chapter 2 - Effects of Dietary L-Carnitine and Dried Distillers Grains with Solubles on Growth, Carcass Characteristics, and Loin and Fat Quality of Growing-Finishing Pigs

ABSTRACT

A total of 1,104 barrows and gilts (PIC 337 × 1050, initially 36 ± 0.5 kg) were used in a 109-d study to evaluate effects of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on growth, carcass traits, and loin and fat quality. Pigs were blocked by BW and randomly assigned to 1 of 6 treatments with 7 pens per treatment. Treatments were arranged as a 2 × 3 factorial with main effects of DDGS (0 or 30% in Phases 1, 2, and 3 and 20% in Phase 4) and L-Carnitine (0, 50, or 100 mg/kg). Overall (d 0 to 109), dietary L-Carnitine tended to improve (linear, $P < 0.07$) ADG. For G:F, a DDGS × L-Carnitine interaction (quadratic, $P < 0.01$) was observed. This was the result of pigs fed 50 mg/kg L-Carnitine, with no DDGS having better G:F than pigs fed 0 or 100 mg/kg, but in diets containing DDGS, pigs fed 50 mg/kg L-Carnitine had worse G:F compared with those fed 0 or 100 mg/kg. For carcass characteristics, no DDGS × L-Carnitine interactions were observed for any carcass traits. Pigs fed increasing dietary L-Carnitine had increased HCW (quadratic, $P < 0.03$), carcass yield (quadratic, $P < 0.07$), and backfat (quadratic, $P < 0.04$), with the greatest response observed in pigs fed 50 mg/kg dietary L-Carnitine. For loin quality traits, feeding dietary L-Carnitine increased (linear, $P < 0.03$) loin purge loss. Feeding dietary DDGS tended ($P < 0.06$) to decrease visual marbling score of loins. There were DDGS × L-Carnitine interactions for Warner-Bratzler Shear Force (WBSF; quadratic, $P < 0.01$) and loin color (linear, $P < 0.03$). Loins

from pigs fed 50 mg/kg L-Carnitine with DDGS had a lower WBSF value compared with either 0 or 100 mg/kg; however, loins from pigs fed no DDGS changed little regardless of L-Carnitine level. Increasing L-Carnitine in DDGS diets increased visual loin color, but pigs not fed DDGS had similar visual color. In jowl fatty acid profile, as expected, feeding DDGS increased ($P < 0.001$) C18:2n-6 and iodine value. A DDGS × L-Carnitine interaction was observed for C18:2n-6 (linear, $P < 0.03$) and C20:2 (linear, $P < 0.04$). The level of C18:2n-6 and C20:2 were decreased with increasing L-Carnitine in DDGS containing diets, but not in diets without DDGS. Feeding L-Carnitine did not alter iodine value. In conclusion, dietary DDGS did not affect growth but led to more unsaturation of jowl fat. Feeding dietary L-Carnitine improved HCW and reduced C18:2n-6 in jowl fat when fed in DDGS containing diets, with the responses maximized at 50 mg/kg.

Key words: carcass, DDGS, fatty acid, finishing pigs, iodine value, L-Carnitine, loin

INTRODUCTION

The primary role of carnitine in intermediary metabolism is tightly related to the β-oxidation of fatty acids (Borum, 1983). It has been well documented that carnitine has an important function in transporting long-chain fatty acids into the mitochondrial matrix for subsequent β-oxidation (McGarry and Brown, 1997). Dietary L-Carnitine inclusion to swine diets stimulates fatty acid oxidation and the utilization of fat for energy (Heo et al., 2000a; Owen et al., 2001a). Previous research suggested that feeding dietary L-Carnitine decreased lipid deposition and increased protein accretion of nursery or growing-finishing pigs (Heo et al., 2000b; Owen et al., 2001b).

Dried distillers grains with solubles (DDGS) is currently a common ingredient in swine diets; however, it can have negative effects on carcass fat quality because DDGS contains 10 to 11% fat, a high proportion of which is polyunsaturated fatty acids (Stein and Shurson, 2009). Feeding ingredient such as DDGS containing high concentrations of unsaturated fatty acids causes increased unsaturated fatty acid composition and iodine value of carcass fat (Xu et al., 2010b; Benz et al., 2011). A recent study evaluating belly composition reported that pigs fed diets containing corn oil and 100 mg/kg L-Carnitine had decreased C18:2n-6 concentration of lean and iodine value of the intermuscular fat layer (Apple et al., 2011) compared to those not fed L-Carnitine. Therefore, it was theorized that dietary L-Carnitine may also increase carcass fat saturation in pigs fed DDGS.

Therefore, the objective of this study was to investigate the effects of dietary L-Carnitine and DDGS on growth performance, carcass characteristics, and fat and loin quality of finishing pigs.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the procedures used in this study.

General

The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. The barn was double-curtain-sided and naturally ventilated. Each pen (3 m × 5.5 m) had completely slatted flooring over a deep pit for manure storage. Each pen was equipped with a 5-hole stainless steel, dry self-feeder and cup waterer for ad libitum access to feed and water. The barn had an automated feeding system (FEEDPro; Feedlogic Corp., Willmar, MN) that was capable of delivering and measuring feed amounts added on an individual pen basis.

Animals and Diets

A total of 1,104 barrows and gilts (PIC 337 × 1050, initially 36 ± 0.5 kg BW) were used in a 109-d study with 26 pigs per pen and 7 pens per treatment in a randomized design. Pigs were housed mixed gender within pen. Pens were ranked by average pig weight then allotted randomly to 1 of 6 dietary treatments. Dietary treatments were corn-soybean meal-based diets and were fed in 4 phases. Treatments were arranged as a 2 × 3 factorial with main effects of added DDGS (0 or 30% in Phases 1, 2, and 3 and 20% in Phase 4) and L-Carnitine (0, 50, or 100 mg/kg). All diets were fed in meal form and

balanced to the same standardized ileal digestible (SID) lysine:ME ratio within each phase (Table 1). Diets were formulated to meet or exceed all requirement estimates suggested by NRC (1998). For both DDGS the NRC (1998) ME value of corn (3,420 kcal/kg) was used in diet formulation. Pedersen et al. (2007) reported that DDGS has the same energy value as corn and the DDGS nutrient composition and digestibility values used in diet formulation were determined by Stein et al. (2006) and Pedersen et al. (2007). Pigs from each pen were weighed as a group and feed disappearance was determined every 2 wk to determine ADG, ADFI, and G:F.

Loin and Jowl Fat Collection and Analysis

On d 83 of the experiment, the 3 heaviest pigs were removed from each pen (determined visually) and sold in accordance with the farm's normal marketing procedure. These pigs were not included in carcass data analysis but were included in the growth portion of the trial. On d 97 of the experiment, 1 barrow and 1 gilt were randomly selected from each pen, tattooed according to gender and pen number and transported approximately 1 h to a commercial packing plant (Sioux-Preme Packing Co., Sioux Center, IA) for collection of jowl fat and whole loins.

After slaughter, the whole boneless loins and approximately 250 g of jowl were collected from the right side of each carcass. The whole loins were individually vacuum-packaged, and each jowl sample was packaged in a sealable plastic bag. After packaging, all loins and jowl samples were stored in the cooler containing ice and transported approximately 5 h and stored at the K-State Meat Laboratory at 0 to 4 ℃.

On d 11 postmortem, loin quality (purge loss, drip loss, shear force, pH, color, and marbling) was evaluated at K-State Meat Laboratory. Purge loss was measured by

weighing the whole loin in the packaging bag, removing the loin and blotting it dry, and reweighing the loin and dried packaging bag. Percentage purge loss was calculated as 100 ×(initial loin weight – packaging bag weight – final loin weight) / (initial loin weight – packaging bag weight). After measuring purge loss, several 2.54-cm. center-cut chops were obtained from each loin. The pH was determined using a pH Meter (Model HI9025, HANNA Instruments, Woonsocket, RI). Objective measures of chop color were determined using a HunterLab Miniscan^{TM} XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10˚ standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA) and reported as Commission International d'Eclairage (CIE) L^* (lightness, black = 0 to white = 100), CIE a^* (redness, a larger positive value indicates a more red color), and CIE b^* (yellowness, a larger positive value indicates a more yellow color). Visual color and marbling were evaluated by using the National Pork Producers Council's color and marbling standards (NPPC, 2000).

One chop from each loin was weighed and placed in a plastic bag and sealed immediately following fabrication. After storage at 0 to 4 ℃ for 24 h, each chop was removed from bag, blotted dry with paper towels, and reweighed to measure percentage drip loss.

Chops for Warner-Bratzler Shear Force (WBSF) were frozen (-40 ℃) on d 11 postmortem. Chops were thawed at 0 to 4 ℃ for approximately 24 h then cooked in a Blodgett oven (model number DFC-102, The G.S. Blodgett Co., Burlington, VT) preheated to 163 ℃. When chops reached 40 ℃, they were turned, and cooked to a final internal temperature of 70 ℃ in Chop temperatures were monitored with thermocouple wires (30-gauge copper and constantan, Omega Engineering; Stamford, CT) inserted into

the approximate geometric center of each chop and attached to a Doric temperature recorder (model 205; Vas Engineering; San Francisco, CA). The chops were then covered with plastic wrap and refrigerated at 3 to 4 ℃ for 24 h. Six round cores (1.27-cm diameter) were obtained from each chop parallel to the long axis of the muscle fibers using a 1.27-cm corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8-in. Electric Drill, Sears, Hoffman Estates, IL). Each core was sheared once perpendicular to the direction of the muscle fibers using a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a 50-kg compression load cell and a crosshead speed of 250 mm/min. Peak shear force values were recorded in kilograms and the values from the cores were averaged for statistical analysis.

Jowl fat samples were thawed and dissected to separate adipose tissue from skin and lean tissue. All fat tissues were cut and then frozen in a bath of liquid N_2, and then ground into fine particles by a blender (Dynamics Corporation of America, New Hartford, CT). Approximately 50 μg ground fat sample were weighed into a tube and mixed with 3 mL of methanolic-HCl and 2 mL of internal standard [2 mg/mL of methyl Heptadecanoic acid (C17:0) in benzene] and then heated in a water bath for 120 min at 70 ℃ for transmethylation. After cooling, 2 mL of benzene and 3 mL of K_2CO_3 were added to extract and transfer methyl esters into a vial for subsequent quantification of the methylated fatty acids by gas chromatography.

Iodine value was calculated from the following equation (AOCS, 1998):

Iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 +[C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723.

The fatty acids results are represented as a percentage of the total fatty acids in the sample.

Carcass Characteristics

At the end of the experiment (d 109), the rest of pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Pigs were transported approximately 96 km to a packing plant (JBS Swift and Company, Worthington, MN) for processing and data collection of HCW, backfat thickness and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant. These carcass measurements were collected with pen as the experimental unit.

Statistical Analysis

Analysis of variance was performed by using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). All data were analyzed as a completely randomized design with pen as the experimental unit. Backfat, loin depth, and percentage lean were adjusted to a common HCW. The main effects of DDGS, L-Carnitine, and DDGS × L-Carnitine interactions were tested. In addition, within L-Carnitine concentration, linear and quadratic contrasts were evaluated. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Growth and Carcass

From d 0 to 55, pigs fed dietary L-Carnitine tended to have improved (linear, $P < 0.06$) ADG (Table 2). A DDGS × L-Carnitine interaction (linear, $P < 0.05$) was observed for G:F. Pigs fed increasing L-Carnitine without dietary DDGS had similar G:F to the control, but G:F worsened in the presence of DDGS when fed 50 mg/kg and improved when 100 mg/kg was fed. Additionally, ADFI was increased (quadratic, $P < 0.05$) in pigs fed increasing L-Carnitine. Pigs fed DDGS had worse ($P < 0.03$) G:F than those fed no DDGS.

From d 55 to 109, pigs fed dietary L-Carnitine tended (quadratic, $P < 0.09$) to have greater ADG, with the greatest response observed at 50 mg/kg L-Carnitine. A DDGS × L-Carnitine interaction (quadratic, $P < 0.01$) was observed for G:F during this period. This was due to pigs fed 50 mg/kg dietary L-Carnitine having the best G:F in diets with no DDGS, but pigs fed DDGS diets had similar G:F regardless of dietary L-Carnitine level.

Overall (d 0 to 109), feeding dietary L-Carnitine tended to improve (linear, $P < 0.07$) ADG, which resulted in greater (linear, $P < 0.07$) final BW. For G:F, a DDGS × L-Carnitine interaction (quadratic, $P < 0.01$) was observed. This was the result of pigs fed 50 mg/kg L-Carnitine with no dietary DDGS having better feed efficiency than pigs fed 0 or 100 mg/kg, but in diets containing DDGS pigs fed diets containing 50 mg/kg L-Carnitine had worse G:F compared with those fed 0 or 100 mg/kg. Finally, the inclusion of DDGS did not affect growth performance.

For carcass characteristics, no DDGS × L-Carnitine interactions were observed for any carcass traits (Table 3). Pigs fed dietary L-Carnitine had greater (quadratic, $P < 0.03$) HCW, with the greatest response observed from pigs fed 50 mg/kg dietary L-Carnitine. Also, increasing the dietary level of L-Carnitine increased backfat (quadratic, $P < 0.04$) and tended to increase carcass yield (quadratic, $P < 0.07$), with the greatest response observed from pigs fed 50 mg/kg dietary L-Carnitine. Pigs fed diets with DDGS tended ($P < 0.09$) to have less loin depth compared with pigs fed no dietary DDGS but did not affect other carcass measurements.

Loin and Jowl Fat Quality

For loin quality, increasing dietary L-Carnitine increased (linear, $P < 0.03$) purge loss (Table 4). There were DDGS × L-Carnitine interactions for WBSF (quadratic, $P < 0.01$) and visual color (linear, $P < 0.03$). Loins from pigs fed 50 mg/kg L-Carnitine with DDGS had a lower WBSF value compared with either 0 or 100 mg/kg with DDGS; however, loins from pigs fed no DDGS changed very little regardless of L-Carnitine level. Pigs fed DDGS diets containing increasing dietary L-Carnitine had increased visual loin color, but pigs not fed DDGS had similar visual loin color regardless of L-Carnitine level. Feeding dietary DDGS tended ($P < 0.06$) to decrease visual loin marbling score compared with pigs fed no DDGS. A trend (quadratic, $P < 0.09$) for a DDGS × L-Carnitine interaction was observed for CIE b^* value (degree of yellowness). Loins obtained from pigs fed 50 mg/kg L-Carnitine with no DDGS had the greatest CIE b^* value, but this same L-Carnitine level had the lowest CIE b^* value when fed with dietary DDGS.

For jowl fatty acid characteristics, Pigs fed 50 mg/kg dietary L-Carnitine had less (quadratic, $P < 0.02$) contents of C17:0 and total trans fatty acids compared with pigs fed 0 or 100 mg/kg L-Carnitine. In addition, the proportion of C20:0 tended (linear, $P < 0.07$) to be increased when increasing inclusion of L-Carnitine. A DDGS × L-Carnitine interaction was observed for proportions of C18:2n-6 (linear, $P < 0.03$) and C20:2 (linear, $P < 0.04$). The level of C18:2n-6 and C20:2 were decreased with the addition of L-Carnitine in DDGS diets, but this was not seen in diets without DDGS with increasing dietary L-Carnitine. However, the iodine value and total polyunsaturated fatty acids (PUFA) content of jowl fat were not affected by feeding dietary L-Carnitine. Feeding dietary DDGS increased ($P < 0.001$) the proportions of C18:2n-6, C18:3n-3, C20:2, C20:4n-6, PUFA, total trans fatty acids, and the ratio of unsaturated fatty acids to SFA and the calculated IV. In addition, pigs fed DDGS had decreased ($P < 0.001$) concentrations of C14:0, C16:0, C16:1, C18:0, C18:1 *cis*-9, C18:1n-7, total monounsaturated fatty acids, and total SFA compared with those not fed DDGS (Table 5).

DISCUSSION

Growth Performance

Researchers have reported that endogenous carnitine is synthesized in sufficient quantity to support growth performance of finishing pigs (Rebouche and Seim, 1998). However, in the present study an improvement in ADG was observed from addition of L-Carnitine in both the grower and finishing periods which resulted in an overall effect as well. James et al. (2002c, d) observed that late-finishing pigs fed diets containing 50

mg/kg L-Carnitine during the last 3 to 4 wk before slaughter had improved growth performance when pigs were reared in a commercial facility. This is in contrast to past studies where inclusion of L-Carnitine inclusion had no effects on ADG of growing-finishing pigs (Owen et al., 2001a; Owen et al., 2001b; Smith et al., 1996). The differing responses may be attributed to location of the research studies. Most of the past research was conducted in university facilities, but the current study was conducted in a commercial facility. Due to some environmental factors, pigs reared in commercial facilities typically have lower feed intake compared with pigs reared in university facilities (De la Llata et al., 2001). Consequently, lower feed intake causes less energy intake, which can result in pigs failing to meet the energy requirement for maximum growth. Heo et al. (2000b) suggested that supplemental L-Carnitine increased β-oxidation of fatty acids and maintained protein synthesis of growing pigs when limited in digestible energy intake.

Previous research reported that 50 mg/kg L-Carnitine supplementation into corn-soybean meal based diet improved G:F of finishing pigs (James et al., 2002c). There was a DDGS × L-Carnitine interaction observed for G:F in the current study. Adding 50 mg/kg L-Carnitine to the corn-soybean meal based diet improved G:F, which agrees with the previous observations (James et al., 2002c). However, the reason that G:F became worse when adding 50 mg/kg L-Carnitine into DDGS diet is unknown.

L-Carnitine has also been evaluated in diets during the nursery phase when feed intake can limit maximum growth performance. Rincker et al. (2003) conducted 5 experiments and summarized that most of the benefits from dietary L-Carnitine on growth performance of nursery pigs were observed during the period from 2 to 5 wk after

weaning when no added animal protein sources were included in the diet. Also, Owen et al. (1996) found nursery pigs fed L-Carnitine had improved G:F when fed diets containing 1000 mg/kg L-Canitine for 14 d post-weaning, but ADG was not influenced. This could be potentially due to insufficient endogenous carnitine synthesized (Borum, 1983), which resulted in supplemental carnitine improving growth of young pigs. Therefore, L-Carnitine supplementation may aid in supplying available energy when insufficient endogenous carnitine is produced or energy intake is not sufficient to meet normal growth.

In the current study, dietary DDGS inclusion did not affect overall growth performance. This is consistent with other research as in a review article levels up to 30% (Stein and Shurson, 2009) did not affect groth performance. Also, more recently 45% dietary DDGS had no effects on growth performance of growing-finishing pigs (Cromwell et al., 2011). However, other research has shown negative effects when feeding DDGS to finishing pigs. Whitney et al. (2006) reported that pigs fed up to 30% DDGS had decreased ADG and G:F when diets were formulated on a total lysine basis. However, since our better understanding of the SID values for AA in DDGS, growth performance is very similar to corn-based diets.

Carcass Characteristics

Past research indicated that feeding supplemental L-Carnitine reduced backfat and increased lean percent of finishing pigs (Owen et al., 2001a; Owen et al., 2001b). Heo et al. (2000a) reported that dietary L-Carnitine increased the activity of carnitine palmitoyltransferase-I in muscle and liver of growing pigs. Carnitine palmitoyltransferase-I is considered a key enzyme in regulating fatty acid oxidation

(McGarry and Brown, 1997), which may cause a reduction in backfat development in finshing pigs. However, other experiments reported that dietary L-Carnitine had no effects on backfat and loin depth (James et al., 2002c; James et al., 2002d; Bertol et al., 2005) as in our study. This inconsistency may be due to the difference in final BW of pigs. The final BW (> 110 kg) of pigs used in this study was greater than that (103 kg) of the pigs used in the Owen et al. (2001a, b) studies. Heavier pigs in the current study may have greater lipid accretion rate and decrease lean tissue deposition. In addition, Owen et al. (2001a) observed that dietary L-Carnitine resulted in greater rates of palmitate oxidation, more rapid flux through pyruvate carboxylase and reduced flux through branched-chain α-keto acid dehydrogenase, which suggested that more fat was metabolized and used for energy. Heo et al. (2000b) suggested that 500 mg/kg L-Carnitine supplementation improved protein synthesis when limited in ME intake, but lipid accretion of growing pigs was not affected. Owen et al. (1996) reported that nursery pigs fed 1000 mg/kg L-Carnitine for 14 d post-weaning had less carcass lipid accretion on d 35 post-weaning (d 35 BW = 20 kg).

For carcass traits, dietary DDGS did not influence the measurements in this study. Stein and Shurson (2009) summarized that dietary corn DDGS had no effects on carcass measurement including HCW, backfat, loin depth and percentage lean in most of past research. Some studies observed that pigs fed DDGS diets had reduced dressing percentage (Whitney et al., 2006; Xu et al., 2010b); however, there was no effect of dietary corn DDGS on dressing percentage from other experiments (Xu et al., 2010a; Cromwell et al., 2011) as well as in the present study. This might be explained by other research demonstrating that reducing or withdrawing DDGS from diet for a period of

time prior to marketing, mitigated the decrease in carcass yield compared to pigs fed a constant level to marketing (Jacela et al., 2009). In our study the level of DDGS was reduced from 30 to 20% for the last dietary phase.

Loin Characteristics

The results of the current study showed that dietary L-Carnitine increased purge loss of LM, which means less water holding capacity and may negatively affect sensory traits including juiciness, flavor and tenderness (Huff-Lonergan and Lonergan, 2005). Purge loss is a concern of packers as product yield at the plant may be reduced prior to carcass or product shipping from the processing plant. Also, purge loss negatively affects retailers by lowering the amount of saleable product due to water loss in the packaging itself. However, another indicator of water holding capacity of LM measured on d 11 postmortem, drip loss, was not affected by feeding dietary L-Carnitine in our study. In contrast to the present data, James et al. (2002b) reported that dietary L-Carnitine supplementation decreased drip loss when being measured at 24-h postmortem. Low pH of LM may be related to development of low water holding capacity (Huff-Lonergan and Lonergan, 2005). There was an increase pH of LM postmortem observed from feeding L-Carnitine in James et al. (2002b)'s study, while no difference was observed for pH of LM among treatments in the current study. While water holding capacity measurements of pH and drip loss were no influenced in the present study, the increase in loin purge loss may be attributed to the higher HCW for pigs fed L-Carnitine, in which a heavier carcass chills more slowly post-harvest due to the larger overall mass.

The present data indicated that L-Carnitine supplementation did not influence color and marbling scores, which were consistent with the results of previous studies (James et al., 2002a; James et al., 2002d; Smith et al., 1996).

Dietary DDGS numerically decrease longissimus (LM) marbling scores in the present study, which means less intramuscular fat within the LM of pigs fed DDGS. Xu et al. (2010b) reported that the LM marbling score was linearly decreased with increasing DDGS inclusion. However, some studies suggested that dietary DDGS did not affect the LM marbling scores (Whitney et al., 2006; Xu et al., 2010a; Yoon et al., 2010).

Fatty Acid Composition of Jowl Fat

Because DDGS contains approximately 10% fat, most of which are unsaturated fatty acids, carcass fat composition is altered as well. Past research consistently observed that dietary DDGS inclusion to the diet increased PUFA resulting in increased carcass fat iodine value (Stein and Shurson, 2009), which are indicative of soft carcass fat and rancidity. In the present study, feeding dietary DDGS resulted in decreased amounts of most of SFA and MUFA and increased PUFA in jowl fat. Particularly, the content of C18:2n-6 was increased by about 3.5% when pigs were fed DDGS. The C18:2n-6 proportion of total fatty acids of DDGS is more than 50%, which may directly result in increased content of C18:2n-6 in jowl fat (Benz et al., 2010; Benz et al., 2011). As expected, iodine value of jowl fat was increased when feeding dietary DDGS in the current study, which was in agreement with previous research (Stein and Shurson, 2009; Benz et al., 2010; Benz et al., 2011). In the current study, dietary L-Carnitine decreased contents of C18:2n-6 and C20:2 in jowl fat of pigs fed DDGS. In a study evaluating belly fat and lean composition, Apple et al. (2011) observed that the inclusion of 100 mg/kg L-

Carnitine increased the contents of C18:1 *cis*-9, all MUFA and decreased C18:2n-6 concentration of lean layers of pork belly when pigs fed diets containing corn oil. They also reported that the C18:2n-6 level and iodine value of the intermuscular fat layer of pork bellies decreased when pigs were fed 100 mg/kg of L-Carnitine. Carnitine palmitoyltransferase-I is considered as a rate-limiting enzyme for transporting long-chain fatty acid into the mitochondria and oxidation (McGarry and Brown, 1997). Heo et al. (2000a) suggested that supplemental L-Carnitine increased the activity of carnitine palmitoyltransferase-I in muscle and liver of growing pigs. Therefore, it may explain the decreased concentrations of C18:2n-6 in this study and that of Apple et al. (2011) for pigs fed L-Carnitine.

In conclusion, dietary DDGS did not affect the growth performance and, as expected, led to more unsaturation of jowl fat, which led to increased IV. Pigs fed dietary L-Carnitine tended to or had significantly improved ADG and HCW, and reduced C18:2n-6 in jowl fat when fed in DDGS containing diets, with the responses maximized at 50 mg/kg. These findings along with data from Apple et al. (2011) suggest that dietary L-Carnitine can decrease C18:2n-6 in carcass fat when fed in diets containing ingredients high in unsaturated fatty acids.

CITED LITERATURES

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. 5th ed. Am. Oil Chem. Soc., Champaign, IL.

Apple, J. K., J. T. Sawyer, C. V. Maxwell, J. W. S. Yancey, J. W. Frank, J. C. Woodworth, and R. E. Musser. 2011. Effects of L-carnitine supplementation on quality characteristics of fresh pork bellies from pigs fed 3 levels of corn oil. J. Anim. Sci. 89:2878-2891.

Benz, J. M., S. K. Linneen, M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M. DeRouchey, R. D. Goodband, R. C. Sulabo and K. J. Prusa. 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. J. Anim. Sci. 88:3666-3682.

Benz, J. M., M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M. Derouchey, R. C. Sulabo and R. D. Goodband. 2011. Effects of dietary iodine value product on growth performance and carcass fat quality of finishing pigs. J. Anim. Sci. 89:1419-1428.

Bertol, T. M., M. Ellis, D. N. Hamilton and M. J. Ritter. 2005. Effects of dietary supplementation with L-Carnitine and fat on blood acid-base responses to handling in slaughter weight pigs. J. Anim. Sci. 83:75-81.

Borum, P. R. 1983. Carnitine. Annu. Rev. Nutr. 3:233-259.

Cromwell, G. L., M. J. Azain, O. Adeola, S. K. Baidoo, S. D. Carter, T. D. Crenshaw, S. W. Kim, D. C. Mahan, P. S. Miller and M. C. Shannon. 2011. Corn distillers dried grains with solubles in diets for growing-finishing pigs: a cooperative study. J. Anim. Sci. 89:2801-2811.

De la Llata, M., S. S. Dritz, M. D. Tokach, R. D. Goodband, J. L. Nelssen and T. M. Loughin. 2001. Effects of dietary fat on growth performance and carcass characteristics of growing-finishing pigs reared in a commercial environment. J. Anim. Sci. 79:2643-2650.

Heo, K., X. Lin, J. Odle and I. K. Han. 2000a. Kinetics of carnitine palmitoyltransferase-I are altered by dietary variables and suggest a metabolic need for supplemental carnitine in young pigs. J. Nutr. 130:2467-2470.

Heo, K., J. Odle, I. K. Han, W. Cho, S. Seo, E. van Heugten and D. H. Pilkington. 2000b. Dietary L-Carnitine improves nitrogen utilization in growing pigs fed low energy, fat-containing diets. J. Nutr. 130:1809-1814.

Huff-Lonergan, E. and S. M. Lonergan. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Science 71:194-204.

Jacela, J. Y., J. M. Benz, S. S. Dritz, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, J. L. Nelssen, and K. J. Prusa. 2009. Effect of Dried Distillers Grains with Solubles Withdrawal Regimens on Finishing Pig Performance and Carcass Characteristics. Kansas Agric. Exp. Sta. Rep. Prog. pp. 181-191.

James, B. W., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz, K. Q. Owen, J. A. Unruh and T. E. Lawrence. 2002a. Effect of L-Carnitine and Paylean (Ractopamine HCl) supplementation on growth performance, carcass characteristics, and postmortem pH decline. Kansas Agric. Exp. Sta. Rep. Prog. pp. 111-115.

James, B. W., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz, K. Q. Owen, J. A. Unruh and T. E. Lawrence. 2002b. Interactive effects between Paylean

(Ractopamine HCl) and dietary L-Carnitine on finishing pig growth performance and carcass characteristics. Kansas Agric. Exp. Sta. Rep. Prog. pp. 106-110.

James, B. W., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz, K. Q. Owen and J. C. Woodworth. 2002c. Supplementation of L-Carnitine and Paylean improve growth performance of pigs in a commercial finishing facility. Kansas Agric. Exp. Sta. Rep. Prog. pp. 122-126.

James, B. W., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz and J. C. Woodworth. 2002d. Interactive effects among L-Carnitine, Paylean (Ractopamine HCl), and dietary energy density on commercial finishing pig growth performance and carcass characteristics. Kansas Agric. Exp. Sta. Rep. Prog. pp. 116-121.

McGarry, J. D. and N. F. Brown. 1997. The mitochondrial carnitine palmitoyltransferase system. From concept to molecular analysis. Eur. J. Biochem. 244:1-14.

National Pork Producers Council. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Counc., Des Moines, IA.

NRC. 1998. Nutrient Requirement of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Owen, K. Q., H. Jit, C. V. Maxwell, J. L. Nelssen, R. D. Goodband, M. D. Tokach, G. C. Tremblay and S. I. Koo. 2001a. Dietary L-Carnitine suppresses mitochondrial branched-chain keto acid dehydrogenase activity and enhances protein accretion and carcass characteristics of swine. J. Anim. Sci. 79:3104-3112.

Owen, K. Q., J. L. Nelssen, R. D. Goodband, M. D. Tokach and K. G. Friesen. 2001b. Effect of dietary L-Carnitine on growth performance and body composition in nursery and growing-finishing pigs. J. Anim. Sci. 79:1509-1515.

Owen, K. Q., J. L. Nelssen, R. D. Goodband, T. L. Weeden and S. A. Blum. 1996. Effect of L-Carnitine and soybean oil on growth performance and body composition of early-weaned pigs. J. Anim. Sci. 74:1612-1619.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Rebouche, C. J. and H. Seim. 1998. Carnitine metabolism and its regulation in microorganisms and mammals. Annu. Rev. Nutr. 18:39-61.

Rincker, M. J., S. D. Carter, D. E. Real, J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, B. W. Senne, R. W. Fent, L. A. Pettey and K. Q. Owen. 2003. Effects of increasing dietary L-Carnitine on growth performance of weanling pigs. J. Anim. Sci. 81:2259-2269.

Smith, J. W., J. L. Nelssen, R. D. Goodband, M. D. Tokach, B. T. Richert, K. Q. Owen and J. R. Berstrom. 1996. The effects of supplementing growing-finishing pig diets with carnitine and (or) chromium on growth and carcass characteristics. Kansas Agric. Exp. Sta. Rep. Prog. pp. 111-113.

Stein, H. H. and G. C. Shurson. 2009. Board-invited review: the use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Xu, G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon and G. C. Shurson. 2010a. The effects of feeding diets containing corn distillers dried grains with solubles, and withdrawal period of distillers dried grains with solubles, on growth performance and pork quality in grower-finisher pigs. J. Anim. Sci. 88:1388-1397.

Xu, G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon and G. C. Shurson. 2010b. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-1410.

Yoon, S. Y., Y. X. Yang, P. L. Shinde, J. Y. Choi, J. S. Kim, Y. W. Kim, K. Yun, J. K. Jo, J. H. Lee, S. J. Ohh, I. K. Kwon and B. J. Chae. 2010. Effects of mannanase and distillers dried grain with solubles on growth performance, nutrient digestibility, and carcass characteristics of grower-finisher pigs. J. Anim. Sci. 88:181-191.

Table 2.1 Diet composition (as-fed basis)[1]

Item	Phase 1		Phase 2		Phase 3		Phase 4	
Dried distillers grains with solubles (DDGS), %	0	30	0	30	0	30	0	20
Ingredient, %								
Corn	76.65	52.30	80.95	56.55	84.60	60.15	85.75	69.50
Soybean meal (46.5% CP)	20.85	15.45	16.75	11.25	13.30	7.80	12.40	8.75
DDGS	--	30.00	--	30.00	--	30.00	--	20.00
Monocalcium P (21% P)	0.55	--	0.40	--	0.33	--	0.25	--
Limestone	0.95	1.25	0.98	1.23	0.95	1.15	0.93	1.08
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[2]	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09
L-thr	0.06		0.04	--	0.03	--	--	--
Biolys[3]	0.45	0.55	0.40	0.50	0.35	0.46	0.20	0.27
Phytase[4]	0.01	0.005	0.01	0.003	0.01	0.002	0.01	0.0045
L-Carnitine[5]	--	--	--	--	--	--	--	--
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lys	0.95	0.95	0.82	0.82	0.71	0.71	0.61	0.61
Ile:lys	62	69	64	71	65	74	73	80
Met:lys	28	33	29	36	30	39	34	41
Met & Cys:lys	56	67	59	73	61	80	70	84
Thr:lys	61	63	61	66	63	70	66	75
Trp:lys	17.0	17.0	17.0	17.0	17.0	17.0	19.0	19.0
Total lys, %	1.06	1.11	0.92	0.97	0.80	0.86	0.70	0.73
ME, Mcal/kg	3.35	3.36	3.35	3.36	3.36	3.36	3.36	3.36
SID Lys:ME, g/Mcal	2.84	2.83	2.44	2.44	2.11	2.11	1.81	1.81
CP, %	16.6	20.2	15.0	18.6	13.7	17.2	13.2	15.6

Ca, %	0.56	0.56	0.53	0.53	0.49	0.49	0.47	0.47
P, %	0.47	0.47	0.43	0.45	0.40	0.44	0.38	0.40
Available P, %	0.28	0.28	0.25	0.25	0.23	0.23	0.21	0.21

[1] Phase 1 diets were fed from 36 to 61 kg. Phase 2 diets were fed from 61 to 84 kg. Phase 3 diets were fed from 84 to 109 kg. Phase 4 diets were fed from 109 to 127 kg. Grower phase was from 36 to 84 kg BW and finisher phase was from 61 to 109 kg BW.

[2] Provided per kilogram of premix: 4,509,409 IU vitamin A; 701,464 IU vitamin $D_{3;}$ 24,050 IU vitamin E; 1,402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3,006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from Ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.

[3] Biolys contains 50.7% L-lys.

[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 0.12% available P.

[5] Carniking 10 (Lonza, Inc., Allendale, NJ) replaced corn to provide 50 or 100 mg/kg L-Carnitine.

Table 2.2 Effect of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on growth performance[1]

								Probability, $P <$				
	No DDGS × L-Carnitine			DDGS × L-Carnitine				DDGS × L-Carnitine			L-Carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
d 0 to 55												
ADG, kg	0.86	0.89	0.89	0.85	0.88	0.87	0.011	0.70	0.64	0.16	0.06	0.20
ADFI, kg	2.16	2.21	2.22	2.20	2.29	2.15	0.037	0.10	0.14	0.58	0.84	0.05
G:F	0.400	0.401	0.400	0.386	0.384	0.405	0.0046	0.05	0.13	0.03	0.05	0.22
d 55 to 109												
ADG, kg	0.76	0.82	0.79	0.80	0.81	0.81	0.015	0.48	0.12	0.12	0.23	0.09
ADFI, kg	2.67	2.67	2.74	2.76	2.84	2.70	0.054	0.23	0.12	0.12	0.90	0.40
G:F	0.285	0.306	0.288	0.291	0.285	0.301	0.0064	0.64	0.01	0.88	0.32	0.45
d 0 to 109												
ADG, kg	0.81	0.85	0.84	0.83	0.85	0.84	0.011	0.50	0.46	0.83	0.07	0.07
ADFI, kg	2.40	2.42	2.47	2.46	2.55	2.41	0.041	0.12	0.10	0.20	0.86	0.15
G:F	0.340	0.352	0.342	0.336	0.332	0.350	0.0049	0.24	0.01	0.18	0.14	0.99
Final BW, kg	121.9	125.8	124.8	123.5	125.2	125.1	1.23	0.62	0.46	0.68	0.07	0.12

[1] A total of 1,104 barrows and gilts (PIC 337 × 1050, initial BW 36 ± 0.5 kg) were used in a 109-d experiment with 27 pigs per pen and 7 pens per treatment.

Table 2.3 Effect of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on carcass traits[1]

								Probability, $P <$				
	No DDGS × L-Carnitine			DDGS × L-Carnitine				DDGS × L-Carnitine			L-Carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
Live BW[2], kg	123.8	125.7	124.4	123.5	125.3	125.2	1.20	0.63	0.75	0.95	0.35	0.23
HCW, kg	92.4	95.4	93.2	92.6	94.2	94.1	0.86	0.70	0.28	0.95	0.17	0.03
Yield[3], %	74.7	75.9	75.0	75.0	75.2	75.1	0.3	0.84	0.17	0.80	0.52	0.07
Backfat[4], cm	1.67	1.75	1.72	1.65	1.72	1.65	0.033	0.44	0.87	0.14	0.56	0.04
Loin depth[4], cm	6.36	6.39	6.34	6.23	6.21	6.23	0.105	0.94	0.74	0.09	0.92	0.91
Lean[4], %	56.3	55.9	56.0	56.3	55.9	56.3	0.24	0.48	0.79	0.76	0.56	0.11

[1] A total of 775 pigs were used for obtaining carcass data.

[2] Live BW was obtained at packing plant.

[3] Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant.

[4] Values were adjusted to a common carcass weight by using carcass weight as a covariate in the model.

Table 2.4 Effect of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on loin quality

								Probability, $P <$				
	No DDGS × L-Carnitine			DDGS × L-Carnitine				DDGS × L-Carnitine			L-Carnitine	
Item [ab]	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
Purge loss, %	2.71	3.38	3.47	2.46	2.92	3.45	0.383	0.76	0.63	0.45	0.03	0.70
Drip loss, %	1.08	1.24	1.36	1.33	0.95	1.35	0.159	0.41	0.14	0.90	0.34	0.17
WBSF[1], kg	3.16	3.33	3.34	3.55	2.90	3.52	0.174	0.53	0.01	0.74	0.64	0.05
pH	5.57	5.57	5.53	5.58	5.59	5.57	0.021	0.57	0.82	0.17	0.25	0.43
NPPC color score[2]	3.5	3.5	3.3	3.1	3.4	3.5	0.14	0.03	0.94	0.54	0.29	0.34
NPPC marbling score[3]	1.9	2.1	1.8	1.7	1.8	1.6	0.15	0.91	0.73	0.06	0.65	0.27
CIE L* (lightness)[4]	53.6	55.1	54.3	54.5	55.3	55.2	0.65	0.97	0.51	0.21	0.28	0.14
CIE a* (redness)[5]	8.4	8.1	7.4	7.9	7.4	8.1	0.37	0.12	0.23	0.55	0.32	0.63
CIE b* (yellowness)[6]	15.5	15.9	14.9	15.7	15.4	15.8	0.33	0.31	0.09	0.51	0.38	0.49

[a] Values represent the mean of 84 observations.

[b] Above values are adjusted by using gender as a covariate in the model.

[1] Warner-Bratzler Shear Force.

[2] 1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 2000).

[3] Marbling score using a 10-point scale, with 1.0 = 1% intramuscular fat and 10 = 10% intramuscular fat (NPPC, 2000).

[4] CIE L^* = measure of darkness to lightness (black = 0 to white = 100).

[5] CIE a^* = measure of redness (a larger value indicates a more red color).

[6] CIE b^* = measure of yellowness (a larger value indicates a more yellow color).

Table 2.5 Effect of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on jowl fatty acid profile

								Probability, $P <$				
	No DDGS × L-Carnitine			DDGS × L-Carnitine				DDGS × L-Carnitine			L-Carnitine	
Item[ab]	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
Myristic acid (14:0), %	1.45	1.44	1.40	1.35	1.40	1.35	0.028	0.38	0.46	0.007	0.46	0.15
Palmitic acid (16:0), %	22.70	22.56	22.21	20.65	21.23	20.95	0.216	0.07	0.39	0.001	0.66	0.15
Palmitoleic acid (16:1), %	3.29	3.36	3.10	2.76	2.80	2.81	0.149	0.41	0.55	0.001	0.64	0.49
Margaric acid (17:0), %	0.45	0.40	0.51	0.48	0.46	0.48	0.024	0.24	0.19	0.28	0.16	0.02
Stearic acid (18:0), %	9.35	9.30	9.39	8.33	8.55	8.71	0.231	0.45	0.79	0.001	0.34	0.91
Oleic acid (18:1 cis-9), %	40.99	41.30	41.24	38.13	38.44	37.81	0.418	0.49	0.69	0.001	0.93	0.36
Vaccenic acid (18:1n-7), %	4.65	4.78	4.65	4.13	4.17	4.18	0.126	0.86	0.59	0.001	0.84	0.51
Linoleic acid (18:2n-6), %	12.57	13.97	14.41	18.58	16.34	16.62	0.829	0.03	0.24	0.001	0.95	0.59
α-Linoleic acid (18:3n-3), %	0.51	0.51	0.51	0.64	0.61	0.65	0.018	0.96	0.28	0.001	0.74	0.17
Arachidic acid (20:0), %	0.20	0.21	0.22	0.19	0.19	0.22	0.013	0.84	0.55	0.42	0.07	0.59
Eicosadienoic acid (20:2), %	0.67	0.67	0.72	0.95	0.91	0.89	0.026	0.04	0.74	0.001	0.68	0.52
Arachidonic acid (20:4n-6), %	0.10	0.09	0.10	0.11	0.10	0.10	0.003	0.09	0.85	0.001	0.37	0.12
Total SFA[1], %	35.12	34.77	34.75	32.07	32.73	32.71	0.352	0.14	0.40	0.001	0.69	0.77
Total MUFA[2], %	49.88	50.33	49.98	45.93	46.31	45.66	0.530	0.72	0.90	0.001	0.87	0.31
Total PUFA[3], %	13.73	13.72	13.92	20.61	19.67	20.24	0.547	0.60	0.48	0.001	0.87	0.35
Total TFA[4], %	0.34	0.32	0.36	0.39	0.34	0.40	0.017	0.69	0.28	0.02	0.45	0.01
UFA:SFA ratio[5]	1.82	1.85	1.84	2.08	2.02	2.02	0.031	0.13	0.37	0.001	0.52	0.87

PUFA:SFA ratio[6]	0.39	0.40	0.40	0.65	0.60	0.62	0.019	0.35	0.39	0.001	0.62	0.38
Iodine value[7], g/100g	66.50	66.85	66.89	74.66	73.33	73.95	0.640	0.38	0.29	0.001	0.80	0.44

[1] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[2] Total monounsaturated fatty acids = {[14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] +[C24:1]}, where the brackets indicate concentration.

[3] Total polyunsaturated fatty acids = {[C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[4] Total trans fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[5] UFA:SFA ratio = [Total MUFA + Total PUFA]/Total SFA.

[6] PUFA:SFA = Total PUFA/Total SFA.

[7] Calculated as iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 +[C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where the brackets indicate concentration.

[a] Values represent the mean of 84 observations.

[b] Percentage of total fatty acid content.

Chapter 3 - Effects of Energy Source and Specialty Animal Protein Source on Nursery Pig Performance

ABSTRACT

Three experiments were conducted to evaluate effects of energy source or specialty protein source on nursery pig growth performance. In Exp. 1, 150 nursery pigs (initially 12.3 kg BW) were used in a 21-d trial. Pens of pigs were randomly allotted to 1 of 5 dietary treatments with 6 pens per treatment. The 5 treatments included a control corn-soybean meal-based diet, the control diet with 2 or 4% choice white grease (CWG), or the control diet with 2 or 4% alcohol based energy source (liquid energy). Overall (d 0 to 21), pigs fed dietary liquid energy tended to have improved (linear, $P < 0.09$) ADG and ADFI with no change in G:F. Pigs fed CWG had greater (linear, $P < 0.05$) ADG and G:F. Feeding CWG diets had improved ($P < 0.02$) G:F compared with pigs fed liquid energy. In Exp. 2, 228 nursery pigs (initially 6.4 kg BW) were used in 30-d trial. Pigs were randomly allotted to 1 of 6 treatments with 7 pens per treatment. The 6 dietary treatments were arranged in a 2 × 3 factorial with main effects of either 0 or 4% CWG and 0, 2, or 4% liquid energy. Overall (d 0 to 30), a CWG × liquid energy interaction was observed for ADFI (quadratic, $P < 0.03$) which was due to adding liquid energy to diets without CWG reduced ADFI; but adding liquid energy to diets containing CWG increased ADFI. Pigs fed CWG had reduced ADFI ($P < 0.01$) and improved G:F ($P < 0.01$) compared with pigs not fed CWG. Feeding liquid energy did not influence growth. In Exp. 3, 270 nursery pigs (initially 5.0 kg BW) were used in 44-d trial with 5 pigs per pen and 9 pens per treatment. Pens of pigs were randomly allotted to 1 of 6 treatments.

Treatments were fed in three phases and arranged as 2 × 3 factorial with two specialty protein source regimens (poultry digest (AV-E Digest) and spray-dried blood cells or spray-dried animal plasma and porcine intestinal mucosa (PEP2+) from d 0 to 9; AV-E Digest or PEP2+ from d 9 to 23 and AV-E partially replacing soybean meal from d 23 to 44) and three energy sources (control, liquid energy, and CWG). Overall (d 0 to 44), no interactions were found. Adding dietary CWG increased ($P < 0.02$) ADG, final BW and G:F. Also, pigs fed dietary CWG had greater ($P < 0.001$) G:F than pigs fed liquid energy. Protein source regimen did not affect growth. In summary, feeding CWG in nursery diets improved growth; however, liquid energy cannot substitute for CWG and maintain similar performance. Also, AV-E Digest resulted in similar nursery performance to other protein sources.

Key words: alcohol, energy, growth, nursery pig, poultry digest, protein source

INTRODUCTION

Adding energy to nursery diets via liquid fat is a practice that is done for several reasons. First, for diets fed immediately post-weaning, liquid fat can aid in pellet quality and help prevent burning of specialty protein and lactose ingredients (Thomas et al., 1998). Second, fat added to diets during the middle to late nursery period can help improve ADG and G:F (Cera et al., 1989, 1988b). However, with the increased price of added fat in recent years, many producers have reduced fat in pelleted diets and removed fat from non-pelleted nursery diets. Thus, other economical sources of energy for nursery pigs are being sought. One potential alternative is XFE Liquid Energy (XFE Products, Des Moines, IA), which is an alcohol-based liquid product. Research has demonstrated that alcohol can be metabolized as an energy source in the body (Mitchell and Herlong, 1986). However, no research is available that has evaluated the energy level of alcohol in diets for swine or its affects on growth performance of swine.

High quality specialty protein sources are continually sought for starter diets to lower feed cost and replace other protein sources, such as fish meal. Previous research have demonstrated that addition of PEP2+ (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN), a porcine intestinal mucosa that is co-dried with vegetable proteins, can replace fish meal as a specialty protein source in diets for nursery pigs (Myers et al., 2011). In addition, high quality poultry meal can be considered as a suitable animal protein in nursery diets (Keegan et al., 2004; Zier et al., 2004). AV-E Digest (XFE Products, Des Moines, IA), derived from poultry, is a commercially available product that has potential to be used as an alternative animal protein source for nursery pigs, but no research has been conducted to validate the quality of this product. Therefore, the

objectives were to: 1) compare the effects of choice white grease and XFE Liquid Energy as energy source, and 2) effects of AV-E Digest as a specialty animal protein source on growth performance of nursery pigs.

MATERIALS and METHODS

The Kansas State University Institutional Animal Care and Use Committee approved all experimental procedures. Based on manufacturer recommendations, the ME of XFE Liquid Energy (liquid energy) used in diet formulation was assumed to that of choice white grease (CWG; 7.97 Mcal/kg) in all experiments.

Experiment 1

A total of 150 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 12.3 ± 0.2 kg BW) were used in a 21-d experiment to compare the effects of CWG and liquid energy on growth performance of nursery pigs. This experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

All pigs were weaned at 21 d of age and fed common starter diets until the beginning of the experimental period. On d 20 post-weaning, pigs were allotted to 1 of 5 treatments with 5 pigs per pen and 6 pens per treatment. Dietary treatments included a corn-soybean meal-based control diet or the control diet with 2 or 4% liquid energy or 2 or 4% CWG. Diets were formulated to a standardized ileal digestible (SID) lysine:ME ratio of 3.81 g/Mcal (Table 1). Diets were formulated to meet or exceed all requirement estimates suggested by NRC (1998).

All experimental diets were fed in meal form and manufactured at the Kansas State University Animal Science Feed Mill. Pigs were weighed and feed disappearance was determined on d 0, 7, 14, and 21 of the trial to calculate ADG, ADFI, and G:F.

Experiment 2

A total of 228 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 6.4 ± 0.1 kg BW) were used in 30-d trial to determine the effect of combination of CWG and liquid energy in nursery diets on growth performance. The trial was also conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS.

All pigs were weaned at 21 d of age and randomly allotted to pens by initial BW. Pigs were fed a common diet for 3 d after weaning. On d 3 post-weaning, pigs were weighed and pens were randomly allotted to 1 of 6 dietary treatments with 7 pens per treatment. Experimental diets were fed in 2 phases. The 6 dietary treatments were arranged in a 2 × 3 factorial with 0 or 4% CWG and 0, 2, or 4% liquid energy (Table 2). Pigs were fed in 2 phases (phase 1, d 0 to 14; phase 2, d 14 to 30), with phase 1 diets containing 4.5% fishmeal and 10% dried whey. All diets were formulated to contain an equal SID lysine:ME ratio within each phase. Diets were formulated to meet or exceed all requirement estimates suggested by NRC (1998).

All experimental diets were fed in meal form and manufactured at the Kansas State University Animal Science Feed Mill. Pigs were weighed and feed disappearance was determined on d 0, 7, 14, 21, and 30 of the trial to calculate ADG, ADFI, and G:F.

Experiment 3

A total of 270 weanling pigs (PIC 1050 × 337, Hendersonville TN; initially 5.0 ± 0.1 kg BW and 21 d of age) were used in 44-d trial to compare different energy sources

or specialty protein sources on growth performance of nursery pigs. The study was conducted at the KSU Segregated Early Weaning Facility (SEW). Each pen (1.52 m × 1.52 m) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water.

Pigs were randomly allotted to 1 of 6 treatments. There were 5 pigs per pen and 9 pens per treatment. Pigs were fed in three dietary phases (phase 1, d 0 to 9; phase 2, d 9 to 23; and phase 3, d 23 to 44). The dietary treatments were in a 2 ×3 factorial with two protein source regimens and three energy sources (control, liquid energy, and CWG).Thus, the 6 treatments were: (1) 7.1% PEP2+ (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN) and 3.75% spray-dried animal plasma (SDAP; AP920; APC, Inc., Ames, IA) in phase 1, 3.8% PEP2+ in phase 2, and no specialty protein sources (control diet) in phase 3; (2) 7.1% PEP2+, 3.75% SDAP and 3% liquid energy in phase 1, 3.8% PEP2+ and 3% liquid energy in phase 2, and 3% liquid energy in phase 3; (3) 7.1% PEP2+, 3.75% SDAP and 3% CWG in phase 1, 3.8% PEP2+ and 3% CWG in phase 2, and 3% CWG in phase 3; (4) 12.5% AV-E Digest (AV-E) and 2.5% spray-dried blood cells (SDBC; AP301G; APC, Inc., Ames, IA) in phase 1, 7.5% AV-E in phase 2, and 2.5% AV-E in phase 3; (5) 12.5% AV-E, 2.5% SDBC and 3% liquid energy in phase 1, 7.5% AV-E and 3% liquid energy in phase 2, 2.5% AV-E and 3% liquid energy in phase 3, and (6) 12.5% AV-E and 2.5% SDBC and 3% CWG in phase 1, 7.5% AV-E and 3% CWG in phase 2, 2.5% AV-E and 3% CWG in phase 3. Diets were formulated to constant SID lysine:ME ratios within each phase (Tables 3, 4 and 5). Also, SID AA digestibly values used in diet formulation for AV-E were assumed to be equal to that of menhaden fish meal (NRC, 1998) since they had not been determined. Diets were

formulated to meet or exceed all requirements recommended by NRC (1998). Spray-dried whey was included at 25 and 10%, respectively, in all phase 1 and 2 diets. Phase 1 diets were fed in pelleted form and manufactured at the Kansas State University Grain Science Feed Mill. Phase 2 and 3 diets were fed in meal form.

Pigs were weighed and feed disappearance was determined on d 0, 5, 9, 16, 23, 33 and 44 of the trial to calculate ADG, ADFI, and G:F.

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, preplanned contrast statements were used to test: (1) linear and quadratic effects of increasing CWG or liquid energy with the control diet used as the lowest dosage level, and (2) CWG vs. liquid energy. In Exp. 2, polynomial contrasts were used to test the linear and quadratic effects of increasing liquid energy. In addition, the main effect of CWG (treatments containing 4% CWG vs. treatments without CWG) and the interactive effect of liquid energy and CWG were tested. In Exp. 3, data was analyzed as a 2×3 factorial with 2 protein and 3 energy sources with barn as random effect and treatments as fixed effects. Contrast statements were also used to test the main effects of liquid energy (treatments 1 and 4 vs. treatments 2 and 5), CWG (treatments 1 and 4 vs. treatments 3 and 6) or protein source (treatments 1, 2 and 3 vs. treatments 4, 5 and 6), and to compare between liquid energy and CWG (treatments 2 and 5 vs. treatments 3 and 6). All results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Experiment 1

Overall (d o to 21), pigs fed diets containing liquid energy tended to have improved ADG (linear, $P < 0.08$; Table 6) and ADFI (linear, $P < 0.09$), but no difference in G:F compared with pigs fed the control diet. Pigs fed CWG had greater (linear, $P < 0.05$) ADG and improved (linear, $P < 0.01$) G:F. Finally, pigs fed CWG tended to have lower ($P < 0.08$) ADFI but improved ($P < 0.02$) G:F compared with pigs fed liquid energy.

Experiment 2

From d 0 to 14, a CWG × liquid energy interaction (quadratic, $P < 0.01$; Table 7) was observed for ADG, which was the result of pigs fed 2% liquid energy having lower ADG than pigs fed 0 or 4% liquid energy when added to diets without CWG but higher ADG when added to diets containing CWG. For the main effects, pigs fed diets containing CWG had decreased ADG ($P < 0.05$) and ADFI ($P < 0.02$), but adding liquid energy to the diet did not influence growth performance.

From d 14 to 30, a CWG × liquid energy interaction (quadratic, $P < 0.02$) was observed for ADFI. Adding 2% liquid energy to the diet resulted in lower ADFI when added to diets without CWG, but resulted in greater ADFI when added to diets containing CWG. The addition of CWG decreased ($P < 0.01$) ADFI but improved ($P < 0.01$) G:F compared with pigs fed diets without CWG.

Overall (d 0 to 30), a tendency (quadratic, $P < 0.07$) was found for a CWG × liquid energy interaction for ADG and a significant interaction (quadratic, $P < 0.03$) for ADFI. Adding liquid energy to diets without CWG reduced ADG and feed intake;

however, adding liquid energy to diets containing CWG increased ADG and ADFI. Neither the addition of CWG nor liquid energy increased ADG compared with the control pigs. For main effects, pigs fed CWG had reduced ($P < 0.01$) ADFI and improved ($P < 0.01$) G:F compared with pigs fed the control diet. Feeding liquid energy did not influence G:F.

Similar to the tendencies for interactions for phase 1 and overall ADG, a tendency occurred for a CWG × liquid energy interaction (quadratic, $P < 0.08$) for BW on d 30 because adding 2% liquid energy to diets without CWG decreased BW on d 30 whereas adding 2% liquid energy to diets with CWG increased BW on d 30. Neither CWG nor liquid energy influenced BW compared with pigs fed the control diet.

Experiment 3

There were no protein source × energy source interactions ($P > 0.05$) within phase or overall for any growth parameters, thus main effects will be reported

From d 0 to 9, pigs fed liquid energy tended ($P < 0.10$; Table 8) to have improved ADG compared with pigs fed diets without liquid energy. No differences between protein source regimen or energy source were found.

During phase 2 (d 9 to 23), pigs fed diets containing AV-E had greater ADG ($P < 0.05$) compared with pigs fed diets containing PEP2+. Pigs fed diets containing CWG had better ($P < 0.02$) G:F than that of pigs fed liquid energy.

From d 23 to 44, pigs had improved ($P < 0.01$) in ADG and G:F from feeding CWG. Also, pigs fed diets containing CWG tended ($P < 0.08$) to have greater ADG and had better ($P < 0.001$) G:F compared with pigs fed diets containing liquid energy.

Overall (d 0 to 44), pigs fed diets with CWG had improved ADG ($P < 0.03$), final BW ($P < 0.02$) and G:F ($P < 0.001$). Pigs fed diets containing CWG had better ($P < 0.001$) G:F than pigs fed liquid energy. There was no difference in growth performance between pigs fed different protein source regimens.

DISCUSSION

Past research has demonstrated that the pigs' ability to utilize of fat is limited during the first 14 d post-weaning for pigs weaned at 21 d of age; however, adding fat to diet has improved feed efficiency of nursery pigs after 5 to 6 wk of age (Li et al., 1990; Tokach et al., 1995). These findings would support the results of Exp. 2 and 3, where no positive or negative effects on growth performance were found when pigs were fed added fat at or just after weaning. However, added CWG improved growth performance in all experiments when fed after approximately 3-wk post-weaning. The reason for this effect could be due to insufficient lipase secretion and activity during the early phase post-weaning which may cause a depression of fat utilization as energy (Cera et al., 1990). In addition, Cera et al. (1988a,b) reported that dietary corn oil reduced N retention as well as the reduction in villus height observed during the first 2 wk post-weaning, which may have negative effect on growth of nursery pigs. This may account for the observed reduction in ADG from feeding fat during the initial 2 wk in Exp. 2. Lipase secretion and activity remarkably increase after 7 d post-weaning and reach the maximal level during 2 to 3 wk post-weaning, which is likely to improve the digestibility of fat (Cera et al., 1990). In addition, other research has shown that lipase activity increases linearly until 6 wk of age in swine (Lindemann et al., 1986).

Due to low feed intake and energy limiting state of newly weaned nursery pigs (Bark et al., 1986), added energy that can be utilized by this age of pig more efficiently then added fat would be highly beneficial.

Alcohol has been shown to provide available energy (Mitchell and Herlong, 1986). Therefore, it was hypothesized that an alcohol based product may be a viable energy source for nursery pigs. However, inconsistent growth results were found to this hypothesis in the present studies. In Exp. 1, the addition of dietary liquid energy improved ADG through an increase in ADFI. However, this response was not found in Exp. 2 and 3, while feed efficiency was not influenced in any of the experiments. Thus, with the improvements in growth criteria found with added CWG but not liquid energy, it appears that the energy concentration of the products is quite different. Due to the fact that the energy concentration of liquid energy was unknown at the time of formulation, the energy of CWG was used. However, it appears that alcohol may have an energy concentration more similar to corn than CWG based on the equal feed efficiency as the control fed pigs without added energy sources.

This finding maybe explained due to different metabolism pathways for fat and alcohol oxidation, which may cause a discrepancy in efficiency of utilization. It has been shown that mitochondrial β-oxidation is the primary pathway for fatty acids metabolism in organs such as the liver, heart and skeletal muscle (Houten and Wanders, 2010). Alcohol is mainly metabolized in liver, and the major pathway involves alcohol dehydrogenase (ADH), which degrades alcohol to produce acetaldehyde and NADH for subsequent ATP synthesis (Zakhari, 2006). In case of chronic alcohol consumers, the microsomal ethanol-oxidizing system at the smooth endoplasmic reticulum of

hepatocytes is the main pathway converting alcohol to acetaldehyde (Mezey and Tobon, 1971). However, excessive acetaldehyde produced due to limited enzyme activity or over-intake alcohol has toxic effects on mitochondrial reactions and functions (Manzo-Avalos and Saavedra-Molina, 2010). Also, it has been reported that the secretion and activity of enzymes for alcohol metabolism in the liver are insufficient for young pigs, indicative of poor alcohol metabolism (Raiha et al., 1967). This might explain why we found a lack of growth response from adding the alcohol based product seen in the present nursery studies.

Specialty animal protein ingredients, such as fish meal and spray-dried animal plasma, are an important component of nursery diets to stimulate feed intake in early phase post-weaning (Bergstrom et al., 1997; DeRouchey et al., 2002). Spray-dried animal plasma has been found to increase ADG and ADFI when included in the diet for newly weaned pigs (Kats et al., 1994; DeRouchey et al., 2003).

In current study, the growth responses to feeding different protein sources were not found during the first period, which may be due to the overall low growth and feed intake levels in the pigs during this period. However, most studies report that specialty protein sources such as PEP2+ (Myers et al., 2011) or whey protein concentrate (Gottlob et al., 2007) do not provide equal growth performance as pigs fed diets containing spray-dried animal plasma during the initial period of post-weaning. Although there were no differences in performance between pigs fed diets containing the AV-E-SDBC regimen and SDAP-PEP2+ regimen, more research is needed to confirm that AV-E can be used as a direct replacement for SDAP in diets for newly weaned pigs.

During the phase 2 period, pigs fed AV-E had improved growth rates above the pigs fed PEP2+. Previously PEP2+ had been found to improve feed intake and ADG (Myers et al., 2011) compared to pigs fed select menhaden fish meal. Thus this data indicates that AV-E has the potential as a specialty animal protein source in this phase of nursery growth. We assumed the SID AA values of AV-E were equal to that of menhaden fish meal at the time of formulation due to having no values that had been generated at that time. However, the improved growth response observed from feeding AV-E diets indicate that the actual SID AA contents of AV-E appear not be underestimated in diet formulation.

While it is typical to include specialty protein sources in phase 1 and 2 nursery diets as in the present study, including them as a partial replacement for soybean meal in phase 3 is not. Dritz et al. (1996) suggested that feeding complexity diets stimulated ADFI and improved ADG in the early period post-weaning but had no influence after pigs reached 7 kg BW. This may help explain the lack of benefit from feeding AV-E during phase 3 compared to pigs fed only soybean meal as an intact protein source. In fact, previous research observed that pigs fed dietary poultry meal had negative effects on ADG and ADFI during grower phase compared with pigs fed soybean meal diet (Shelton et al., 2001).

In summary, feeding CWG improved G:F during the middle or late nursery period as expected in all 3 experiments. Although ADG was improved for pigs fed liquid energy in Exp. 1, that response was not repeated in Exp 2 and 3 with no differences in G:F in any study. Pigs fed CWG diets had increased G:F compared with feeding liquid energy. These results indicate liquid energy cannot be used as a substitute for added fat in nursery

pig diets and maintain similar performance. Also, AV-E has the potential as a replacement for other animal specialty protein sources such as PEP2+ in nursery diets. However, more research is needed validating AV-E as a direct SDAP replacement immediately post-weaning.

CITED LITERAURES

Bark, L. J., T. D. Crenshaw and V. D. Leibbrandt. 1986. The effect of meal intervals and weaning on feed intake of early weaned pigs. J. Anim. Sci. 62:1233-1239.

Bergstrom, J. R., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, K. Q. Owen and W. B. Nessmith, Jr. 1997. Evaluation of spray-dried animal plasma and select menhaden fish meal in transition diets of pigs weaned at 12 to 14 days of age and reared in different production systems. J. Anim. Sci. 75:3004-3009.

Cera, K. R., D. C. Mahan, R. F. Cross, G. A. Reinhart and R. E. Whitmoyer. 1988a. Effect of age, weaning and postweaning diet on small intestinal growth and jejunal morphology in young swine. J. Anim. Sci. 66:574-584.

Cera, K. R., D. C. Mahan and G. A. Reinhart. 1988b. Effects of dietary dried whey and corn oil on weanling pig performance, fat digestibility and nitrogen utilization. J. Anim. Sci. 66:1438-1445.

Cera, K. R., D. C. Mahan and G. A. Reinhart. 1989. Apparent Fat Digestibilities and Performance Responses of Postweaning Swine Fed Diets Supplemented with Coconut Oil, Corn-Oil or Tallow. J. Anim. Sci. 67:2040-2047.

Cera, K. R., D. C. Mahan and G. A. Reinhart. 1990. Effect of weaning, week postweaning and diet composition on pancreatic and small intestinal luminal lipase response in young swine. J. Anim. Sci. 68:384-391.

DeRouchey, J. M., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. C. Woodworth and B. W. James. 2002. Comparison of spray-dried blood meal and blood cells in diets for nursery pigs. J. Anim. Sci. 80:2879-2886.

DeRouchey, J. M., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. C. Woodworth, B. W. James, and D. E. Real. 2003. Effect of irradiation of individual feed ingredients and the complete diet on nursery pig performance. J. Anim. Sci. 81:1799-1805.

Dritz, S. S., K. Q. Owen, J. L. Nelssen, R. D. Goodband and M. D. Tokach. 1996. Influence of weaning age and nursery diet complexity on growth performance and carcass characteristics and composition of high-health status pigs from weaning to 109 kilograms. J. Anim. Sci. 74:2975-2984.

Gottlob, R. O., J. M. DeRouchey, M. D. Tokach, J. L. Nelssen, R. D. Goodband, PAS, and S. S. Dritz. 2007. Comparison of whey protein concentrate and spray-dried plasma protein in diets for weanling pigs. Prof. Anim. Sci. 23:116-122.

Houten, S. M. and R. J. Wanders. 2010. A general introduction to the biochemistry of mitochondrial fatty acid beta-oxidation. J. Inherit. Metab. Dis. 33:469-477.

Kats, L. J., J. L. Nelssen, M. D. Tokach, R. D. Goodband, J. A. Hansen and J. L. Laurin. 1994. The effect of spray-dried porcine plasma on growth peformance in the early-weaned pig. J. Anim. Sci. 72:2075-2081.

Keegan, T. P., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, R. D. Goodband and S. S. Dritz. 2004. The effects of poultry meal source and ash level on nursery pig performance. J. Anim. Sci. 82:2750-2756.

Li, D. F., R. C. Thaler, J. L. Nelssen, D. L. Harmon, G. L. Allee and T. L. Weeden. 1990. Effect of fat sources and combinations on starter pig performance, nutrient digestibility and intestinal morphology. J. Anim. Sci. 68:3694-3704.

Lindemann, M. D., S. G. Cornelius, S. M. el Kandelgy, R. L. Moser and J. E. Pettigrew. 1986. Effect of age, weaning and diet on digestive enzyme levels in the piglet. J. Anim. Sci. 62:1298-1307.

Manzo-Avalos, S. and A. Saavedra-Molina. 2010. Cellular and mitochondrial effects of alcohol consumption. Int. J. Environ. Res. Public Health 7:4281-4304.

Mezey, E. and F. Tobon. 1971. Rates of ethanol clearance and activities of the ethanol-oxidizing enzymes in chronic alcoholic patients. Gastroenterology 61:707-715.

Mitchell, M. C. and H. F. Herlong. 1986. Alcohol and nutrition: caloric value, bioenergetics, and relationship to liver damage. Annu. Rev. Nutr. 6:457-474.

Myers, A. J. 2011. The effects of porcine intestinal mucosa products on the growth performance of nursery pigs and feeder adjustment on finishing pig growth performance. M. S. thesis. Kansas State University, Manhattan.

NRC. 1998. Nutrient Requirement of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Raiha, N. C., M. Koskinen and P. Pikkarainen. 1967. Developmental changes in alcohol-dehydrogenase activity in rat and guinea-pig liver. Biochem. J. 103:623-626.

Shelton, J. L., M. D. Hemann, R. M. Strode, G. L. Brashear, M. Ellis, F. K. McKeith, T. D. Bidner and L. L. Southern. 2001. Effect of different protein sources on growth and carcass traits in growing-finishing pigs. J. Anim. Sci. 79:2428-2435.

Thomas, M., T. van Vliet and A. F. B. van der Poel. 1998. Physical quality of pelleted animal feed 3. Contribution of feedstuff components. Anim. Feed Sci. Tech.70:59-78.

Tokach, M. D., J. E. Pettigrew, L. J. Johnston, M. Overland, J. W. Rust and S. G. Cornelius. 1995. Effect of adding fat and (or) milk products to the weanling pig diet on performance in the nursery and subsequent grow-finish stages. J. Anim. Sci. 73:3358-3368.

Zakhari, S. 2006. Overview: how is alcohol metabolized by the body? Alcohol. Res. Health 29:245-254.

Zier, C. E., R. D. Jones and M. J. Azain. 2004. Use of pet food-grade poultry by-product meal as an alternate protein source in weanling pig diets. J. Anim. Sci. 82:3049-3057.

Table 3.1 Composition of experimental diets (Exp. 1, as-fed basis)[1]

		CWG[2] or liquid energy[3]	
Item	Control	2	4
Ingredient, %			
Corn	65.00	61.50	58.15
Soybean meal (46.5% CP)	31.40	32.85	34.20
CWG or liquid energy	--	2.00	4.00
Monocalcium P (21% P)	1.10	1.10	1.10
Limestone	1.03	1.03	1.00
Salt	0.35	0.35	0.35
Vitamin premix[4]	0.25	0.25	0.25
Trace mineral premix[5]	0.15	0.15	0.15
L-lys HCl	0.35	0.355	0.36
DL-met	0.135	0.15	0.16
L-thr	0.135	0.145	0.15
Phytase[6]	0.125	0.125	0.125
Total	100.0	100.0	100.0
Calculated analysis			
Standard ileal digestible (SID) amino acids			
Lys, %	1.26	1.30	1.33
Ile:lys, %	60	60	60
Met:lys, %	34	34	35
Met & cys:lys, %	58	58	58
Thr:lys, %	63	63	63
Trp:lys, %	17.2	17.2	17.2
Val:lys, %	67	67	66
Total lys, %	1.39	1.43	1.47
ME, Mcal/kg	3.31	3.40	3.49
SID Lys:ME, g/Mcal	3.81	3.81	3.81
CP, %	20.6	21.0	21.4
Ca, %	0.72	0.72	0.72
P, %	0.63	0.63	0.63
Available P, %	0.43	0.43	0.43

[1] A total of 150 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 12.3 ± 0.2 kg BW) were used in a 21-d study with 5 pigs per pen and 6 replications per treatment.
[2] CWG: choice white grease.
[3] XFE Products, Des Moines, IA.
[4] Provided per kg of complete feed: 11,025 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin k (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}.
[5] Provided per kg of complete feed: 16.5 mg of Cu as $CuSO_4$ $5H_2O$; 165.4 mg of Fe as $FeSO_4$ H_2O; 39.7 mg of Mn as $MnSO_4$ H_2O; 0.30 mg of Se as Na_2SeO_3; 165.4 mg of Zn as ZnO; and 0.30 mg of I as $C_2H_2(NH_2)_2$ 2HI.
[6] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg with a release of 0.10% available P.

Table 3.2 Composition of experimental diets (Exp. 2, as-fed basis)[1]

		Phase 1[4]						Phase 2[5]					
	CWG[2], %	0	0	0	4	4	4	0	0	0	4	4	4
Item	Liquid energy[3], %	0	2	4	0	2	4	0	2	4	0	2	4
Ingredient, %													
Corn		55.25	51.90	48.45	48.45	45.00	41.75	65.00	60.15	58.15	58.15	54.60	51.05
Soybean meal (46.5% CP)		27.45	28.75	30.25	30.25	31.65	32.85	31.40	32.85	34.20	34.20	35.75	37.30
Select menhaden fish meal		4.50	4.50	4.50	4.50	4.50	4.50	--	--	--	--	--	--
Spray-dried whey		10.00	10.00	10.00	10.00	10.00	10.00	--	--	--	--	--	--
Choice white grease		--	--	--	4.00	4.00	4.00	--	--	--	4.00	4.00	4.00
Liquid energy[3]		--	2.00	4.00	--	2.00	4.00	--	2.00	4.00	--	2.00	4.00
Monocalcium P (21% P)		0.45	0.45	0.45	0.45	0.45	0.45	1.10	1.10	1.10	1.10	1.10	1.10
Limestone		0.65	0.65	0.63	0.63	0.63	0.63	1.13	1.00	1.00	1.00	1.00	0.98
Salt		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide		0.275	0.275	0.275	0.275	0.275	0.275	--	--	--	--	--	--
Vitamin premix[6]		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[7]		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl		0.265	0.275	0.28	0.28	0.29	0.30	0.35	0.355	0.36	0.36	0.36	0.36
DL-met		0.14	0.155	0.17	0.17	0.185	0.20	0.135	0.15	0.165	0.16	0.175	0.18
L-thr		0.125	0.145	0.15	0.145	0.155	0.165	0.125	0.145	0.15	0.15	0.15	0.15
L-val		--	--	--	--	0.005	0.0075	--	--	--	--	--	--
Phytase[8]		0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis													
Standard ileal digestible (SID) amino acids													
Lys, %		1.35	1.39	1.42	1.42	1.46	1.50	1.26	1.30	1.33	1.33	1.37	1.40
Ile:lys, %		61	60	60	60	60	60	60	60	60	60	60	60
Met:lys, %		35	36	36	36	36	37	34	34	35	34	35	35
Met & cys:lys, %		58	58	58	58	58	58	58	58	58	58	58	58
Thr:lys, %		64	64	64	64	64	64	63	63	63	63	63	62

Trp:lys, %	17	17	17	17	17	17	17.2	17.2	17.2	17.2	17.3	17.4
Val:lys, %	67	66	66	66	66	65	67	67	66	66	66	66
Total lys, %	1.49	1.52	1.56	1.56	1.61	1.64	1.39	1.43	1.47	1.47	1.50	1.54
ME, Mcal/kg	3.30	3.39	3.48	3.48	3.57	3.66	3.31	3.40	3.49	3.49	3.58	3.67
SID Lys:ME, g/Mcal	4.09	4.09	4.09	4.09	4.09	4.09	3.81	3.81	3.81	3.81	3.81	3.81
CP, %	21.9	22.2	22.7	22.7	23.0	23.4	20.6	21.0	21.4	21.4	21.8	22.2
Ca, %	0.75	0.75	0.75	0.75	0.75	0.75	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.65	0.65	0.65	0.65	0.65	0.65	0.63	0.64	0.63	0.63	0.63	0.63
Available P, %	0.48	0.48	0.48	0.48	0.48	0.48	0.43	0.43	0.43	0.43	0.43	0.43

[1] A total of 228 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 6.4 ± 0.1 kg and 3 d post-weaning) were used in a 30-d study with 7 replications per treatment.

[2] CWG: choice white grease.

[3] XFE Products, Des Moines, IA.

[4] Phase 1 diets were fed from d 0 to 14.

[5] Phase 2 diets were fed from d 14 to 30.

[6] Provided per kg of complete feed: 11,025 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin k (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}.

[7] Provided per kg of complete feed: 16.5 mg of Cu as $CuSO_4 \cdot 5H_2O$; 165.4 mg of Fe as $FeSO_4 \cdot H_2O$; 39.7 mg of Mn as $MnSO_4 \cdot H_2O$; 0.30 mg of Se as Na_2SeO_3; 165.4 mg of Zn as ZnO; and 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$.

[8] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg with a release of 0.10% available P.

Table 3.3 Composition of Phase 1 diets (Exp. 3, as-fed basis)[1]

	Treatment					
	1	2	3	4	5	6
Item	7.1%PEP2+[2] & 3.75%SDAP[3] None	7.1%PEP2+ & 3.75%SDAP 3% liquid energy[4]	7.1%PEP2+ & 3.75%SDAP 3% CWG[5]	12.5%AV-E[6] & 2.5%SDBC[7] None	12.5%AV-E & 2.5%SDBC 3% liquid energy	12.5%AV-E & 2.5%SDBC 3% CWG
Ingredient, %						
Corn	45.75	40.80	40.80	41.10	37.70	37.70
Soybean meal (46.5% CP)	15.15	17.00	17.00	15.15	17.00	17.00
PEP2+	7.10	7.10	7.10	--	--	--
AV-E Digest	--	--	--	12.50	12.50	12.50
Spray-dried animal plasma	3.75	3.75	3.75			
Spray-dried blood cells	--	--	--	2.50	2.50	2.50
Spray-dried whey	25.00	25.00	25.00	25.00	25.00	25.00
Choice white grease	--	--	3.00	--	--	3.00
Liquid energy	--	3.00	--	--	3.00	--
Monocalcium P (21% P)	0.58	0.58	0.58	0.10	0.10	0.10
Limestone	0.93	0.93	0.93	0.43	0.40	0.40
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.415	0.415	0.415	0.415	0.415	0.415
Vitamin premix[8]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[9]	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.225	0.25	0.25	0.175	0.2	0.2
DL-met	0.185	0.21	0.21	0.16	0.19	0.19
L-thr	0.09	0.11	0.11	0.10	0.12	0.12
L-val	--	--	--	--	--	--
Phytase[10]	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0

Calculated analysis						
Standard ileal digestible (SID) amino acids						
Lys, %	1.41	1.47	1.47	1.40	1.46	1.46
Ile:lys, %	55	55	55	55	55	55
Met:lys, %	33	34	34	34	35	35
Met & cys:lys, %	58	58	58	58	58	58
Thr:lys, %	64	64	64	64	64	64
Trp:lys, %	18	18	18	17	17	17
Val:lys, %	66	65	65	77	75	75
Total lys, %	1.55	1.61	1.61	1.53	1.59	1.59
ME, Mcal/kg	3.26	3.40	3.40	3.24	3.38	3.38
SID Lys:ME, g/Mcal	4.32	4.32	4.32	4.32	4.32	4.32
CP, %	21.4	21.9	21.9	22.8	23.3	23.3
Ca, %	0.74	0.74	0.74	0.74	0.74	0.74
P, %	0.66	0.65	0.65	0.63	0.63	0.63
Available P, %	0.55	0.55	0.55	0.55	0.55	0.55

[1] A total of 270 weanling pigs (PIC 1050 × 337, Hendersonville, TN, initially 5.0 ± 0.1 kg BW) were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 1 diets were fed from d 0 to 9.

[2] Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.

[3] SDAP: spray-dried animal plasma (AP920; APC, Inc., Ames, IA).

[4] XFE Products, Des Moines, IA.

[5] CWG: choice white grease.

[6] AV-E: AV-E Digest (XFE Products, Des Moines, IA).

[7] SDBC: spray-dried blood cells (AP302G APC, Inc., Ames, IA).

[8] Provided per kg of complete feed: 11,025 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin k (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}.

[9] Provided per kg of complete feed: 16.5 mg of Cu as $CuSO_4$ 5H_2O; 165.4 mg of Fe as $FeSO_4$ ·H_2O; 39.7 mg of Mn as $MnSO_4$ ·H_2O; 0.30 mg of Se as Na_2SeO_3; 165.4 mg of Zn as ZnO; and 0.30 mg of I as $C_2H_2(NH_2)_2$ ·2HI.

[10] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg with a release of 0.10% available P.

Table 3.4 Composition of Phase 2 diets (Exp. 3, as-fed basis)[1]

	Treatment					
	1	2	3	4	5	6
Item	3.8%PEP2+[2]	3.8%PEP2+, 3%liquid energy[3]	3.8%PEP2+, 3%CWG[4]	7.5%AV-E[5]	7.5%AV-E, 3%liquid energy	7.5%AV-E, 3%CWG
Ingredient, %						
Corn	53.80	48.60	48.60	50.90	45.60	45.75
Soybean meal (46.5% CP)	29.05	31.20	31.20	27.55	31.20	31.20
PEP2+	3.80	3.80	3.80	--	--	--
AV-E Digest	--	--	--	7.50	7.50	7.50
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00
Choice white grease	--	--	3.00	--	--	3.00
Liquid energy	--	3.00	--	--	3.00	--
Monocalcium P (21% P)	0.88	0.85	0.85	0.45	0.43	0.43
Limestone	0.83	0.83	0.83	0.58	0.58	0.58
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.275	0.275	0.275	0.275	0.275	0.275
Vitamin premix[6]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[7]	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.25	0.255	0.255	0.175	0.185	0.185
DL-met	0.15	0.17	0.17	0.09	0.11	0.11
L-thr	0.11	0.12	0.12	0.075	0.09	0.085
Phytase[8]	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standard ileal digestible (SID) amino acids						
Lys, %	1.33	1.38	1.38	1.33	1.39	1.39
Ile:lys, %	62	62	62	66	66	66

Met:lys, %	34	35	35	32	32	32
Met & cys:lys, %	58	58	58	58	58	58
Thr:lys, %	64	64	64	64	64	64
Trp:lys, %	18.1	18.1	18.1	18.4	18.3	18.4
Val:lys, %	68	68	68	75	73	73
Total lys, %	1.47	1.53	1.53	1.47	1.53	1.53
ME, Mcal/kg	3.28	3.42	3.42	3.28	3.42	3.42
SID Lys:ME, g/Mcal	4.05	4.04	4.04	4.05	4.05	4.05
CP, %	21.9	22.5	22.5	23.2	23.8	23.8
Ca, %	0.68	0.68	0.68	0.68	0.68	0.68
P, %	0.64	0.63	0.63	0.63	0.62	0.62
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46

[1] A total of 270 nursery pigs (PIC 1050 × 337, Hendersonville, TN, initially 5.0 ± 0.1 kg BW) were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 2 diets were fed from d 9 to 23.

[2] Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.

[3] XFE Products, Des Moines, IA.

[4] CWG: choice white grease.

[5] AV-E: AV-E Digest (XFE Products, Des Moines, IA).

[6] Provided per kg of complete feed: 11,025 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin k (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}.

[7] Provided per kg of complete feed: 16.5 mg of Cu as $CuSO_4$ $5H_2O$; 165.4 mg of Fe as $FeSO_4$ H_2O; 39.7 mg of Mn as $MnSO_4$ H_2O; 0.30 mg of Se as Na_2SeO_3; 165.4 mg of Zn as ZnO; and 0.30 mg of I as $C_2H_2(NH_2)_2$ 2HI.

[8] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg with a release of 0.10% available P.

Table 3.5 Composition of Phase 3 diets (Exp. 3, as-fed basis)[1]

	Treatment					
	1	2	3	4	5	6
Item	Control	3%liquid energy[2]	3%CWG[3]	2.5%AV-E[4]	2.5%AV-E, 3%liquid energy	2.5%AV-E, 3%CWG
Ingredient, %						
Corn	65.45	60.70	60.70	65.35	60.45	60.45
Soybean meal (46.5% CP)	31.05	32.80	32.80	28.95	30.85	30.85
AV-E Digest	--	--	--	2.50	2.50	2.50
Choice white grease	--	--	3.00	--	--	3.00
Liquid energy	--	3.00	--	--	3.00	--
Monocalcium P (21% P)	1.05	1.05	1.05	0.90	0.90	0.90
Limestone	0.90	0.88	0.88	0.83	0.80	0.80
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[6]	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.36	0.375	0.375	0.34	0.35	0.35
DL-met	0.14	0.16	0.155	0.125	0.14	0.14
L-thr	0.14	0.15	0.15	0.125	0.14	0.14
Phytase[7]	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standard ileal digestible (SID) amino acids						
Lys, %	1.26	1.31	1.31	1.26	1.31	1.31
Ile:lys, %	60	59	59	61	60	60
Met:lys, %	34	34	34	34	34	34
Met & cys:lys, %	58	58	58	58	58	58

Thr:lys, %	63	63	63	63	63	63
Trp:lys, %	17.0	17.0	17.0	17.0	17.0	17.0
Val:lys, %	67	66	66	69	68	68
Total lys, %	1.39	1.44	1.44	1.39	1.44	1.44
ME, Mcal/kg	3.31	3.45	3.45	3.31	3.45	3.45
SID Lys:ME, g/Mcal	3.80	3.79	3.79	3.80	3.79	3.79
CP, %	20.5	21.0	21.0	20.8	21.3	21.3
Ca, %	0.66	0.66	0.66	0.66	0.66	0.66
P, %	0.62	0.62	0.62	0.61	0.61	0.61
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42

[1] A total of 270 nursery pigs (PIC 1050 × 337, Hendersonville, TN, initially 5.0 ± 0.1 kg BW) were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 3 diets were fed from d 23 to 44.

[2] XFE Products, Des Moines, IA.

[3] CWG: choice white grease.

[4] AV-E: AV-E Digest (XFE Products, Des Moines, IA).

[5] Provided per kg of complete feed: 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin k (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}.

[6] Provided per kg of complete feed: 16.5 mg of Cu as $CuSO_4$ $5H_2O$; 165.4 mg of Fe as $FeSO_4$ H_2O; 39.7 mg of Mn as $MnSO_4$ H_2O; 0.30 mg of Se as Na_2SeO_3; 165.4 mg of Zn as ZnO; and 0.30 mg of I as $C_2H_2(NH_2)_2$ 2HI.

[7] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg with a release of 0.10% available P.

Table 3.6 Effects of XFE Liquid Energy and choice white grease on nursery pig performance (Exp. 1)[1]

							Probability, $P <$				
		CWG[2]		Liquid energy[3]			CWG		Liquid energy		CWG vs.
Item	Control	2%	4%	2%	4%	SEM	Linear	Quadratic	Linear	Quadratic	Liquid energy
d 0 to 21											
ADG, g	628	660	670	674	665	14.0	0.05	0.52	0.08	0.12	0.75
ADFI, g	964	1000	958	1018	1012	19.8	0.83	0.11	0.09	0.22	0.08
G:F	0.652	0.660	0.699	0.662	0.657	0.0008	0.01	0.18	0.65	0.40	0.02
BW, kg											
d 0	12.3	12.3	12.3	12.3	12.3	0.19	0.99	0.97	0.99	0.96	0.99
d 21	25.5	26.1	26.3	26.4	26.2	0.37	0.11	0.59	0.15	0.21	0.80

[1] A total of 150 pigs (PIC TR4 × 1050, Hendersonville, TN, initially 12.3 ± 0.2 kg BW) were used with 5 pigs per pen and 6 pens per treatment.
[2] CWG: choice white grease.
[3] XFE Products, Des Moines, IA.

Table 3.7 Effects of combination of XFE Liquid Energy and choice white grease on nursery pig performance (Exp. 2)[1]

									Probability, $P <$			
	CWG[2], %	0	0	0	4	4	4		CWG × liquid energy			Liquid energy
Item	Liquid energy[3], %	0	2	4	0	2	4	SEM	Linear	Quad	CWG	Linear	Quad
d 0 to 14													
ADG, g		272	239	270	216	258	249	11.7	0.14	0.01	0.05	0.19	0.73
ADFI, g		384	379	396	333	365	344	20.2	0.98	0.29	0.02	0.55	0.67
G:F		0.709	0.637	0.694	0.651	0.711	0.725	0.0271	0.11	0.11	0.45	0.38	0.48
d 14 to 30													
ADG, g		518	503	507	504	529	522	18.3	0.44	0.42	0.54	0.88	0.84
ADFI, g		847	777	820	739	783	758	21.1	0.28	0.02	0.01	0.85	0.55
G:F		0.612	0.646	0.618	0.683	0.676	0.688	0.0152	0.93	0.13	0.01	0.82	0.38
d 0 to 30													
ADG, g		403	380	396	370	403	394	12.7	0.22	0.07	0.69	0.49	0.99
ADFI, g		631	591	622	550	588	565	17.1	0.48	0.03	0.01	0.84	0.87
G:F		0.639	0.643	0.637	0.674	0.685	0.699	0.0149	0.41	0.83	0.01	0.56	0.79
BW, kg													
d 0		6.4	6.4	6.4	6.4	6.4	6.4	0.05	0.96	0.93	0.99	0.94	0.99
d 30		18.5	17.8	18.3	17.5	18.5	18.2	0.40	0.24	0.08	0.70	0.51	0.99

[1] A total of 228 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 6.4 ± 0.1 kg BW) were used in a 30-d trial with 7 pens per treatment. Phase 1 diets were fed from d 0 to 14, and Phase 2 diets were fed from d 14 to 30.
[2] CWG: choice white grease.
[3] XFE Products, Des Moines, IA.

Table 3.8 Effect of AV-E Digest and XFE Liquid Energy on nursery pig performance (Exp. 3)[1]

		Treatment										
		1	2	3	4	5	6					
d 0 to 9		7.1%PEP2+, 3.75%SDAP[2]	7.1%PEP2+, 3.75%SDAP, 3%liquid energy	7.1%PEP2+, 3.75%SDAP, 3%CWG	12.5%AV-E, 2.5%SDBC	12.5%AV-E, 2.5%SDBC, 3%liquid energy	12.5%AV-E, 2.5%SDBC, 3%CWG					
d 9 to 23		3.8%PEP2+	3.8%PEP2+, 3%liquid energy	3.8%PEP2+, 3%CWG	7.5%AV-E	7.5%AV-E, 3%liquid energy	7.5%AV-E, 3%CWG					
									Probability, $P <$[3]			
Item	d 23 to 44	Control	3%liquid energy	3%CWG	2.5%AV-E	2.5%AV-E, 3%liquid energy	2.5%AV-E, 3%CWG	SEM	Protein source[4]	Liquid energy[5]	CWG[6]	Liquid energy vs. CWG[7]
d 0 to 9												
ADG, g		110	145	122	122	123	135	18.2	0.94	0.10	0.27	0.58
ADFI, g		110	125	116	120	118	124	18.1	0.60	0.45	0.57	0.86
G:F		1.011	1.151	1.028	1.029	1.030	1.095	0.0504	0.76	0.14	0.38	0.54
d 9 to 23												
ADG, g		293	327	315	339	322	358	25.9	0.05	0.61	0.23	0.50
ADFI, g		447	500	462	489	487	500	25.5	0.20	0.24	0.56	0.55
G:F		0.654	0.656	0.684	0.692	0.657	0.717	0.0253	0.13	0.38	0.15	0.02
d 23 to 44												
ADG, g		504	522	541	512	515	542	12.8	0.93	0.44	0.01	0.08
ADFI, g		799	813	807	813	828	816	21.6	0.47	0.50	0.81	0.66
G:F		0.634	0.642	0.670	0.631	0.622	0.665	0.0081	0.16	0.99	0.001	0.001
d 0 to 44												
ADG, g		356	383	383	377	373	400	15.2	0.29	0.31	0.03	0.22
ADFI, g		546	573	556	568	575	574	18.2	0.31	0.33	0.66	0.60
G:F		0.655	0.669	0.689	0.664	0.649	0.697	0.0103	0.91	0.95	0.001	0.001
BW, kg												
d 0		5.0	5.0	5.0	5.0	5.0	5.0	0.07	0.28	0.78	0.51	0.70
d 44		20.7	21.8	21.8	21.6	21.4	22.6	0.71	0.35	0.33	0.03	0.24

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

[1] A total of 270 weanling pigs (PIC 1050 × 337, Hendersonville, TN, initially 5.0 ± 0.1 kg BW) were used with 5 pigs per pen and 9 pens per treatment.

[2] SDAP: spray-dried animal plasma (AP920; APC, Inc., Ames, IA); liquid energy: XFE Liquid Energy (XFE Products, Des Moines, IA); CWG: choice white grease; SDBC: spray-dried blood cells (AP302G APC, Inc., Ames, IA); AV-E: AV-E Digest (XFE Products, Des Moines, IA).

[3] No protein × energy sources interaction, $P > 0.05$.

[4] Protein source = Treatment 1, 2, and 3 vs. Treatment 4, 5, and 6.

[5] Liquid energy = Treatment 1 and 4 vs. Treatment 2 and 5.

[6] CWG = Treatment 1 and 4 vs. Treatment 3 and 6.

[7] Liquid energy vs. CWG = Treatment 2 and 5 vs. Treatment 3 and 6.