# The effects of immunological castration and corn dried distillers grains with solubles withdrawal on growth performance, carcass characteristics, fatty acid analysis, and iodine value of pork fat depots[1,2]

**M.D. Asmus,* M.A. Tavarez,† M.D. Tokach,*[3] S.S. Dritz,‡ A.L. Schroeder,§ J.L. Nelssen,* R.D. Goodband,* and J.M. DeRouchey***

*Department of Animal Sciences and Industry, College of Agriculture, Kansas State University, Manhattan 66506, †Department of Animal Sciences, University of Illinois, Urbana 61801; ‡Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan 66506, and § Zoetis, Kalamazoo, MI 49007

**ABSTRACT:** A total of 1,360 pigs were used in a 125-d study to determine the effects of corn dried distillers grains with solubles (DDGS) withdrawal after immunological castration (Improvest, Zoetis, Kalamazoo, MI) on growth performance and carcass fat quality of pigs. Pens of male pigs (initially 24 kg) were randomly allotted by BW and castration method (physically castrated [PC] or immunologically castrated [IC] barrows) to 1 of 3 diets with 8 replications per treatment and 27 to 29 pigs per pen. Treatments were arranged in a 2 × 3 factorial with main effects of castration method and diet (0% DDGS throughout, 30% DDGS throughout, or 30% DDGS through d 75 then no DDGS to d 125). Intact males were injected with Improvest on d 39 and 74 (IC). No castration method × diet interactions ($P > 0.12$) were observed for growth performance. Before the second Improvest injection (d 0 to 74), PC barrows had increased ($P < 0.05$) ADFI but were less efficient ($P < 0.05$) than intact males. After the second Improvest injection until the first marketing event (d 74 to 107), IC barrows had improved ($P < 0.05$) ADG and G:F compared with PC barrows. From d 0 to 107, IC barrows had improved ($P < 0.05$) ADG, G:F, and lower ADFI than PC barrows. The inclusion of 30% DDGS decreased ($P < 0.05$) G:F compared with pigs fed the control diet. For the period after the second Improvest injection (d 74 to 125), IC barrows had increased ($P < 0.05$) ADG, ADFI, and G:F compared with PC barrows. Overall (d 0 to 125), IC barrows had improved ($P < 0.05$) ADG and G:F and lower ADFI than PC barrows. The inclusion of 30% DDGS decreased ($P < 0.05$) G:F. Carcass yield was lower ($P < 0.05$) for IC than PC barrows. Pigs fed 30% DDGS throughout had decreased ($P < 0.05$) carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss. Carcass fat iodine values (IV) were consistently higher ($P < 0.05$), regardless of fat depot or harvest time when 30% DDGS were included in the diet. Multiple 2-way interactions ($P < 0.05$) were detected between castration method, DDGS, depot, and time. Interactions were a result of fatty acid profiles changing more rapidly in backfat and belly fat than in jowl fat from d 107 to 125 and more dramatically in IC than PC barrows in the same period. This improvement from d 107 to 125 could be caused by the dilution of unsaturated fatty acids, specifically C18:2 and C18:3, due to rapid deposition of fat from de novo synthesis in IC barrows.

**Key words:** dried distiller grains, fatty acids, immunologic castration, pigs, withdrawal



J. Anim. Sci. 2014.92:2116–2132
doi:10.2527/jas2013-6910

## INTRODUCTION

Byproducts such as dried distillers grains with solubles (**DDGS**) are often used in swine diets to lower feed costs, but they have been shown to negatively affect carcass yield and fat quality (Whitney et al., 2006; Linneen et al., 2008; Stein and Shurson, 2009). A high carcass fat iodine value (**IV**) is associated with more unsaturated fat and has consistently been observed

[1]Contribution no. 13–398-J from the Kansas Agric. Exp. Sta., Manhattan, KS 66506–0210.

[2]Appreciation is expressed to New Horizon Farms for use of pigs and facilities; to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance; to Zoetis (Kalamazoo, MI) for partial financial support of this project; and to John Ymker and Amanda Koele at Natural Food Holdings (Sioux Center, IA) for technical assistance.

[3]Corresponding author: mtokach@ksu.edu.

Received July 15, 2013.
Accepted March 8, 2014.

in pigs fed DDGS (Hill et al., 2008; Benz et al., 2010). However, removing DDGS as the source of unsaturated fat from the diet before harvest lowers carcass fat IV (Jacela et al., 2010; Xu et al., 2010a; Asmus et al., 2014).

Immunization against gonadotropin-releasing factor (Improvest; Zoetis, Kalamazoo, MI) allows pigs to perform as intact males until the second immunization injection (Dunshea et al., 2001). After the second immunization, feed intake and growth rate increase rapidly (Dunshea et al., 2001; Cronin et al., 2003; Zamaratskaia et al., 2008). Because intact males deposit less fat than barrows (Knudson et al., 1985), our hypothesis was that intact males would deposit less fat before the second dose, with a greater portion of their total fat deposition occurring late in the finishing stage (Rikard-Bell et al., 2009). Thus, we speculated that feeding high levels of unsaturated fat before the second dose may have less overall impact on carcass fat IV when less unsaturated fat (from DDGS) is fed during the post–second dose phase before market.

Previous research has shown that reducing the dietary level of DDGS before harvest improves carcass yield and fat quality (Gaines et al., 2007a; Hill et al., 2008; Xu et al., 2010a); however, no studies have determined the impact of DDGS feeding strategy in combination with immunological castration. The objective of this study was to determine the effects of withdrawing DDGS from the diets of barrows and immunological castrates before market on growth performance and carcass fat quality of growing-finishing pigs.

## MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee (Manhattan, KS) approved the protocol used in this experiment.

### *General*

The study was conducted at a commercial research-finishing barn in southwestern Minnesota. The facility was double-curtain-sided with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 3.0 × 5.5 m. Each pen was equipped with a single-sided, 152.4-cm-wide, 5-hole, stainless steel dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. Pigs had ad libitum access to feed and water throughout the study.

**Table 1.** Phase 1 and 2 diet composition (as-fed basis)[1]

| | Phase 1, % DDGS[2] | | Phase 2, % DDGS | |
|---|---|---|---|---|
| Item | 0 | 30 | 0 | 30 |
| Ingredient, % | | | | |
| Corn | 67.85 | 45.25 | 72.90 | 50.20 |
| Soybean meal, 46.5% CP | 29.45 | 22.40 | 24.70 | 17.55 |
| DDGS | – | 30 | – | 30 |
| Monocalcium P, 21% P | 0.60 | – | 0.45 | – |
| Limestone | 0.90 | 1.20 | 0.90 | 1.20 |
| Salt | 0.35 | 0.35 | 0.35 | 0.35 |
| VTM[3] | 0.09 | 0.09 | 0.09 | 0.09 |
| L-Thr | 0.09 | 0.04 | 0.08 | 0.03 |
| DL-Met | 0.12 | 0.01 | 0.07 | – |
| L-Lys sulfate | 0.51 | 0.64 | 0.45 | 0.58 |
| Phytase[4] | 0.01 | 0.01 | 0.01 | 0.01 |
| Calculated analysis | | | | |
| Standardized ileal digestible (SID) AA | | | | |
| Lys, % | 1.14 | 1.14 | 1.00 | 1.00 |
| Met:Lys, % | 32 | 29 | 30 | 30 |
| Met & Cys:Lys, % | 56 | 56 | 56 | 60 |
| Thr:Lys, % | 62 | 62 | 63 | 63 |
| Trp:Lys, % | 18 | 18 | 18 | 18 |
| Total Lys, % | 1.26 | 1.33 | 1.11 | 1.18 |
| CP, % | 19.9 | 22.9 | 18.1 | 21.0 |
| SID Lys:ME, g/Mcal | 3.41 | 3.39 | 2.98 | 2.98 |
| ME, kcal/kg | 3,340 | 3,353 | 3,346 | 3,355 |
| Ca, % | 0.57 | 0.55 | 0.53 | 0.54 |
| Available P, % | 0.3 | 0.32 | 0.27 | 0.32 |
| Laboratory analysis, % | | | | |
| CP | 19.2 | 23.1 | 17.8 | 20.8 |
| Crude fat | 3.0 | 5.1 | 2.8 | 5.0 |
| ADF | 3.3 | 5.9 | 3.4 | 6.1 |
| NDF | 8.2 | 12.8 | 8.8 | 13.2 |
| Crude fiber | 2.3 | 3.9 | 2.4 | 4.1 |

[1]Phase 1 and 2 diets were fed from d 0 to 25 and 25 to 53 (approximately 24 to 45 kg and 45 to 68 kg), respectively.

[2]DDGS = corn dried distillers grains with solubles.

[3]VTM = vitamin and trace mineral premix.

[4]Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per kilogram of diet: 998.8 phytase units (FTU)/kg and 0.11% available P released.

### *Animals and Diets*

A total of 1,360 pigs (Line 337 × 1050: PIC Hendersonville, TN; initially 24.1 kg) were used in a 125-d study. To minimize maternal effects, all pigs used in the study were individually tagged and tattooed at birth in sequential order with the same number of pigs used from each litter. All odd-numbered pigs were left intact and even-numbered pigs were physically castrated (**PC**) at 2 d of age per standard farm procedures. At weaning (~19 d of age), all pigs were transported to the commercial wean-to-finish barn and placed in pens by castration method with 56 pigs per pen. Pens on one half of the barn were randomly assigned to 1 of the 6 treatments (2 castration methods × 3 dietary treatments) in a completely randomized manner. The other half of the

**Table 2.** Phase 3, 4, and 5 diet composition (as-fed basis)[1]

| Item | Phase 3, % DDGS[2] | | Phase 4, % DDGS | | Phase 5, % DDGS | |
|---|---|---|---|---|---|---|
| | 0 | 30 | 0 | 30 | 0 | 30 |
| Ingredient, % | | | | | | |
| Corn | 75.75 | 53.00 | 80.10 | 57.15 | 85.30 | 62.25 |
| Soybean meal, 46.5% CP | 22.00 | 14.75 | 17.80 | 10.70 | 12.75 | 5.65 |
| DDGS | – | 30 | – | 30 | – | 30 |
| Monocalcium P, 21% P | 0.35 | – | 0.30 | – | 0.30 | – |
| Limestone | 0.90 | 1.20 | 0.85 | 1.20 | 0.85 | 1.20 |
| Salt | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| VTM[3] | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| L-Thr | 0.07 | 0.02 | 0.06 | 0.02 | 0.03 | – |
| DL-Met | 0.04 | – | 0.03 | – | – | – |
| L-Lysine sulfate | 0.42 | 0.55 | 0.37 | 0.50 | 0.31 | 0.44 |
| Phytase[4] | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Calculated analysis | | | | | | |
| Standardized ileal digestible (SID) AA | | | | | | |
| Lys, % | 0.92 | 0.92 | 0.80 | 0.80 | 0.65 | 0.65 |
| Met: Lys, % | 29 | 31 | 30 | 34 | 31 | 39 |
| Met & Cys: Lys, % | 56 | 63 | 59 | 68 | 63 | 78 |
| Thr: Lys, % | 64 | 64 | 66 | 66 | 66 | 69 |
| Trp: Lys, % | 18 | 18 | 18 | 18 | 18 | 18 |
| Total Lys, % | 1.03 | 1.09 | 0.9 | 0.96 | 0.73 | 0.8 |
| CP, % | 17.0 | 20.0 | 15.4 | 18.4 | 13.4 | 16.4 |
| SID Lys:ME, g/Mcal | 2.74 | 2.74 | 2.38 | 2.38 | 1.93 | 1.93 |
| ME, kcal/kg | 3,351 | 3,355 | 3,355 | 3,357 | 3,355 | 3,357 |
| Ca, % | 0.50 | 0.53 | 0.46 | 0.52 | 0.45 | 0.50 |
| Available P, % | 0.24 | 0.31 | 0.23 | 0.31 | 0.22 | 0.3 |
| Laboratory analysis, % | | | | | | |
| CP | 15.7 | 21.0 | 15.2 | 18.8 | 13.0 | 16.8 |
| Crude fat | 2.6 | 5.2 | 3.0 | 5.4 | 3.1 | 5.3 |
| ADF | 2.9 | 5.6 | 3.2 | 5.7 | 3.1 | 5.5 |
| NDF | 8.0 | 13.4 | 8.5 | 13.1 | 8.4 | 13.8 |
| Crude fiber | 2.2 | 4.1 | 2.3 | 4.0 | 2.2 | 3.7 |

[1]Phase 3, 4, and 5 diets were fed from d 53 to 74, 74 to 87, and 87 to 125 (approximately 68 to 90 kg, 90 to 103 kg, and 103 to 133 kg), respectively.

[2]DDGS = corn dried distillers grains with solubles.

[3]VTM = vitamin and trace mineral premix.

[4]Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per kilogram of diet: 998.8 phytase units (FTU)/kg and 0.11% available P released.

barn was stocked with gilts. When pigs reached ~24 kg BW, all gilts were removed and half the pigs within each pen (barrow or intact male) were moved to a pen across the aisle. Thus, each initial pen (56 pigs) was split into 2 replicate pens (~28 pigs). Dietary treatments were based on DDGS feeding (0% throughout, 30% throughout, or 30% from d 0 to 74 and no DDGS fed from d 74 to market). Dietary treatments were corn–soybeanmeal based and fed in 5 phases (Tables 1 and 2). All diets were fed in meal form and balanced to similar standardized ileal digestible Lys:ME ratios. Diets were formulated to meet or exceed the amino acid requirements in each phase, including the requirements of intact males before immunological castration. The same source of DDGS was used throughout the study, with analyzed values of 0.86% lysine, 27.3% CP, and 10.7% ether extract. Diets were analyzed at Ward Laboratories, Inc. (Kearney, NE) for CP (AOAC, 2006; method 990.03), crude fat (AOAC, 2006; method 920.39 A), ADF (ANKOM Technology, Macedon, NY), NDF (ANKOM Technology), and crude fiber (AOAC, 2006; method 978.10). Phytase was added to all diets at a constant level of 0.01% of the diet, which provided 998.8 phytase units/kg of complete diet. Therefore, the 6 treatments for the overall period were arranged in a 2 × 3 factorial with the main effects of castration method (PC vs. immunologically castrated [**IC**] barrow) and DDGS feeding (0, 30%, or 30% then 0% DDGS). This resulted in 8 intact male and 8 barrow pen replications per dietary treatment.

All intact male pigs were immunized against gonadotropin-releasing factor through administration of Improvest (Zoetis, Kalamazoo, MI) by a certified injection team (**ZTS**). Intact males were injected with a 2-mL primer dose on d 39 (~110 d of age) and second

**Table 3**. Effects of corn dried distillers grains with solubles (DDGS) level and withdrawal on growth performance of physically- and immunologically-castrated barrows[1]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | | Probability, $P <$ | | | | |
| d 0 to 74: | Corn–soy | 30% DDGS | 30% DDGS | Corn–soy | 30% DDGS | 30% DDGS | | | Castration | | DDGS | DDGS |
| d 74 to 125: | Corn–soy | Corn–soy | 30% DDGS | Corn–soy | Corn–soy | 30% DDGS | SEM | Interaction[3] | method[4] | Diet[5] | before[6] | withdrawal[6] |
| d 0 to 25 | | | | | | | | | | | | |
| ADG, kg | 0.904 | 0.860 | 0.855 | 0.874 | 0.817 | 0.835 | 0.013 | 0.659 | 0.005 | <0.001 | <0.001 | |
| ADFI, kg | 1.578 | 1.538 | 1.516 | 1.469 | 1.426 | 1.451 | 0.032 | 0.71 | <0.001 | 0.350 | 0.150 | |
| G:F | 0.573 | 0.559 | 0.567 | 0.597 | 0.573 | 0.576 | 0.010 | 0.747 | 0.059 | 0.136 | 0.055 | |
| d 25 to 53 | | | | | | | | | | | | |
| ADG, kg | 0.813 | 0.780 | 0.786 | 0.812 | 0.787 | 0.789 | 0.014 | 0.945 | 0.783 | 0.079 | 0.027 | |
| ADFI, kg | 1.840 | 1.940 | 1.813 | 1.632 | 1.666 | 1.678 | 0.040 | 0.222 | <0.001 | 0.200 | 0.272 | |
| G:F | 0.443 | 0.402 | 0.435 | 0.499 | 0.474 | 0.471 | 0.008 | 0.118 | <0.001 | 0.001 | <0.001 | |
| d 53 to 74 | | | | | | | | | | | | |
| ADG, kg | 1.072 | 1.076 | 1.081 | 1.078 | 1.064 | 1.049 | 0.019 | 0.613 | 0.421 | 0.861 | 0.640 | |
| ADFI, kg | 2.635 | 2.604 | 2.648 | 2.378 | 2.346 | 2.325 | 0.040 | 0.628 | <0.001 | 0.731 | 0.462 | |
| G:F | 0.407 | 0.413 | 0.408 | 0.454 | 0.453 | 0.451 | 0.005 | 0.778 | <0.001 | 0.687 | 0.790 | |
| d 74 to 87 | | | | | | | | | | | | |
| ADG, kg | 0.978 | 0.973 | 0.999 | 1.026 | 1.026 | 0.997 | 0.018 | 0.224 | 0.026 | 0.978 | 0.850 | 0.926 |
| ADFI, kg | 2.995 | 3.014 | 3.023 | 2.669 | 2.767 | 2.688 | 0.051 | 0.637 | <0.001 | 0.507 | 0.349 | 0.492 |
| G:F | 0.327 | 0.323 | 0.331 | 0.385 | 0.371 | 0.371 | 0.005 | 0.217 | <0.001 | 0.216 | 0.121 | 0.415 |
| d 87 to 107 | | | | | | | | | | | | |
| ADG, kg | 0.910 | 0.923 | 0.962 | 1.021 | 1.064 | 1.093 | 0.030 | 0.880 | <0.001 | 0.133 | 0.093 | 0.264 |
| ADFI, kg | 3.028 | 3.205 | 3.227 | 3.337 | 3.441 | 3.548 | 0.078 | 0.839 | <0.001 | 0.036 | 0.014 | 0.412 |
| G:F | 0.300 | 0.288 | 0.299 | 0.307 | 0.309 | 0.308 | 0.007 | 0.469 | 0.032 | 0.660 | 0.641 | 0.436 |
| d 107 to 125 | | | | | | | | | | | | |
| ADG, kg | 0.937 | 0.975 | 0.959 | 1.038 | 1.058 | 1.038 | 0.030 | 0.929 | <0.001 | 0.618 | 0.446 | 0.540 |
| ADFI, kg | 3.048 | 3.038 | 3.250 | 3.313 | 3.422 | 3.674 | 0.060 | 0.392 | <0.001 | <0.001 | 0.003 | <0.001 |
| G:F | 0.307 | 0.321 | 0.295 | 0.313 | 0.309 | 0.283 | 0.006 | 0.236 | 0.252 | <0.001 | 0.139 | <0.001 |

[1]A total of 1,360 pigs (PIC 337 × 1050, initially 24 kg) were used in a 125-d study.

[2]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[3]Interaction castration method × diet.

[4]Main effect of castration method (treatments 1, 2, and 3 vs. 4, 5, and 6).

[5]Main effect of diet type (corn–soy or 30% DDGS).

[6]Effect of DDGS before second injection (treatments 1 and 4 vs. 2, 3, 5, and 6).

[7]Effect of withdrawing DDGS after second injection (treatments 2 and 5 vs. 3 and 6).

2-mL dose on d 74 (~145 d of age) in the high lateral aspect of the neck. A ZTS quality assurance check was performed on d 88 to ensure all pigs received both doses and did not exhibit any signs of typical boar behavior. Any pig thought to be a "suspect pig" (21 total) was redosed with an additional 2 mL of Improvest in the high lateral aspect of the neck, and the individual pig ID was recorded.

Pens of pigs were weighed and feed disappearance was recorded on d 0, 25, 53, 74, 87, 107, and 125 to determine ADG, ADFI, and G:F. On d 107 (~180 d of age), all pigs were weighed individually, and the 9 heaviest pigs per pen were tattooed by pen to be transported to Natural Food Holdings (Sioux Center, IA). At d 107, the 4 pigs closest to the pen median weight in each pen (32 pigs per treatment) were also identified to gain representative fat samples over time. These pigs were individually tattooed with a unique number (1 through 192), and the 2 heaviest median pigs per pen (16 per treatment) were transported with the 9 heaviest pigs to Natural Food Holdings for harvest. During harvest, the 2 selected median-weight pigs were sequenced with a unique number corresponding to the tattoo given at the farm to allow for further tracking. The day after harvest, the left side of each carcass was transported by refrigerated truck to the University of Illinois Meat Sciences Laboratory (Urbana, IL) for full carcass breakdown. Standard carcass criteria of HCW and percentage carcass yield were collected on all pigs harvested. The other 2 median-weight pigs remained in their respective pens and were harvested on d 125, then transported to the University of Illinois Meat Sciences Laboratory (Champaign, IL) for carcass processing. Fat samples were collected for both harvest dates from 4 fat depots (jowl, backfat between 10th and 11th rib, clear plate at the top of the boston butt between first and second rib, and belly) at the

**Table 4.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on overall growth performance of physical and immunologically castrated barrows[1]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | | Probability, $P <$ | | | | |
| d 0 to 74: | Corn–soy | 30% DDGS | 30% DDGS | Corn–soy | 30% DDGS | 30% DDGS | | | Castration | | DDGS | DDGS |
| d 74 to 125: | Corn–soy | Corn–soy | 30% DDGS | Corn–soy | Corn–soy | 30% DDGS | SEM | Interaction[3] | method[4] | Diet[5] | before[6] | withdrawal[6] |
| Weight, kg | | | | | | | | | | | | |
| d 0 | 24.2 | 24.3 | 24.3 | 24.0 | 24.1 | 24.0 | 0.526 | 0.995 | 0.636 | 0.997 | 0.960 | |
| d 25 | 46.8 | 45.8 | 45.6 | 45.9 | 44.6 | 45.0 | 0.793 | 0.954 | 0.169 | 0.261 | 0.105 | |
| d 53 | 69.7 | 67.7 | 67.7 | 68.8 | 67.0 | 67.2 | 0.927 | 0.976 | 0.365 | 0.083 | 0.027 | |
| d 74 | 92.3 | 90.4 | 90.4 | 91.5 | 89.4 | 89.5 | 0.968 | 0.996 | 0.287 | 0.071 | 0.022 | |
| d 87 | 105.0 | 103.0 | 103.4 | 104.9 | 102.8 | 102.6 | 1.003 | 0.935 | 0.666 | 0.077 | 0.024 | 0.901 |
| d 107 | 117.1 | 115.6 | 115.9 | 119.9 | 117.8 | 118.1 | 1.358 | 0.957 | 0.036 | 0.369 | 0.164 | 0.847 |
| d 125 | 133.9 | 133.7 | 133.2 | 138.6 | 137.0 | 137.0 | 1.458 | 0.892 | 0.002 | 0.698 | 0.408 | 0.872 |
| d 0 to 74 | | | | | | | | | | | | |
| ADG, kg | 0.916 | 0.889 | 0.891 | 0.907 | 0.873 | 0.877 | 0.009 | 0.924 | 0.082 | 0.002 | <0.001 | 0.738 |
| ADFI, kg | 1.970 | 1.985 | 1.942 | 1.784 | 1.770 | 1.780 | 0.026 | 0.597 | <0.001 | 0.768 | 0.737 | 0.522 |
| G:F | 0.465 | 0.448 | 0.460 | 0.509 | 0.494 | 0.493 | 0.005 | 0.343 | <0.001 | 0.003 | 0.001 | 0.245 |
| d 74 to 107 | | | | | | | | | | | | |
| ADG, kg | 0.937 | 0.943 | 0.977 | 1.023 | 1.049 | 1.054 | 0.021 | 0.775 | <0.001 | 0.238 | 0.157 | 0.350 |
| ADFI, kg | 3.014 | 3.128 | 3.144 | 3.065 | 3.168 | 3.198 | 0.063 | 0.993 | 0.353 | 0.098 | 0.034 | 0.715 |
| G:F | 0.311 | 0.301 | 0.311 | 0.334 | 0.331 | 0.330 | 0.005 | 0.510 | <0.001 | 0.399 | 0.298 | 0.385 |
| d 74 to 125 | | | | | | | | | | | | |
| ADG, kg | 0.937 | 0.951 | 0.973 | 1.027 | 1.051 | 1.050 | 0.017 | 0.808 | <0.001 | 0.238 | 0.114 | 0.553 |
| ADFI, kg | 3.022 | 3.105 | 3.170 | 3.127 | 3.228 | 3.314 | 0.052 | 0.933 | 0.005 | 0.009 | 0.006 | 0.153 |
| G:F | 0.310 | 0.306 | 0.307 | 0.329 | 0.325 | 0.317 | 0.004 | 0.438 | <0.001 | 0.191 | 0.114 | 0.364 |
| d 0 to 107 | | | | | | | | | | | | |
| ADG, kg | 0.922 | 0.905 | 0.917 | 0.942 | 0.925 | 0.929 | 0.010 | 0.912 | 0.032 | 0.221 | 0.127 | 0.407 |
| ADFI, kg | 2.280 | 2.333 | 2.300 | 2.164 | 2.183 | 2.199 | 0.033 | 0.801 | <0.001 | 0.577 | 0.302 | 0.883 |
| G:F | 0.405 | 0.389 | 0.399 | 0.436 | 0.424 | 0.423 | 0.004 | 0.369 | <0.001 | 0.006 | 0.002 | 0.294 |
| d 0 to 125 | | | | | | | | | | | | |
| ADG, kg | 0.924 | 0.911 | 0.921 | 0.950 | 0.936 | 0.939 | 0.009 | 0.891 | 0.003 | 0.374 | 0.211 | 0.530 |
| ADFI, kg | 2.346 | 2.389 | 2.383 | 2.265 | 2.290 | 2.329 | 0.031 | 0.756 | 0.003 | 0.264 | 0.124 | 0.592 |
| G:F | 0.394 | 0.382 | 0.387 | 0.420 | 0.409 | 0.403 | 0.004 | 0.292 | <0.001 | 0.004 | <0.001 | 0.930 |

[1]A total of 1,360 pigs (PIC 337 × 1,050, initially 24 kg) were used in a 125-d study.

[2]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[3]Interaction castration method × diet.

[4]Main effect of castration method (treatments 1, 2, and 3 vs. 4, 5, and 6).

[5]Main effect of diet type (corn–soy or 30% DDGS).

[6]Effect of DDGS before second injection (treatments 1 and 4 vs. 2, 3, 5, and 6).

[7]Effect of withdrawing DDGS after second injection (treatments 2 and 5 vs. 3 and 6).

University of Illinois Meat Sciences Laboratory. These fat samples were then transported frozen to the Kansas State University Analytical Lab (Manhattan, KS) for full fatty acid analyses. Backfat depth was measured at the 10th rib, and percentage lean was calculated using the equation (SFK Technologies; Herlev, Denmark): = 58.86 – (backfat × 0.61) + (loin depth × 0.12). All harvested pigs were utilized in calculating percentage yield, which was calculated by dividing HCW at the slaughter plant by live weight at the slaughter plant.

For fatty acid analysis, fat samples were thawed and dissected to separate adipose tissue from skin and lean tissue as needed. Care was taken to uniformly sample all backfat layers. All fat tissues were cut and then frozen in a bath of liquid nitrogen, then ground into fine particles by a blender (Dynamics Corp. of America, New Hartford, CT). Approximately 50 µg of ground fat 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], then heated in a water bath for 120 min at 70°C 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. Injection port and detector temperatures were 250°C, with a flow rate of 1 mL/min helium and a split ratio of 100:1. Oven temperature began at 140°C, increased at

**Table 5.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on carcass characteristics of physical and immunologically castrated barrows

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | | | | | | | |
| d 0 to 74: | Corn–soy | 30% DDGS | 30% DDGS | Corn–soy | 30% DDGS | 30% DDGS | | | | | | | |
| d 74 to 125: | Corn–soy | Corn–soy | 30% DDGS | Corn–soy | Corn–soy | 30% DDGS | SEM | Castration × time[2,3] | Castration × DDGS[4] | DDGS × time[5] | Castration method[6] | DDGS[7] | Time[8] |
| HCW, kg[9] | | | | | | | | | | | | | |
| d 107 | 94.7 | 93.6 | 93.1 | 95.0 | 94.5 | 92.9 | 0.94 | | | | | | |
| d 125 | 97.0 | 96.7 | 95.5 | 98.4 | 97.2 | 96.3 | 1.04 | 0.636 | 0.922 | 0.999 | 0.284 | 0.036 | <0.001 |
| Yield, %[9] | | | | | | | | | | | | | |
| d 107 | 76.6 | 76.4 | 75.9 | 74.8 | 74.8 | 73.6 | 0.13 | | | | | | |
| d 125 | 76.3 | 76.2 | 75.8 | 74.9 | 74.8 | 74.0 | 0.16 | 0.030 | 0.050 | 0.426 | <0.001 | <0.001 | 0.564 |
| Backfat depth, mm [10,11] | | | | | | | | | | | | | |
| d 107 | 20.02 | 20.65 | 21.45 | 17.31 | 17.97 | 20.35 | 1.14 | | | | | | |
| d 125 | 25.98 | 22.81 | 24.21 | 24.34 | 24.69 | 23.22 | 1.14 | 0.155 | 0.533 | 0.077 | 0.068 | 0.626 | 0.970 |
| Loin depth, mm [10,11] | | | | | | | | | | | | | |
| d 107 | 68.17 | 68.11 | 66.60 | 66.22 | 67.77 | 65.64 | 1.25 | | | | | | |
| d 125 | 66.24 | 68.18 | 69.13 | 68.27 | 67.47 | 67.64 | 1.25 | 0.487 | 0.770 | 0.336 | 0.428 | 0.708 | 0.376 |
| Loin area, mm [10,11] | | | | | | | | | | | | | |
| d 107 | 49.49 | 47.95 | 48.43 | 51.10 | 48.79 | 48.86 | 1.24 | | | | | | |
| d 125 | 55.32 | 54.47 | 55.56 | 54.61 | 53.98 | 54.66 | 1.25 | 0.258 | 0.924 | 0.583 | 0.855 | 0.332 | 0.158 |
| Percentage lean [10,11] | | | | | | | | | | | | | |
| d 107 | 54.83 | 54.44 | 53.77 | 56.25 | 56.03 | 54.32 | 0.74 | | | | | | |
| d 125 | 50.96 | 53.13 | 52.39 | 52.20 | 51.89 | 52.82 | 0.74 | 0.233 | 0.521 | 0.063 | 0.121 | 0.575 | 0.885 |

[1]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[2]No 3 or 4 way interactions occurred ($P > 0.34$).

[3]Castration method × time (d 107 or 125) interaction.

[4]Castration method × DDGS (0% throughout, 30% then withdraw, 30% throughout) interaction.

[5]DDGS (0% throughout, 30% then withdraw, 30% throughout) × time (d 107 or 125) interaction.

[6]Main effect of castration method.

[7]Main effect of DDGS (0% throughout, 30% then withdraw, 30% throughout).

[8]Main effect of time (d 107 or 125).

[9]Data include all pigs harvested on d 107 (528 pigs; 9 heaviest and 2 median-weight pigs per pen; 8 pens per treatment) and on d 125 (739 pigs; 2 median-weight pigs identified on d 107 and all remaining pigs; 8 pens per treatment).

[10]Data include only pigs sent to University of Illinois for carcass analysis (2 pigs per pen for a total of 96 pigs on d 107 and 96 pigs on d 125). These pigs were identified as median-weight pigs on d 107.

[11]Covariate was used to adjust to a common HCW within day.

2°C/min to 200°C, increased at 4°C/min to 245°C, and was held for 17 min. Iodine value was calculated using the equation (AOCS, 1998): 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).

### *Statistical Analysis*

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The main effects of castration method and DDGS during withdrawal, as well as interactive effects, were tested. For carcass characteristics and fatty acid analysis, interactive effects of DDGS, harvest time, fat depot, and castration method were tested using repeated measures. Additionally, preplanned single degree of freedom contrasts were used to compare pigs not fed DDGS with those fed DDGS before second injection (treatments 1 and 4 vs. 2, 3, 5, and 6) and to determine the effect of withdrawing DDGS after second injection (treatments 2 and 5 vs. 3 and 6). Means are reported as least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

## RESULTS

### *Growth Performance*

No castration method × diet interactions ($P > 0.12$) occurred for any growth performance measurements. The PC barrows had greater ($P < 0.05$) ADG (0.87 vs. 0.84 kg) than intact males from d 0 to 25 (Table 3), which resulted in a tendency for PC barrows to have greater ($P < 0.10$) ADG (0.90 vs. 0.89 kg) than intact males before the second Improvest immunization (d 0

**Table 6.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on belly fatty acid analysis of physical and immunologically castrated barrows harvested at d 107[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.40 | 1.36 | 1.31 | 1.35 | 1.29 | 1.22 | 0.03 |
| Palmitic acid (C16:0), % | 24.50 | 23.28 | 22.56 | 23.60 | 23.38 | 22.27 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.59 | 2.38 | 2.26 | 2.52 | 2.16 | 2.11 | 0.09 |
| Margaric acid (C17:0), % | 0.55 | 0.58 | 0.63 | 0.54 | 0.54 | 0.57 | 0.03 |
| Stearic acid (C18:0), % | 12.43 | 11.40 | 10.85 | 12.67 | 12.82 | 11.11 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 39.12 | 37.44 | 36.13 | 37.89 | 36.29 | 35.58 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.77 | 3.50 | 3.34 | 3.71 | 3.35 | 3.22 | 0.08 |
| Linoleic acid (C18:2n-6), % | 11.63 | 15.64 | 18.37 | 13.49 | 15.89 | 19.32 | 0.52 |
| α-linoleic acid (C18:3n-3), % | 0.52 | 0.59 | 0.64 | 0.60 | 0.60 | 0.65 | 0.02 |
| Arachidic acid (C20:0), % | 0.25 | 0.24 | 0.25 | 0.23 | 0.26 | 0.24 | 0.01 |
| Gadoleic acid (C20:1), % | 0.82 | 0.82 | 0.78 | 0.75 | 0.77 | 0.77 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.66 | 0.85 | 0.93 | 0.74 | 0.83 | 1.00 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.23 | 0.26 | 0.27 | 0.29 | 0.30 | 0.30 | 0.01 |
| Other fatty acids, % | 1.54 | 1.65 | 1.66 | 1.62 | 1.53 | 1.62 | 0.05 |
| Total SFA, %[4] | 39.39 | 37.12 | 35.83 | 38.66 | 38.54 | 35.67 | 0.56 |
| Total MUFA, %[5] | 46.37 | 44.22 | 42.59 | 44.96 | 42.64 | 41.76 | 0.56 |
| Total PUFA, %[6] | 13.24 | 17.57 | 20.44 | 15.35 | 17.82 | 21.50 | 0.57 |
| Total *trans* fatty acids, %[7] | 0.79 | 0.91 | 0.94 | 0.88 | 0.85 | 0.94 | 0.03 |
| UFA:SFA ratio[8] | 1.52 | 1.67 | 1.77 | 1.58 | 1.59 | 1.79 | 0.04 |
| PUFA:SFA ratio[9] | 0.34 | 0.48 | 0.58 | 0.40 | 0.47 | 0.61 | 0.02 |
| Iodine value, g/100g[10] | 62.07 | 67.41 | 70.86 | 64.32 | 66.40 | 71.79 | 0.81 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

to 74; Table 4). Intact males had decreased ($P < 0.05$) ADFI and improved ($P < 0.05$) G:F for all periods before the second immunization. Immediately after the second immunization (d 74 to 87), IC barrows continued to have lower ($P < 0.05$) ADFI (2.71 vs. 3.01 kg) but grew faster ($P < 0.05$) than PC barrows (1.02 vs. 0.98 kg), resulting in improved ($P < 0.05$) G:F (0.38 vs. 0.33). After this 2-wk period, feed intake increased in IC barrows such that they had greater ($P < 0.05$) ADFI for the last 2 phases of the trial (d 87 to 107 and d 107 to 125) than PC barrows. The higher feed intake allowed IC barrows to have greater ($P < 0.05$) ADG during the last 2 phases than PC barrows. Feed efficiency was also better ($P < 0.05$) from d 87 to 107 for IC barrows but was similar to that of PC barrows between d 107 and 125.

For the period after the second Improvest injection until the first marketing event (d 74 to 107), IC barrows had increased ($P < 0.05$) ADG (1.04 vs. 0.95 kg) and were more feed efficient ($P < 0.05$; 0.33 vs. 0.31) than PC barrows. From d 0 to 107, IC barrows had improved ($P < 0.05$) ADG (0.93 vs. 0.92 kg) and G:F (0.43 vs. 0.40) and lower ($P < 0.05$) ADFI (2.18 vs. 2.30 kg) than PC barrows. The inclusion of 30% DDGS did not influence ADG or ADFI regardless of withdrawal or castration method but did reduce ($P < 0.05$) G:F.

For the period after the second Improvest immunization to the end of the trial (d 74 to 125; 51 d after the second dose), IC barrows had increased ($P < 0.05$) ADG (1.04 vs. 0.95 kg) and ADFI (3.22 vs. 3.10 kg) and were more feed efficient ($P < 0.05$; 0.33 vs. 0.31) than PC barrows. Overall (d 0 to 125), IC barrows had improved ($P < 0.05$) ADG (0.94 vs. 0.92 kg) and G:F (0.41 vs. 0.39) and lower ADFI (2.30 vs. 2.37 kg) than PC barrows. The inclusion of 30% DDGS again did

**Table 7.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on clear plate fatty acid analysis of physical and immunologically castrated barrows harvested at d 107[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.36 | 1.32 | 1.27 | 1.31 | 1.23 | 1.17 | 0.03 |
| Palmitic acid (C16:0), % | 25.24 | 23.89 | 23.04 | 24.16 | 23.52 | 22.26 | 0.29 |
| Palmitoleic acid (C16:1), % | 1.99 | 1.85 | 1.75 | 1.94 | 1.64 | 1.60 | 0.09 |
| Margaric acid (C17:0), % | 0.65 | 0.70 | 0.74 | 0.66 | 0.67 | 0.70 | 0.03 |
| Stearic acid (C18:0), % | 14.91 | 13.41 | 12.43 | 14.52 | 14.21 | 12.30 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 36.01 | 34.29 | 33.54 | 35.36 | 33.47 | 32.76 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.02 | 2.84 | 2.72 | 3.03 | 2.68 | 2.62 | 0.08 |
| Linoleic acid (C18:2n-6), % | 12.78 | 17.24 | 19.91 | 14.90 | 18.18 | 21.81 | 0.51 |
| α-linoleic acid (C18:3n-3), % | 0.56 | 0.64 | 0.68 | 0.64 | 0.67 | 0.73 | 0.02 |
| Arachidic acid (C20:0), % | 0.27 | 0.27 | 0.27 | 0.24 | 0.26 | 0.26 | 0.01 |
| Gadoleic acid (C20:1), % | 0.81 | 0.78 | 0.75 | 0.71 | 0.74 | 0.76 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.68 | 0.87 | 0.95 | 0.73 | 0.88 | 1.07 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.22 | 0.25 | 0.26 | 0.28 | 0.30 | 0.30 | 0.01 |
| Other fatty acids, % | 1.50 | 1.65 | 1.70 | 1.52 | 1.54 | 1.67 | 0.05 |
| Total SFA, %[4] | 42.68 | 39.83 | 37.98 | 41.13 | 40.14 | 36.93 | 0.55 |
| Total MUFA, %[5] | 41.89 | 39.82 | 38.83 | 41.11 | 38.60 | 37.81 | 0.55 |
| Total PUFA, %[6] | 14.43 | 19.25 | 22.04 | 16.74 | 20.26 | 24.17 | 0.56 |
| Total *trans* fatty acids, %[7] | 0.82 | 0.97 | 1.01 | 0.90 | 0.94 | 1.04 | 0.03 |
| UFA:SFA ratio[8] | 1.33 | 1.49 | 1.61 | 1.42 | 1.48 | 1.69 | 0.04 |
| PUFA:SFA ratio[9] | 0.34 | 0.48 | 0.58 | 0.41 | 0.51 | 0.66 | 0.02 |
| Iodine value, g/100g[10] | 60.23 | 66.52 | 70.39 | 63.45 | 67.09 | 72.94 | 0.80 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

not influence ADG or ADFI regardless of withdrawal or castration method but reduced ($P < 0.05$) G:F.

Regardless of castration method, pigs fed 30% DDGS had decreased ($P < 0.05$) ADG compared with pigs fed the control diet without DDGS from d 0 to 25, d 25 to 53, and for the entire period before the second Improvest immunization (d 0 to 74; 0.84 vs. 0.89, 0.81 vs. 0.79, and 0.90 vs. 0.89 kg, respectively). Withdrawing DDGS from the diet on d 74 did not influence pig performance from d 74 to 107 but resulted in lower ($P < 0.05$) ADFI and improved ($P < 0.05$) G:F from d 107 to 125. The inclusion of 30% DDGS did not influence ($P > 0.12$) overall ADG or ADFI but reduced ($P = 0.05$) G:F regardless of withdrawal strategy.

### *Carcass Characteristics*

Final HCW was greater ($P < 0.05$) on d 125 than on d 107, and pigs fed DDGS throughout had lower ($P < 0.05$) HCW than pigs fed corn–soybean meal diets; pigs withdrawn from DDGS were intermediate (Table 5). Castration method did not influence ($P = 0.28$) HCW. Carcass yield was lower ($P < 0.05$) for IC barrows than PC barrows for all diet strategies, but feeding 30% DDGS to market reduced yield to a greater extent in IC barrows than in PC barrows (castration method × DDGS; $P < 0.05$). Pigs fed the 30% DDGS diet throughout had decreased ($P < 0.05$) carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss, returning yield to levels similar to that of pigs fed the corn–soybean meal diet throughout. Carcass yield was similar on d 107 and 125 for IC barrows but decreased

**Table 8.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on jowl fatty acid analysis of physical and immunologically castrated barrows harvested at d 107[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.35 | 1.30 | 1.25 | 1.28 | 1.22 | 1.20 | 0.03 |
| Palmitic acid (C16:0), % | 23.23 | 21.74 | 21.17 | 22.02 | 21.64 | 21.05 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.50 | 2.36 | 2.15 | 2.40 | 2.12 | 2.12 | 0.09 |
| Margaric acid (C17:0), % | 0.60 | 0.66 | 0.72 | 0.62 | 0.62 | 0.67 | 0.03 |
| Stearic acid (C18:0), % | 11.67 | 10.21 | 9.95 | 11.53 | 11.52 | 10.23 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 39.62 | 37.36 | 36.20 | 38.05 | 35.76 | 35.31 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.84 | 3.62 | 3.35 | 3.77 | 3.36 | 3.32 | 0.08 |
| Linoleic acid (C18:2n-6), % | 12.70 | 17.73 | 19.99 | 15.53 | 18.85 | 20.77 | 0.51 |
| α-linoleic acid (C18:3n-3), % | 0.58 | 0.69 | 0.73 | 0.71 | 0.72 | 0.74 | 0.02 |
| Arachidic acid (C20:0), % | 0.23 | 0.22 | 0.24 | 0.21 | 0.23 | 0.21 | 0.01 |
| Gadoleic acid (C20:1), % | 0.88 | 0.85 | 0.83 | 0.80 | 0.80 | 0.84 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.75 | 0.97 | 1.07 | 0.84 | 1.00 | 1.13 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.26 | 0.31 | 0.31 | 0.34 | 0.36 | 0.36 | 0.01 |
| Other fatty acids, % | 1.80 | 1.98 | 2.04 | 1.90 | 1.81 | 2.06 | 0.05 |
| Total SFA, %[4] | 37.34 | 34.39 | 33.59 | 35.93 | 35.49 | 33.64 | 0.55 |
| Total MUFA, %[5] | 46.94 | 44.31 | 42.64 | 45.12 | 42.14 | 41.72 | 0.55 |
| Total PUFA, %[6] | 14.57 | 20.01 | 22.44 | 17.73 | 21.20 | 23.38 | 0.56 |
| Total *trans* fatty acids, %[7] | 0.90 | 1.07 | 1.13 | 1.03 | 1.00 | 1.12 | 0.03 |
| UFA:SFA ratio[8] | 1.66 | 1.88 | 1.95 | 1.76 | 1.80 | 1.96 | 0.04 |
| PUFA:SFA ratio[9] | 0.39 | 0.58 | 0.67 | 0.50 | 0.61 | 0.71 | 0.02 |
| Iodine value, g/100g[10] | 64.70 | 71.54 | 74.15 | 68.43 | 71.53 | 74.78 | 0.80 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

slightly over time, with PC barrows leading to a castration method × time interaction ($P < 0.05$).

Immunological castrates tended ($P < 0.10$) to have reduced backfat compared with PC barrows. There was also a tendency for a DDGS × time interaction ($P < 0.10$) in which pigs fed corn–soybean meal diets throughout tended to have a greater increase in backfat from d 107 to 125 than pigs fed diets containing DDGS or withdrawn from DDGS. No other differences ($P > 0.16$) were detected for backfat depth. No differences were detected ($P > 0.12$) for loin area, loin depth, or percentage lean regardless of castration method, DDGS, or time, with the exception of a tendency for a DDGS × time interaction ($P < 0.10$) for percentage lean in which lean reduced more from d 107 to d 125 for pigs fed corn–soybean meal diets than for pigs fed DDGS or pigs withdrawn from DDGS.

### *Analysis of Fat Depots*

No 3- or 4-way interactions ($P > 0.07$) were observed for fatty acid analysis or IV with the exception of a DDGS × time × depot interaction ($P < 0.05$) for PUFA in which PUFA levels were lower at d 125 than at d 107 in belly and backfat samples. However, jowl and clear plate fat samples had similar or increased PUFA at d 125 compared with d 107 (Tables 6 to 14). The reduction in PUFA was also greater for belly and backfat samples when DDGS was withdrawn, leading to the 3-way interaction.

***Castration Method*** × DDGS. Multiple castration method × DDGS interactions ($P < 0.05$) were observed for C18:2n-6, C18:3n-3, MUFA, PUFA, PUFA:SFA, and IV. These interactions were caused by IC barrows having a greater decrease in unsaturated fatty acids and increase in saturated fatty acids than PC barrows

**Table 9.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on backfat fatty acid analysis of physical and immunologically castrated barrows harvested at d 107[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.36 | 1.34 | 1.29 | 1.34 | 1.25 | 1.22 | 0.03 |
| Palmitic acid (C16:0), % | 25.41 | 24.30 | 23.22 | 24.53 | 23.80 | 22.95 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.10 | 1.95 | 1.79 | 2.07 | 1.82 | 1.76 | 0.09 |
| Margaric acid (C17:0), % | 0.65 | 0.66 | 0.75 | 0.65 | 0.64 | 0.67 | 0.03 |
| Stearic acid (C18:0), % | 14.76 | 13.57 | 12.32 | 14.48 | 14.03 | 12.33 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 35.83 | 34.43 | 32.84 | 34.66 | 33.35 | 32.52 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.11 | 2.93 | 2.71 | 3.07 | 2.82 | 2.69 | 0.08 |
| Linoleic acid (C18:2n-6), % | 12.76 | 16.45 | 20.46 | 15.01 | 17.93 | 21.27 | 0.51 |
| α-linoleic acid (C18:3n-3), % | 0.54 | 0.61 | 0.68 | 0.64 | 0.66 | 0.69 | 0.02 |
| Arachidic acid (C20:0), % | 0.30 | 0.28 | 0.29 | 0.27 | 0.29 | 0.28 | 0.01 |
| Gadoleic acid (C20:1), % | 0.80 | 0.78 | 0.72 | 0.72 | 0.72 | 0.73 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.66 | 0.82 | 0.95 | 0.71 | 0.85 | 0.99 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.23 | 0.25 | 0.27 | 0.28 | 0.29 | 0.28 | 0.01 |
| Other fatty acids, % | 1.50 | 1.63 | 1.70 | 1.58 | 1.55 | 1.62 | 0.05 |
| Total SFA, %[4] | 42.72 | 40.38 | 38.12 | 41.54 | 40.26 | 37.70 | 0.55 |
| Total MUFA, %[5] | 41.92 | 40.18 | 38.14 | 40.58 | 38.79 | 37.77 | 0.55 |
| Total PUFA, %[6] | 14.37 | 18.35 | 22.60 | 16.85 | 19.95 | 23.48 | 0.56 |
| Total *trans* fatty acids, %[7] | 0.80 | 0.93 | 1.01 | 0.92 | 0.92 | 0.97 | 0.03 |
| UFA:SFA ratio[8] | 1.32 | 1.45 | 1.60 | 1.39 | 1.47 | 1.64 | 0.04 |
| PUFA:SFA ratio[9] | 0.34 | 0.46 | 0.60 | 0.41 | 0.50 | 0.63 | 0.02 |
| Iodine value, g/100g[10] | 60.17 | 65.34 | 70.76 | 63.24 | 66.78 | 71.82 | 0.80 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

when DDGS were withdrawn from the diet, resulting in a greater improvement in fatty acid profiles for IC barrows. This change in fatty acid profile led to IC barrows having a greater reduction in IV than PC barrows when DDGS were removed from the diet (Fig. 1).

***Castration Method*** × Depot. Multiple interactions ($P < 0.05$) were detected for castration method × depot (belly, backfat, clear plate, jowl). Interactions were detected in C16:0, C18:0, C18:1*cis*-9, C18:2n-6, C18:3n-3, C20:2, C20:4n-6, all other fatty acids, MUFA, trans fatty acids, UFA:SFA, and IV. The interactive effects ($P < 0.05$) occurred because fatty acid profiles were similar between PC and IC barrows in backfat and belly samples, but IC barrows had increased values for unsaturated fatty acids and decreased values for saturated fatty acids compared with PC barrows in jowl and clear plate samples.

***Castration Method*** × Time. Several castration method × time interactions ($P < 0.05$) occurred in fatty acid analysis. Immunological castrates had higher concentrations of unsaturated fatty acids and lower concentrations of saturated fatty acids at d 107 than PC barrows, but the levels of saturated fatty acids (C14:0, C16:0) increased and unsaturated fatty acids (C18:2n-6, C18:3n-3, C20:4n-6, MUFA), UFA:SFA, and IV decreased to a greater extent in IC barrows by d 125 compared with PC barrows resulting in the interaction. Similarly, the rapid improvement in fat quality from d 107 to 125 for IC barrows resulted in a tendency ($P < 0.10$) for an interaction for C20:2, all other, and total trans fatty acids compared with PC barrows.

***DDGS* × *Depot.*** Numerous interactive effects were detected between DDGS level (0% throughout, 30% withdrawal, and 30% throughout) and fat sample depot (backfat, belly, clear plate, and jowl). All depots showed improvements in C14:0, C16:0, C18:0, C18:1 *cis*-9, C18:1n-7, and IV as DDGS were withdrawn

**Table 10.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on belly fatty acid analysis of physical and immunologically castrated barrows harvested at d 125[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.38 | 1.32 | 1.28 | 1.42 | 1.30 | 1.28 | 0.03 |
| Palmitic acid (C16:0), % | 24.64 | 23.35 | 21.99 | 24.67 | 23.79 | 22.42 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.46 | 2.40 | 2.20 | 2.56 | 2.31 | 2.12 | 0.09 |
| Margaric acid (C17:0), % | 0.52 | 0.56 | 0.59 | 0.52 | 0.57 | 0.54 | 0.03 |
| Stearic acid (C18:0), % | 12.80 | 11.85 | 10.13 | 12.88 | 12.54 | 11.33 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 39.70 | 37.95 | 37.19 | 38.56 | 38.25 | 36.16 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.72 | 3.54 | 3.38 | 3.71 | 3.49 | 3.22 | 0.08 |
| Linoleic acid (C18:2n-6), % | 10.83 | 14.72 | 18.63 | 11.67 | 13.55 | 18.57 | 0.51 |
| α-linoleic acid (C18:3n-3), % | 0.47 | 0.54 | 0.63 | 0.51 | 0.51 | 0.60 | 0.02 |
| Arachidic acid (C20:0), % | 0.26 | 0.26 | 0.26 | 0.25 | 0.28 | 0.26 | 0.01 |
| Gadoleic acid (C20:1), % | 0.86 | 0.80 | 0.82 | 0.81 | 0.83 | 0.75 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.63 | 0.79 | 0.99 | 0.64 | 0.76 | 0.94 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.22 | 0.26 | 0.27 | 0.24 | 0.25 | 0.27 | 0.01 |
| Other fatty acids, % | 1.52 | 1.66 | 1.65 | 1.57 | 1.58 | 1.53 | 0.05 |
| Total SFA, %[4] | 39.85 | 37.60 | 34.48 | 40.01 | 38.72 | 36.06 | 0.55 |
| Total MUFA, %[5] | 46.83 | 44.77 | 43.66 | 45.73 | 44.97 | 42.33 | 0.55 |
| Total PUFA, %[6] | 12.36 | 16.56 | 20.77 | 13.29 | 15.29 | 20.61 | 0.56 |
| Total *trans* fatty acids, %[7] | 0.77 | 0.88 | 0.93 | 0.81 | 0.81 | 0.88 | 0.03 |
| UFA:SFA ratio[8] | 1.49 | 1.64 | 1.88 | 1.49 | 1.56 | 1.76 | 0.04 |
| PUFA:SFA ratio[9] | 0.31 | 0.44 | 0.61 | 0.34 | 0.40 | 0.58 | 0.02 |
| Iodine value, g/100g[10] | 60.95 | 66.21 | 72.21 | 61.60 | 64.19 | 70.82 | 0.80 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

from the diet; however, jowl fat responded less than all other depots, resulting in an interaction.

***DDGS × Time.*** An interaction was detected ($P < 0.05$) for the fatty acid C18:2n-6 because the concentration of C18:2n-6 in the fat was lower at d 125 than 107 for pigs withdrawn from DDGS at d 74, with pigs fed DDGS throughout having similar levels of C18:2n-6 on d 107 and 125. There also was an interaction for MUFA because it increased at d 125 for pigs fed the corn–soy diet throughout and for pigs that had DDGS removed from their diet, whereas the pigs fed DDGS throughout had similar MUFA concentrations at d 107 and 125.

***Time × Depot.*** Multiple interactions ($P < 0.05$) were observed for time (d 107 and 125) and depot (backfat, belly, clear plate, and jowl), including interactions for concentrations of C14:0, C16:0, C17:0, C18:0, C18:1*cis*-9, C18:2n-6, C18:3n-3, C20:0, C20:1, C20:2, C20:4n-6, other fatty acids, SFA, MUFA, PUFA, trans fatty acids, UFA:SFA, PUFA:SFA, and IV. The interactions were caused by jowl fat samples showing very little to no change over time, whereas fat samples from the belly, clear plate, and back all showed similar responses with increasing saturated fatty acids and decreasing unsaturated fatty acids.

***Castration Method.*** Overall, the main effect of castration method resulted in IC barrows having reduced ($P < 0.05$) concentrations of C14:0, C18:1 cis-9, C18:1n-7, C20:1, MUFA, and UFA:SFA as well as a tendency ($P < 0.10$) for reduced concentrations of C16:1. However, IC barrows also had increased ($P < 0.05$) concentrations of C18:0, C18:2n-6, C18:3n-3, C20:4n-6, and SFA and tended to show increased ($P < 0.10$) concentrations of C20:2 and PUFA:SFA.

***DDGS.*** Overall, the inclusion of DDGS increased ($P < 0.01$) C17:0, C18:2n-6, C18:3n-3, C20:2,

**Table 11.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on clear plate fatty acid analysis of physical and immunologically castrated barrows harvested at d 125[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.32 | 1.26 | 1.21 | 1.34 | 1.22 | 1.19 | 0.03 |
| Palmitic acid (C16:0), % | 25.06 | 23.62 | 22.41 | 25.02 | 23.71 | 22.50 | 0.29 |
| Palmitoleic acid (C16:1), % | 1.95 | 1.88 | 1.63 | 1.95 | 1.78 | 1.47 | 0.09 |
| Margaric acid (C17:0), % | 0.62 | 0.66 | 0.72 | 0.62 | 0.69 | 0.67 | 0.03 |
| Stearic acid (C18:0), % | 15.00 | 13.63 | 12.15 | 14.92 | 14.00 | 13.04 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 36.46 | 34.61 | 33.28 | 35.07 | 34.96 | 31.54 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 2.98 | 2.88 | 2.63 | 2.95 | 2.81 | 2.42 | 0.08 |
| Linoleic acid (C18:2n-6), % | 12.72 | 17.19 | 21.46 | 14.14 | 16.60 | 22.70 | 0.52 |
| α-linoleic acid (C18:3n-3), % | 0.55 | 0.61 | 0.69 | 0.60 | 0.60 | 0.72 | 0.02 |
| Arachidic acid (C20:0), % | 0.24 | 0.25 | 0.25 | 0.25 | 0.25 | 0.24 | 0.01 |
| Gadoleic acid (C20:1), % | 0.79 | 0.76 | 0.75 | 0.75 | 0.77 | 0.72 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.67 | 0.84 | 1.02 | 0.70 | 0.84 | 1.03 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.21 | 0.24 | 0.25 | 0.23 | 0.24 | 0.27 | 0.01 |
| Other fatty acids, % | 1.43 | 1.55 | 1.56 | 1.48 | 1.55 | 1.49 | 0.05 |
| Total SFA, %[4] | 42.46 | 39.64 | 36.95 | 42.37 | 40.08 | 37.88 | 0.56 |
| Total MUFA, %[5] | 42.24 | 40.20 | 38.34 | 40.78 | 40.39 | 36.21 | 0.56 |
| Total PUFA, %[6] | 14.32 | 19.09 | 23.61 | 15.84 | 18.46 | 24.91 | 0.57 |
| Total *trans* fatty acids, %[7] | 0.80 | 0.93 | 0.97 | 0.87 | 0.89 | 0.98 | 0.03 |
| UFA:SFA ratio[8] | 1.34 | 1.50 | 1.68 | 1.34 | 1.47 | 1.62 | 0.04 |
| PUFA:SFA ratio[9] | 0.34 | 0.49 | 0.64 | 0.37 | 0.46 | 0.66 | 0.02 |
| Iodine value, g/100g[10] | 60.36 | 66.61 | 72.56 | 61.73 | 65.65 | 72.91 | 0.81 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

C20:4n-6, other, PUFA, trans, UFA:SFA, PUFA:SFA, and IV fatty acid concentrations. Inclusion of 30% DDGS, however, reduced ($P < 0.05$) concentrations of C14:0, C16:0, C16:1, C18:0, C18:1 cis-9, C18:1n-7, C20:1, SFA, and MUFA fatty acids.

***Time.*** Increases ($P < 0.05$) in C18:1 cis-9 and MUFA fatty acid concentrations and reductions ($P < 0.05$) in C17:0, C18:2n-6, C18:3n-3, C20:4n-6, PUFA, and PUFA:SFA fatty acid concentrations were observed from d 107 to 125.

***Depot.*** Differences ($P < 0.05$) were observed between depots in C14:0, C16:0, C16:1, C17:0, C18:0, C18:1 cis-9, C18:1n-7, C18:2n-6, C18:3n-3, C20:0, C20:1, C20:2, C20:4n-6, other, SFA, MUFA, PUFA, trans, UFA:SFA, PUFA:SFA, and IV fatty acids. The main differences were caused by jowl fat samples resulting in consistently higher levels of unsaturated fatty acids and lower levels of saturated fatty acids.

## DISCUSSION

Pigs that were immunologically castrated had increased ADG, reduced ADFI, and improved feed efficiency compared with PC barrows. This result agrees with research by Dunshea et al. (2001) and Turkstra et al. (2002). Morales et al. (2011) reported no overall differences in ADG, but they reported similar reductions in ADFI and improvement in feed efficiency for IC barrows compared with PC barrows. Immunological castrates tended to have reduced ADG and had improved feed efficiency before the second injection while they were still intact males, due to reductions in feed intake. The tendency for reduced ADG was driven by the significant reduction from d 0 to 25, with no differences in ADG from d 25 to 53 or 53 to 74 of the study. This result agrees with Morales et al. (2011), who reported PC barrows had greater ADG than IC barrows before the second immu-

**Table 12.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on jowl fatty acid analysis of physical and immunologically castrated barrows harvested at d 125[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.33 | 1.25 | 1.22 | 1.35 | 1.20 | 1.21 | 0.03 |
| Palmitic acid (C16:0), % | 22.60 | 20.95 | 20.50 | 22.44 | 20.99 | 20.63 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.53 | 2.46 | 2.17 | 2.56 | 2.31 | 2.02 | 0.09 |
| Margaric acid (C17:0), % | 0.60 | 0.63 | 0.66 | 0.59 | 0.65 | 0.61 | 0.03 |
| Stearic acid (C18:0), % | 10.82 | 9.64 | 9.01 | 10.83 | 10.04 | 9.88 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 40.44 | 38.36 | 37.26 | 38.94 | 37.94 | 35.74 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.84 | 3.66 | 3.34 | 3.78 | 3.52 | 3.13 | 0.08 |
| Linoleic acid (C18:2n-6), % | 13.43 | 18.24 | 20.84 | 15.02 | 18.51 | 21.93 | 0.52 |
| α-linoleic acid (C18:3n-3), % | 0.61 | 0.70 | 0.73 | 0.67 | 0.71 | 0.75 | 0.02 |
| Arachidic acid (C20:0), % | 0.21 | 0.22 | 0.21 | 0.21 | 0.21 | 0.21 | 0.01 |
| Gadoleic acid (C20:1), % | 0.90 | 0.82 | 0.84 | 0.85 | 0.84 | 0.80 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.79 | 0.98 | 1.13 | 0.83 | 1.03 | 1.15 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.26 | 0.30 | 0.30 | 0.27 | 0.31 | 0.31 | 0.01 |
| Other fatty acids, % | 1.64 | 1.79 | 1.79 | 1.67 | 1.74 | 1.62 | 0.05 |
| Total SFA, %[4] | 35.81 | 32.91 | 31.81 | 35.66 | 33.33 | 32.78 | 0.56 |
| Total MUFA, %[5] | 47.76 | 45.37 | 43.67 | 46.20 | 44.68 | 41.75 | 0.56 |
| Total PUFA, %[6] | 15.31 | 20.50 | 23.26 | 17.00 | 20.80 | 24.39 | 0.57 |
| Total *trans* fatty acids, %[7] | 0.90 | 1.06 | 1.06 | 0.98 | 1.03 | 1.02 | 0.03 |
| UFA:SFA ratio[8] | 1.77 | 2.01 | 2.11 | 1.78 | 1.97 | 2.03 | 0.04 |
| PUFA:SFA ratio[9] | 0.43 | 0.63 | 0.73 | 0.48 | 0.63 | 0.75 | 0.02 |
| Iodine value, g/100g[10] | 66.65 | 73.31 | 76.37 | 68.24 | 73.11 | 76.56 | 0.81 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

nization for the IC barrows. Weiler et al. (1996) reported that increased testosterone levels in intact males were associated with reductions in feed intake, which could explain the reduced feed intake seen in our study from d 0 to 74. These results also agree with Campbell and Taverner (1988) and Bonneau et al. (1994), who reported that barrows have increased levels of feed intake compared with intact males. Similarly, Quiniou et al. (1996) reported that intact males reach maximum protein deposition at a lower energy intake, which could allow IC barrows to be more efficient before their second immunization because lean muscle deposition is more energetically efficient than fat deposition (NRC, 1998).

For the 13 d immediately following second Improvest injection (d 74 to 87), IC barrows had lower ADFI and improved ADG and feed efficiency. After this transition phase, IC barrows had greater ADG, driven mostly by a large increase in ADFI compared with PC barrows. These results agree with those of Lealiifano et al. (2011), who reported no difference in ADFI for 2 wk immediately following the second dose of Improvest. However, during the following 2 wk (2 to 4 wk after second injection), the authors reported a 32% increase in ADFI for IC barrows compared with PC barrows. Similar to work by Dunshea et al. (2001), Rikard-Bell et al. (2009), McCauley et al. (2003), and Oliver et al. (2003), IC barrows had increased ADFI from 2 wk after second injection through harvest. This rapid change in intake could be partially explained by the change in behavior when IC barrows transition from an intact male to an immunologically castrated state, including spending less time engaged in fighting and sexual behavior (Dunshea et al., 2001) and more time at the feeder (Cronin et al., 2003).

Although no data have reported the inclusion of dietary DDGS in diets fed to immunological castrates, a large amount of work has reported on the dietary inclusion of

**Table 13.** Effect of corn dried distillers grains with solubles (DDGS) level and withdrawal on backfat fatty acid analysis of physical and immunologically castrated barrows harvested at d 125[1,2]

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| | Physical castrate | | | Immunological castrate[2] | | | |
| d 0 to 74: | Corn–soy | DDGS | DDGS | Corn–soy | DDGS | DDGS | |
| d 74 to 125: | Corn–soy | Corn–soy | DDGS | Corn–soy | Corn–soy | DDGS | SEM |
| Myristic acid (C14:0), % | 1.35 | 1.33 | 1.27 | 1.38 | 1.29 | 1.28 | 0.03 |
| Palmitic acid (C16:0), % | 25.60 | 24.51 | 23.19 | 25.86 | 24.80 | 23.52 | 0.29 |
| Palmitoleic acid (C16:1), % | 2.10 | 2.05 | 1.73 | 2.03 | 1.95 | 1.68 | 0.09 |
| Margaric acid (C17:0), % | 0.53 | 0.57 | 0.65 | 0.52 | 0.58 | 0.60 | 0.03 |
| Stearic acid (C18:0), % | 14.97 | 13.99 | 12.48 | 15.52 | 14.49 | 13.27 | 0.34 |
| Oleic acid (C18:1 *cis*-9), % | 37.29 | 35.48 | 33.54 | 35.92 | 36.31 | 32.60 | 0.44 |
| Vaccenic acid (C18:1n-7), % | 3.08 | 2.94 | 2.64 | 2.94 | 2.91 | 2.53 | 0.08 |
| Linoleic acid (C18:2n-6), % | 11.27 | 14.97 | 20.15 | 12.08 | 13.73 | 20.28 | 0.51 |
| α-linoleic acid (C18:3n-3), % | 0.48 | 0.53 | 0.64 | 0.49 | 0.49 | 0.63 | 0.02 |
| Arachidic acid (C20:0), % | 0.30 | 0.31 | 0.28 | 0.30 | 0.30 | 0.27 | 0.01 |
| Gadoleic acid (C20:1), % | 0.83 | 0.79 | 0.76 | 0.82 | 0.82 | 0.72 | 0.02 |
| Eicosadienoic acid (C20:2), % | 0.62 | 0.77 | 0.96 | 0.62 | 0.72 | 0.94 | 0.03 |
| Arachidonic acid (C20:4n-6), % | 0.20 | 0.23 | 0.24 | 0.20 | 0.22 | 0.25 | 0.01 |
| Other fatty acids, % | 1.37 | 1.51 | 1.48 | 1.31 | 1.39 | 1.45 | 0.05 |
| Total SFA, %[4] | 43.01 | 40.96 | 38.11 | 43.82 | 41.69 | 39.19 | 0.55 |
| Total MUFA, %[5] | 43.38 | 41.34 | 38.73 | 41.77 | 42.06 | 37.59 | 0.55 |
| Total PUFA, %[6] | 12.75 | 16.72 | 22.18 | 13.56 | 15.33 | 22.28 | 0.56 |
| Total *trans* fatty acids, %[7] | 0.71 | 0.84 | 0.89 | 0.74 | 0.74 | 0.89 | 0.03 |
| UFA:SFA ratio[8] | 1.31 | 1.42 | 1.61 | 1.27 | 1.38 | 1.54 | 0.04 |
| PUFA:SFA ratio[9] | 0.30 | 0.41 | 0.59 | 0.31 | 0.37 | 0.57 | 0.02 |
| Iodine value, g/100g[10] | 58.65 | 63.58 | 70.45 | 58.69 | 61.79 | 69.69 | 0.80 |

[1]All values are on a DM basis.

[2]Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[3]Immunological castrates received immunizations against gonadotropin-releasing hormone on d 39 and 74.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8]UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9]PUFA:SFA = total PUFA/total SFA.

[10]Calculated as IV 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; brackets indicate concentration.

DDGS for PC barrows. For growth performance, PC and IC barrows responded similarly to dietary treatments. The addition of 30% DDGS to the diet reduced ADG through numeric reductions in feed intake and feed efficiency from d 0 to 25 for pigs. This initial reduction in ADFI could be explained by the pigs' reduced preference for diets that include DDGS (Seabolt et al., 2010). Including 30% DDGS in the diet reduced ADG and feed efficiency for the entire period from d 0 to 74 with no difference in ADFI, which agrees with previous research by Whitney et al. (2006). From d 74 to 125 (period after second injection), ADFI increased with the inclusion of 30% DDGS compared with pigs fed the control diet, with the pigs withdrawn from DDGS having intermediate consumption. These data agree with Asmus et al. (2014), who saw increased feed intake when pigs remained on a higher fiber diet containing DDGS and wheat middlings compared with pigs fed a corn–soybean meal control diet, with pigs withdrawn from the high-fiber diet having intermediate intake levels. These differences within phase resulted in no overall (d 0 to 125) differences in ADG or ADFI; however, the inclusion of 30% DDGS reduced G:F, which agrees with data by Gaines et al. (2007b). The effects of DDGS on feed efficiency have been shown to be variable; for example, Hill et al. (2008) and Xu et al. (2010a) found no differences in G:F. The variability in response could be attributed to variability between DDGS sources. We also had a greater number of pigs and replications in our experiment than in some previous experiments, which allowed us to detect smaller differences in feed efficiency.

In the current trial, carcass yield was lower for IC barrows than PC barrows regardless of dietary inclusion of DDGS. Yield has been shown to be lower in intact males and IC barrows than in PC barrows due in part to the presence of testicles and other accessory tissues (Hansen and Lewis, 1993; Babol and Squires, 1995). Although immu-

**Table 14.** Probability of interactive and main effects of corn dried distillers grains with solubles (DDGS) level and withdrawal on fatty acid analysis of physical and immunologically castrated barrows harvested at d 107 and 125[1]

| | Castration × DDGS[2] | Castration × Depot[3] | Castration × Time[4] | DDGS × Depot[5] | DDGS × Time[6] | Time × Depot[7] | Castration method | DDGS | Time | Depot |
|---|---|---|---|---|---|---|---|---|---|---|
| Myristic acid (C14:0), % | 0.455 | 0.347 | 0.049 | 0.017 | 0.716 | <0.001 | 0.023 | <0.001 | 0.949 | <0.001 |
| Palmitic acid (C16:0), % | 0.341 | 0.027 | 0.023 | <0.001 | 0.292 | <0.001 | 0.219 | <0.001 | 0.577 | <0.001 |
| Palmitoleic acid (C16:1), % | 0.549 | 0.591 | 0.615 | 0.441 | 0.342 | 0.081 | 0.060 | <0.001 | 0.756 | <0.001 |
| Margaric acid (C17:0), % | 0.423 | 0.776 | 0.684 | 0.170 | 0.704 | <0.001 | 0.241 | 0.014 | 0.026 | <0.001 |
| Stearic acid (C18:0), % | 0.193 | 0.033 | 0.554 | <0.001 | 0.872 | <0.001 | 0.015 | <0.001 | 0.916 | <0.001 |
| Oleic acid (C18:1 *cis*-9), % | 0.313 | 0.034 | 0.670 | 0.002 | 0.106 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Vaccenic acid (C18:1n-7), % | 0.687 | 0.596 | 0.921 | 0.031 | 0.193 | 0.168 | 0.012 | <0.001 | 0.719 | <0.001 |
| Linoleic acid (C18:2n-6), % | 0.041 | 0.002 | 0.035 | <0.001 | 0.024 | <0.001 | <0.001 | <0.001 | 0.012 | <0.001 |
| α-linoleic acid (C18:3n-3), % | 0.013 | 0.007 | 0.029 | <0.001 | 0.202 | <0.001 | 0.004 | <0.001 | <0.001 | <0.001 |
| Arachidic acid (C20:0), % | 0.335 | 0.317 | 0.258 | 0.040 | 0.646 | <0.001 | 0.157 | 0.362 | 0.867 | <0.001 |
| Gadoleic acid (C20:1), % | 0.264 | 0.836 | 0.322 | <0.001 | 0.391 | <0.001 | 0.008 | 0.054 | 0.126 | <0.001 |
| Eicosadienoic acid (C20:2), % | 0.445 | <0.001 | 0.079 | <0.001 | 0.299 | <0.001 | 0.068 | <0.001 | 0.113 | <0.001 |
| Arachidonic acid (C20:4n-6), % | 0.520 | 0.010 | <0.001 | 0.146 | 0.613 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Other fatty acids, % | 0.196 | 0.027 | 0.083 | <0.001 | 0.529 | <0.001 | 0.530 | <0.001 | 0.976 | <0.001 |
| Total SFA, % | 0.608 | 0.082 | 0.643 | 0.009 | 0.077 | <0.001 | <0.001 | <0.001 | 0.003 | <0.001 |
| Total MUFA, % | 0.040 | 0.001 | 0.028 | <0.001 | 0.033 | <0.001 | <0.001 | <0.001 | 0.006 | <0.001 |
| Total PUFA, % | <0.001 | 0.247 | 0.277 | 0.063 | 0.877 | <0.001 | 0.661 | <0.001 | <0.001 | <0.001 |
| Total *trans* fatty acids, % | 0.244 | 0.050 | 0.080 | <0.001 | 0.549 | <0.001 | 0.599 | <0.001 | 0.709 | <0.001 |
| UFA:SFA ratio | 0.072 | 0.001 | 0.025 | <0.001 | 0.136 | <0.001 | 0.020 | <0.001 | 0.096 | <0.001 |
| PUFA:SFA ratio | 0.022 | 0.858 | 0.624 | 0.405 | 0.074 | <0.001 | 0.072 | <0.001 | <0.001 | <0.001 |
| Iodine value, g/100g | 0.041 | <0.001 | 0.028 | <0.001 | 0.164 | <0.001 | 0.110 | <0.001 | 0.155 | <0.001 |

[1]No 3 or 4 way interactions occurred ($P > 0.09$), with the exception of DDGS × time × depot ($P < 0.03$) for total PUFA.

[2]Castration method × DDGS (0% throughout, 30% then withdraw, 30% throughout) interaction.

[3]Castration method × depots (belly, clear plate, jowl, backfat) interaction.

[4]Castration method × time (d 107 or 125) interaction.

[5]DDGS (0% throughout, 30% then withdraw, 30% throughout) × depots (belly, clear plate, jowl, backfat) interaction.

[6]DDGS (0% throughout, 30% then withdraw, 30% throughout) × time (d 107 or 125) interaction.

[7]Time (d 107 or 125) × depots (belly, clear plate, jowl, backfat) interaction.

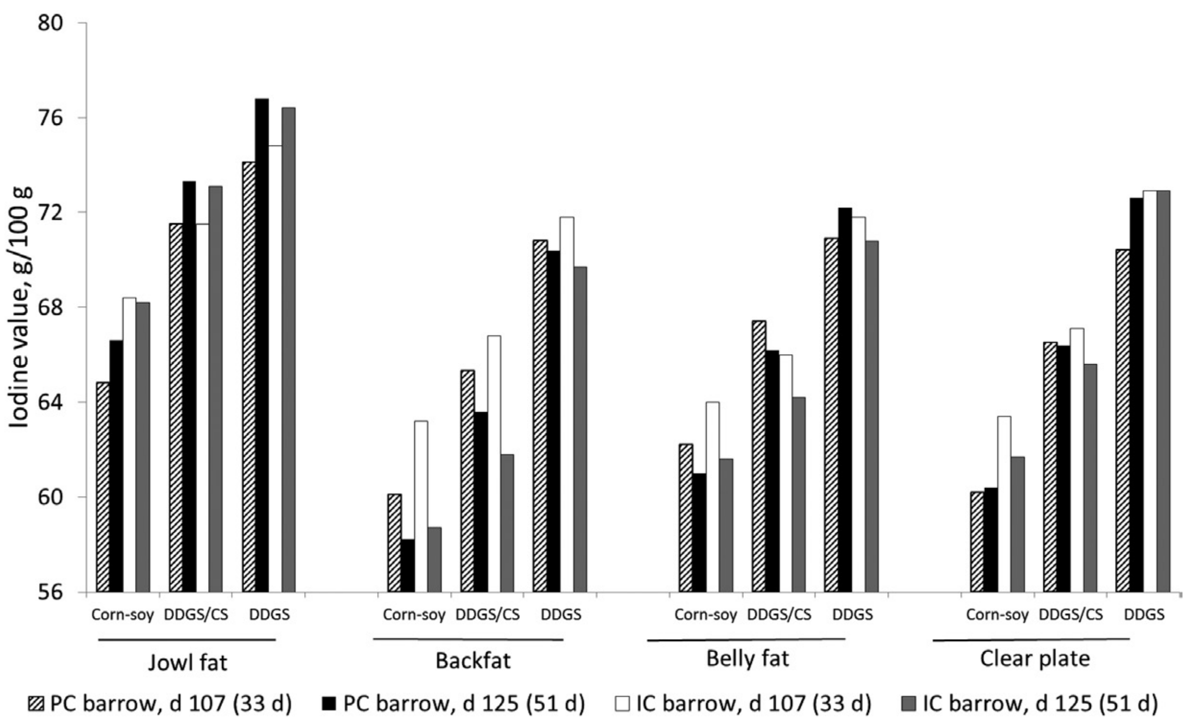


**Figure 1.** Differences in fat depot iodine values and changes between physical castrates (PC) and immunological castrates (IC) and time post second injection (d 107 and 125 were 33 and 51 d after the second injection). Pigs were fed diets containing no DDGS (Corn-soy) or 30% DDGS (DDGS) from d 0 to 125. For the DDGS/CS diet regimen, pigs received 30% DDGS diets from d 0 to 74 and diets without DDGS from d 74 to 125.

nological castration has been shown to reduce the weight of testes and bulbourethral glands compared with intact males (Pauly et al., 2009; Gispert et al., 2010), IC barrows still have increased testes, which are absent from PC barrows. It has also been hypothesized that the reduction in yield could be due to increased amounts of gut fill due to the large increase in ADFI exhibited after the second injection of Improvest, as well as increased amounts of abdominal fat (Dunshea et al., 2001; Zamaratskaia et al., 2008). Another possible cause for the reduction in yield could be the heavier kidneys and intestines in intact males than in barrows (Hansen and Lewis, 1993; Babol and Squires, 1995). It has also been reported that liver weights tended to be heavier in IC barrows than in PC barrows (Pauly et al., 2009).

In the current trial, DDGS inclusion reduced SFA and MUFA proportions regardless of fat depot; however, total trans and PUFA were increased mainly though increases in C18:2 and C18:3 fatty acid concentrations, resulting in increased carcass fat IV. The findings agree with work by Xu et al. (2010b) and Hill et al. (2008), who reported increased fat IV when pigs were fed increasing levels of DDGS. Immunologically castrated pigs had reduced MUFA, but PUFA was increased through increased C18:2 and C18:3, causing increases in IV for backfat, clear plate, and jowl fat. Similarly, Pauly et al. (2009) reported increased PUFA for IC barrows compared with PC barrows. Conversely, Boler et al. (2011) and Font-i-Furnols et al. (2012) did not find a difference in PUFA in individual cuts (bellies and hams, respectively) between IC and PC barrows. The degree of unsaturation has been reported to be higher in intact males than barrows; IC should be intermediate (EFSA, 2004). The IV of jowl fat was considerably greater than the IV of backfat, belly fat, or clear plate regardless of castration method or dietary regimen. Increasing feeding duration from 33 to 51 d after second injection reduced IV for backfat and belly fat for IC barrows but did not influence IV of jowl or clear plate fat. These results were expected, because more of the fat in the late finishing period is deposited in the belly and backfat. The data also demonstrate the difference in conclusion, depending on which fat source is being measured. For jowl fat, IV was greater for IC barrows than PC barrows regardless of diet and did not decrease with days on feed (in this case, an additional 18 d). For backfat and belly fat, increasing days on feed from d 107 to d 125 reduced IV, with IC barrows having a much greater reduction in IV than PC barrows. Carcass fat IV regardless of depot was greater when 30% DDGS were included in the diet. The withdrawal strategy was successful at lowering the IV compared with pigs fed DDGS throughout. However, as observed in previous studies (Xu et al., 2010a), it was not successful at fully lowering IV to values similar to pigs fed the control diet throughout. The large difference in IV between depots and in rate of change over time indicates that choice of fat depot should be carefully considered when using IV to assess fat quality. For example, jowl fat IV responds more slowly to dietary changes before market than IV of other fat depots.

The withdrawal of dietary DDGS before marketing improved fat firmness as measured by IV regardless of castration method, but IC barrows had more dramatic changes in fatty acid profiles and IV with the removal of DDGS than PC barrows. These changes could be caused by the rapid deposition of backfat that occurs after the second injection (Lealiifano et al., 2011), which causes increased backfat depths and a dilution effect for unsaturated fatty acids.

In summary, withdrawing DDGS from the diet before harvest, regardless of castration method, can regain yield loss and improve carcass IV; however, regardless of withdrawal strategy or castration method, feed efficiency was poorer when feeding DDGS. Immunological castrates had reduced carcass yield and ADFI regardless of diet type, but they also had improved ADG, which resulted in improved G:F compared with PC barrows. Although immunological castration can increase IV of fat depots when pigs are harvested at 5 wk after second injection, extending the length of feeding duration before harvest after the second injection returns IV values to levels similar to those of PC barrows, probably caused by a dilution effect of unsaturated fatty acids coming from dietary sources.

## LITERATURE CITED

AOAC. 2006. Official methods of analysis. 18th ed. Assoc. Off. Anal. Chem., Washington, DC.

AOCS. 1998. Official methods and recommended practices of the AOCS. 5th ed. Am. Oil. Chem. Soc., Champaign, IL.

Asmus, M. D. J. M. DeRouchey, M. D. Tokach, S. S. Dritz, T. E. Houser, J. L. Nelssen, and R. D. Goodband. 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. J. Anim. Sci. 92:119-128

Babol, J., and E. J. Squires. 1995. Quality of meat from entire male pigs. Food Res. Int. 28:201–212.

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 distiller grains with solubles on fat quality of finishing pigs. J. Anim. Sci. 88:3666–3682.

Boler, D. D., D. L. Clark, A. A. Baer, D. M. Meeuwse, V. L. King, F. K. McKeith, and J. Killefer. 2011. Effects of increasing lysine on further processed product characteristics from immunologically castrated male pigs. J. Anim. Sci. 89:2200–2209

Bonneau, M., R. Dufour, C. Chouvet, C. Roulet, W. Meadus, and E. Squires. 1994. The effects of immunization against luteinizing hormone-releasing hormone on performance, sexual development, and levels of boar taint-related compounds in intact male pigs. J. Anim. Sci. 72:14–20.>

Campbell, R. G., and M. R. Taverner. 1988. Genotype and sex effects on the relationship between energy-intake and protein deposition in growing-pigs. J. Anim. Sci. 66:676–686.

Cronin, G. M., F. R. Dunshea, K. L. Butler, I. McCauley, J. L. Barnett, and P. Hemsworth. 2003. The effects of immuno- and surgical-castration on the behaviour and consequently growth of group-housed, male finisher pigs. Appl. Anim. Behav. Sci. 81:111–126.

Dunshea, F. R., C. Colantoni, K. Howard, I. McCauley, P. Jackson, K. A. Long, S. Lopaticki, E. A. Nugent, J. A. Simons, J. Walker, and D. P. Hennessy. 2001. Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. J. Anim. Sci. 79:2524–2535.

European Food Safety Authority. 2004. Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of the castration of piglets. EFSA Journal 91:1–18.

Font-i-Furnols, M., Gispert, J. Soler, M. Díaz, J. A. Garcia-Regueiro, I. Diaz, and M. C. Pearce. 2012. Effect of vaccination against gonadotropin-releasing factor on growth performance, carcass, meat and fat quality of male Duroc pigs for dry-cured ham production. Meat Sci. 91:148–154.

Gaines, A. M., J. D. Spencer, G. I. Petersen, and N. R. Augspurger. 2007a. Effect of corn distiller's dried grains with solubles (DDGS) withdrawal program on growth performance and carcass yield in grow-finish pigs. J. Anim. Sci. 85(Suppl. 1):438 (Abstr.).

Gaines, A. M., G. I. Petersen, J. D. Spencer, and N. R. Augspurger. 2007b. Use of corn distillers dried grains with solubles (DDGS) in finishing pigs. J. Anim. Sci. 85(Suppl. 2):96.

Gispert, M., O. M. Angels, A. Velarde, P. Suarez, J. Perez, and M. Furnols. 2010. Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci. 85:664–670.

Hansen, B. C., and A. J. Lewis. 1993. Effects of dietary protein concentration (corn:soybean meal ratio) on the performance and carcass characteristics of growing boars, barrows, and gilts: Mathematical descriptions. J. Anim. Sci. 71:2122–2132.

Hill, G. M., J. E. Link, D. O. Liptrap, M. A. Giesemann, M. J. Dawes, J. A. Snedegar, N. M. Bello, and R. J. Tempelman. 2008. Withdrawal of distillers dried grains with solubles (DDGS) prior to slaughter in finishing pigs. J. Anim. Sci. 86(Suppl. 2):50 (Abstr.).

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. 2010. Effect of dried distillers grains with solubles (DDGS) withdrawal regimens on finishing pig performance and carcass traits. J. Anim. Sci. 88(Suppl. 3):53 (Abstr.).

Knudson, B. K., M. G. Hogberg, R. A. Merkel, R. E. Allen, and W. T. Magee. 1985. Developmental comparisons of boars and barrows: I. Growth rate, carcass and muscle characteristics. J. Anim. Sci. 61:789–796.

Lealiifano, A. K., J. R. Pluske, R. R. Nicholls, F. R. Dunshea, R. G. Campbell, D. P. Hennessy, D. W. Miller, C. F. Hansen, and B. P. Mullan. 2011. Reducing the length of time between slaughter and the secondary gonadotropin-releasing factor immunization improves growth performance and clears boar taint compounds in male finishing pigs. J. Anim. Sci. 89:2782–2792.

Linneen, S. K., J. M. DeRouchey, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J. L. Nelssen. 2008. Effects of dried distiller grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579–1587.

McCauley, I., M. Watt, D. Suster, D. J. Kerton, W. T. Oliver, R. J. Harrell, and F. R. Dunshea. 2003. A GnRF vaccine (Improvac®) and porcine somatotropin (Reporcin ®) have synergistic effects upon growth performance in both boars and gilts. Aust. J. Agric. Res. 54:11–20.

Morales, J. I., L. Camara, J. D. Berrocoso, J. P. Lopez, G. G. Mateos, and M. P. Serrano. 2011. Influence of sex and castration on growth performance and carcass quality of crossbred pigs from 2 large white sire lines. J. Anim. Sci. 89:3481–3489.

NRC. 1998. Nutrient requirements of swine. 10th ed. Natl. Acad. Press, Washington, DC.

Oliver, W. T., I. McCauley, R. J. Harrell, D. Suster, D. J. Kerton, and F. R. Dunshea. 2003. A gonadotropin-releasing factor vaccine (Improvac) and porcine somatotropin have synergistic and additive effects on growth performance in group-housed boars and gilts. J. Anim. Sci. 81:1959–1966.

Pauly, C., P. Spring, J. V. O'Doherty, S. Ampuero Kragten, and G. Bee. 2009. Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac) and entire male pigs and individually penned entire male pigs. Animal 3(7):1057–1066.

Quiniou, N., J. Y. Dourmad, and J. Noblet. 1996. Effect of energy intake on the performance of different types of pig from 45 to 100 kg body weight. 1. Protein and lipid deposition. Anim. Sci. 63:277–288.

Rikard-Bell, C., M. A. Curtis, R. J. van Barneveld, B. P. Mullan, A. C. Edwards, N. J. Gannon, D. J. Henman, P. E. Hughes, and F. R. Dunshea. 2009. Ractopamine hydrochloride improves growth performance and carcass composition in immunocastrated boars, intact boars, and gilts. J. Anim. Sci. 87:3536–3543.

Seabolt, B. S., E. van Heugten, S. W. Kim, K. D. Ange-van Heugten, and E. Roura. 2010. Feed preference and performance of nursery pigs fed diets containing various inclusion amounts and quantities of distillers coproducts and flavor. J. Anim. Sci. 88:3725–3738.

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.

Turkstra, J.A., X.Y. Zeng, J.Th.M. van Diepen, A.W. Jongbloed, H.B. Oonk, D.F.M. van de Wiel, and R.H. Meloen. 2002. Performance of male pigs immunized against GnRH is related to the time of onset of biological response. J. Anim. Sci. 80:2953–2959.

Weiler, U., R. Claus, M. Dehnhard, and S. Hofacker. 1996. Influence of the photoperiod and a light reverse program on metabolically active hormones and food intake in domestic pigs compared with a wild boar. Can. J. Anim. Sci. 76:531–539.

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.

Zamaratskaia, G., H. Andersson, G. Chen, K. Andersson, A. Madej, and K. Lundstrom. 2008. Effect of a gonadotropin-releasing hormone vaccine (Improvac) on steroid hormones, boar taint compounds and performance in entire male pigs. Reprod. Domest. Anim. 43:351–359.