EVALUATING FAT QUALITY AND BACON SLICING YIELDS IN IMMUNOLOGICALLY CASTRATED BARROWS

BY

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DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Animal Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2014

Urbana, Illinois

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ABSTRACT

The objective of this dissertation was to determine the effects of immunological castration (Improvest; Zoetis, Kalamazoo, MI) on lipid deposition, fresh belly quality and bacon slicing yields. Immunological castration allows producers to capitalize on the increased feed efficiency and leanness associated with intact males while controlling boar taint. One disadvantage of leaner pigs, however, is that their adipose tissue has increased amounts of unsaturated fatty acids (UFA). This is a cause for concern to packers and processors because it increased issues with fat quality (increased soft and oily fat), especially that of the belly. Bellies with soft and oily fat produce bacon that is difficult to slice. In general, immunological castrated (IC) barrows were leaner, had thinner bellies with greater concentrations of UFA, greater iodine values (IV), and inferior bacon slicing yields compared to physically castrated (PC) barrows. However, lipid composition may be altered and consequently belly firmness improved in IC barrows with increasing time after second Improvest dose. The underlying cause for this improvement is thought to be increased *de novo* synthesis of fat as a consequence of increase in feed intake. This *de novo* synthesis was reflected in the first study by increased lipid content (71.6% at 4 wk to 77.2% at 8 wk after second dose in IC) and reduced IV of belly adipose tissue (64.0 at 4 wk to 60.9 g/100g at 8 wk after second Improvest dose in IC). In PC barrows, lipid content was also increased (81.7% at 4 wk to 84.9% at 8 wk), but IV of the belly adipose tissue unchanged (61.5 at 4 weeks to 61.6 g/100g at 8 wk). Therefore, from this first study it was concluded that, as time after second Improvest dose progressed, IV of the belly was reduced with a concomitant increased in lipid deposition. In the second study, the effects of feeding distillers dried grains with solubles (DDGS) to IC barrows were evaluated. Inclusion of 30% DDGS in swine diets increased concentrations of UFA in pork fat. This effect may be magnified in the

leaner IC barrows, but potentially improved with increased time after second dose. At 5 wk after second dose, bellies were thicker (*P* < 0.01) and tended to have greater belly flop distances (*P* = 0.07) in PC compared to IC barrows, however IV were not different (*P* = 0.84). Bacon slicing yields (percentage of green weight) were 6.1 percentage units less (*P* < 0.01) in IC compared with PC. At 7 wk after second dose, bellies from PC tended to be thicker (*P* = 0.07), have similar flop distances (*P* = 0.44) and IV (*P* = 0.54) when compared with IC. Iodine value was greater (*P* = 0.03) in 30% DDGS fed barrows compared with control fed barrows. Bacon slicing yields (percentage of green weight) were 4.3 percentage units less (*P* = 0.05) in IC compared with PC barrows. From this second study, it was concluded that while bacon slicing yield was reduced in IC barrows fed control and 30% DDGS diets compared with PC barrow counterparts, withdrawal of DDGS improved bacon slicing yields of IC barrows. For the third study, both the effects of age at slaughter and time after second Improvest dose were quantified on fresh belly characteristics and commercial bacon production in IC barrows compared with PC barrows and gilts. For pigs slaughtered at 24 wk, administration of the second Improvest dose was staggered so that IC barrows were slaughtered at 4, 6, 8, and 10 wk after second dose. In pigs slaughtered at 26 and 28 wk, IC barrows were slaughtered at 6 and 8 weeks after second dose, respectively. In pigs slaughtered at 24 wk of age, belly thickness, flop distance, and bacon lipid content were increased linearly (*P* < 0.04) and iodine value (IV) tended to decrease (*P* = 0.08) with time after second dose in IC barrows. Bacon slicing yields (as percent of green and cooked weight) were curvilinearly increased with time after second dose (*P* < 0.05), but were similar (*P* > 0.14) between sex classes. In pigs slaughtered from 24 to 28 wk of age, fatness (last rib and bacon) was increased (*P* < 0.01) and IV reduced (*P* < 0.01) in IC barrows with age at slaughter, but not (*P* > 0.11) in PC barrows and gilt combined. Slicing yields (green and cooked weight) were increased ($P < 0.01$) with age at slaughter in IC barrows. Both yields were superior ($P < 0.01$) in IC barrows compared to PC and gilts at 28 wk. Increasing both, age at slaughter and the time after second Improvest dose improved fresh and cured belly characteristics in IC barrows, however age at slaughter seemed to have a greater marginal effect on the belly. Conclusions from these studies indicate that, in general, increasing age at slaughter coupled with time after second Improvest dose allow IC barrows to become heavier and to increase fat deposition, as a result fresh belly quality and bacon slicing yields are improved while becoming more similar to PC barrows.

Dedicated to my wife Michelle and my daughter Eva for their unconditional love and kindness during these years

ACKNOWLEDGMENTS

First and foremost, I would like to thank my savior and Lord Jesus Christ as I have leaned that through him all things are possible. Thus, all the glory to him.

I would like to thank Dr. Floyd McKeith, Dr. Dustin Boler and Dr. Anna Dilger for advising me though my doctoral reseach. I have been fortunate to learn from them how to conduct reseach and then apply this reseach to real world situations. Doctor McKeith was very influential with his advise on the pork industry. Dustin Boler, now a faculty, but a graduate student when I first started, imprinted in me a strong work ethic and a love for statistics. My adviser, Dr. Anna Dilger not only provided great guidance and expertise, but also made me believe in myself. For that I will be forever grateful. I also would like to thank Dr. Aubrey Schroeder for not only serving on my committee and funding my research, but also for his perspective and insight on the US swine industry. I would like to thank Dr. Michael Ellis and Christopher Puls for taking care of the pigs used in my research during the growing and finishing phase.

I am also appreciative of my fellow graduate students, both past and present, in the Meat Science Lab. Much of what I have accomplished would have not have been possible without their help. I would like to thank my Alma Mater, ISA University, and Don Juan Lucas Alba for the unconditional support and understanding throughout these past 6 years.

I would like to thank my family members and friends who have supported me throughout this journey known as graduate school. I would like to thank my father, Onésimo and my mother, Jesulina for their unconditional love and understanding. Additionally, I would like to thank my brothers Domingo, Amaury, Renso, and my sister Marycruz for making my education their

priority and their own personal goal. I also would like to thank Amarilis for giving the best years of her live to make me the man I am today. For that, I will be forever grateful.

Lastly and certainly not the least, I would like to thank my lovely wife Michelle and my daughter Eva. Both of you have provided the motivation to make me a better individual in all aspects of live. Michelle, in my eyes, you are the gold standard for professional excellence and unconditional love. If I could be half of what you are in those areas, I will be succesul in life. I am trully honored to be your husband and thanks for making my dreams yours as well. I look forward to spend the rest of my life with you raising our princess Eva.

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Chapter 1

REVIEW OF LITERATURE

INTRODUCTION

In the US, 80% of pork is consumed as further processed items (ham, bacon, sausage, smoked chops). Within further processed items, bacon accounts for 30% of products consumed (Pork Checkoff, 2009). Thus, given the market share of these items, it is imperative that new production technologies that increase efficiency and lean meat yield do not reduce quality of raw materials used to manufacture further processed pork products, especially bacon.

In 2011, the FDA approved the use of Improvest in entire males as a means to control boar taint. Generally, Improvest is administered subcutaneously around the base of the ear in two 2-ml doses at approximately 16 and 20 weeks of age. While the first dose primes the immune system, the second dose stimulates the immune system to suppressed testicular function resulting in clearing of boar taint compounds (androstenone and skatole). Therefore, IC barrows spent 80% (20 out of 25 weeks) of their production life as boars. Hence, Improvest management takes advantage of the reduced feed consumption with greater or similar rates of gain and increased leanness of boars compared to PC barrows. Difference in calculated lean between PC and IC barrows can range from -1.8 to 2.3% (Table 1.1). Nevertheless, Boler et al. (2011) reported that current equations to calculate lean overestimate lean in PC barrows by 1.4% and underestimate in IC barrows by 2.3%. Therefore, differences in lean observed in Table 1.1 should be greater in favor of the IC. However, one disadvantage of leaner pigs is that as they deposit less fat and this is generally more unsaturated in nature, their chances of fat quality issues (softer, oily, and yellowish fat) are increased. This ultimately can negatively impact fat quality in fresh bellies and reduce bacon slicing yields.

Fat quality of fresh bellies and bacon slicing yields are currently one main concern with Improvest managed pigs, and thus prevent full adoption of Improvest. The following review will focus on fat quality in fresh bellies from Improvest managed pigs and how this relates to bacon slicing yields. Additionally, opportunities to improve fat deposition with concomitant improvement in fresh belly characteristics and bacon slicing yields in IC pigs are explored.

FRESH BELLY QUALITY AND BACON PROCESSING CHARACTERISTICS OF IMPROVEST MANAGED PIGS

FRESH BELLY QUALITY

Generalities about Fat Quality

The term fat quality refers to the firmness, consistency, and color of adipose tissue in meat. In fresh bellies, soft and oily fat is indicative of poor fat quality. This leads to bacon that is of reduced workability; in other words, it difficult to slice, and its slices do not hold shape which is unappealing to consumers. Additionally, bacon shelf life may be compromised due to increased development of rancidity.

Fat quality in fresh bellies, is commonly measured by physical and chemical methods. The two most common physical methods are flop distance and thickness. To measure flop distance, bellies are draped over a stationary bar, skin side down, perpendicular to the length of the belly. The distance between the two skin edges is measured. This gives an indicator of firmness of the belly (Thiel-Cooper et al., 2001).

Generally, bellies that are soft are also thin. Therefore, thickness is also used as an indicator of quality. Thickness is measured at 8 locations along the belly using a probe. Briefly, locations 1 through 4 are equally space and obtained on the dorsal half of the belly starting at the anterior end and working towards the posterior end. Similarly, measurements 5 through 8 are obtained on the ventral side of the belly (Figure 1.1). The average of the 8 measurements is reported as thickness of the belly.

Data from several studies conducted at the University of Illinois Meat Science Laboratory reported flop distances ranging from 7.6 to 58.1 cm. In those studies, average belly thickness ranged from 2.2 to 5.3 cm (Boler et al., 2011; Boler et al., 2012; Kyle et al., 2014; Lowe et al., 2014a). These bellies are thicker than what would be classified as thin (2.0 cm) and are within the average (2.5 cm) and thick (3.0 cm) groups as described by Person et al. (2005).

Belly firmness and thickness are thought to be related to the composition of belly adipose tissue. Chemical methods allow for determining composition of adipose tissue directly and help to provide a basis for understanding differences in flop distances and thickness between groups of bellies. Some of the most common chemical methods are: proximate composition (lipid and moisture content), fatty acid profile, and iodine value (IV) of belly adipose tissue.

Adipose tissue has the vital role of energy storage. This storage occurs when nutrients are in abundance which is common after the animal has satisfied most of its energy needs for lean growth. Adipose tissue is mainly composed of lipids, proteins, and water. From these components, lipids account for the majority of the tissue. In swine adipose tissue 97% of lipids are triglycerides (glycerol + fatty acids) and the remainder are mostly phospholipids (diglyceride + phosphate group + organic molecule)(McCluer et al., 1989). In data from Lowe et al. (2014a), this lipid content ranged from 49 to 90% on wet basis. Composition of adipose tissue is determined by drying samples in an oven to remove moisture, samples are then washed multiple times with an organic solvent, either ether or chloroform-methanol, to extract lipids present in sample (Lowe et al., 2014b). Moisture and lipid are determined by weight differences after drying (moisture) and extraction (lipid).

Fatty acids, which are the main components in lipids, are also related to firmness and thickness. These are chemically classified according to their level of saturation (number of double bonds) in the following categories: saturated (no double bonds), monounsaturated (one double bond), and polyunsaturated (more than two double bonds). A global reporting of the fatty acids presents in a sample is termed the fatty acid profile. For pork bellies, this profile is determined from a sample of adipose tissue removed at the dorsal-anterior edge of the belly. Subsequently, lipids are extracted from the sample and using gas chromatography, individual fatty acids are identified according to their retention time and area under the curve at a set temperature. A standard containing fatty acids of interest is also analyzed for comparison. In a typical fatty acid profile from pork adipose tissue, the following are the most common fatty acids: saturated – myristic acid (14:0), palmitic (16:0), and steric (18:0); monounsaturated – oleic (18:1n-9) and gadoleic (20:1); and polyunsaturated – linoleic (18:2n-6) and arachidonic (20:4n-6). From these, the most abundant is oleic acid (22 – 44 g/100g lipid), followed by palmitic acid (20 – 33 g/100g lipid), stearic (8 – 15 g/100g lipid) and linoleic (9 – 27 g/100g lipid). Linoleic acid is termed an essential fatty acid because cannot be synthetized by the pig, thus need to be obtained from the diet. This fatty acid is the most abundant in corn (Weber and Alexander, 1975) and once absorbed, majority is inserted as part of phospholipids in adipose tissue. As the lipid deposition is increased, concentration of linoleic acid is diluted and thus its concentration is commonly thought of as an indicator of fatness and overall fat quality (Wood et al., 2008). Concentrations of linoleic acid greater than 14% in adipose tissue are identified as potential candidates for firmness issues (NPPC, 2000).

From a historical perspective, IV has been used in the food industry to characterize the behavior of fats and oils at room temperature and is typically expressed as amount of iodine absorbed by a fat sample. For example, corn oil has an IV of 109 – 133 and is liquid at room temperature, whereas, coconut oil has an IV of 7 -10 and is solid at room temperature (Thomas, 2000). In the pork industry, IV is used an indicator of fat firmness and is typically assessed by direct chemical methods (Hanus and Wijs), Near Infra-Red (NIR), and via equations using the concentration of fatty acids in g/100 g lipid extracted from a sample. Different equations are used to calculate IV, however one of the most common is the following from the AOCS (1998): $C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785 + C22:1(0.723)$. Other equations include more fatty acids resulting in relatively greater IV values (Meadus et al., 2009). Thus, caution should be taken to compare between experiments that use different equations. Iodine value is an indication of unsaturation with greater values indicating softer fat and lesser values firmer fat. Compiled data from Kyle et al. (2014), Lowe et al. (2014a); Lowe et al. (2014b); Tavárez et al. (2014a), and in PC barrows, IC barrows, and gilts indicate belly IV ranging from 56 to 80; with values greater than 70 being associated with soft and thin bellies.

Though measures of belly quality such as IV, flop distance, and thickness are often reported separately as indicators of quality, these are not independent of each other. Nor these are independent of lipid content of adipose tissue. Figure 1.2 illustrates association among traits used to determine quality in fresh belly. In general, as lipid deposition is increased in adipose tissue, bellies become thicker (1.2.A) and flop distance (1.2.B) is increased. Under this scenario, belly thickness and flop distance seemed to be positively correlated (1.2.C) because thicker bellies have greater flop distance. This increased in flop distance is most likely related to reduction in IV with increased lipid deposition (1.2.D). Additionally, as IV and linoleic acid concentration are increased, flop distance is reduced (1.2.E, 1.2.F). These findings demonstrate the interconnection between traits. Therefore, inferences should not be drawn from single traits, but rather as a group of traits.

Leanness and Fat Quality

Several factors – genetics, sex, stressors, seasonality, and diet – are blame for causing fat quality issue. Leanness of pigs, however, underlies many of these factors. In an early experiment, Scott et al. (1981b) reported that adipose tissue from an obese breed of swine had greater concentrations of saturated fatty acids and less linoleic acid than that of a lean breed. These differences between breeds were linked to a reduced number of fat cells (adipocytes) with greater volume to store lipid in the obese breed compared to lean breed (Scott et al., 1981a). Differences in fat quality are also expected between PC barrows and gilts. Gilts typically reach their plateau in their growth curve later in time compared to PC barrows. As a consequence, most of the energy consumed before reaching this plateau is directed towards lean deposition as supposed to fat deposition (White et al., 1995). Therefore, gilts are typically leaner than PC barrows (Correa et al., 2008). Adipose tissue of gilts has been reported to have greater concentration of linoleic acid and IV as compared to PC barrows (Correa et al., 2008; Martin et al., 1972; Villegas et al., 1973).

Stressors, such as the combination of temperature and reduced spatial allocation, can also altered fat deposition and adipose tissue characteristics. In a study conducted by White et al. (2008), fat deposition in bacon was reduced by 6.25 percentage units, linoleic acid, and IV were increased by 2.86 percentage units and 3.54 IV units in pigs housed at 32.2°C and 0.66 m^2 compared to those house at 23.9°C and 0.93 m^2. These effects on fat were probably mediated through suppression of feed intake. Suppression of feed intake for prolonged periods reduces fat deposition and makes pigs leaner (Leymaster and Mersmann, 1991). Leaner pigs typically have greater concentration of linoleic acid in adipose tissue, which make bellies softer and also increases IV, as this is the most abundant polyunsaturated fatty acid in pork.

Diet has the most immediate impact on fat quality. Fatty acid composition of swine adipose tissue is reflective of dietary fatty acid composition (Averette Gatlin et al., 2002). For example, when pigs are fed distillers dried grains with solubles (DDGS) for a prolonged time, the fatty acid profile of adipose tissue resembles that of DDGS, which is increased concentration of linoleic acid. A similar situation is observed during summer months in which the energy density of swine diets is increased by the addition of unsaturated oils (vegetable oils, rendering products from animal sources). The use of these oils is justified because of greater energy content as compared to carbohydrates sources (9 vs. 4.5 kcal/ g). Therefore, their inclusion mitigates the reduction in performance due to suppressed feed intake during the summer. The combination of increased unsaturation, due to oils in the diet; and increased leanness, due to reduced feed intake; results in greater IV during the summer month.

Figure 1.3 illustrates the relationship of leanness, as measured by 10th rib backfat depth, to flop distance and thickness. In comparison with lean pigs (< 17 mm), flop distance was increased by 7.5 cm in ideal pigs (18 – 24 mm) and by 18.3 cm in fat pigs (> 25 mm; 1.3.A). Similarly, belly thickness was increased by 0.3 cm in ideal pigs and by 0.7 cm in fat pigs when compared with lean pigs (1.3.B). Backfat depth was well correlated with belly flop distance (r = 0.61; $P < 0.01$) and thickness (r = 0.59; $P < 0.01$). Backfat depth was also as good of a predictor of belly flop distance as IV (r = -0.59; $P < 0.01$). This is of great importance as backfat depth is commonly measured at slaughtered and it’s easier, and less expensive to collect than IV.

Data discussed in this section were originated from PC barrows and gilts fed a conventional corn-soy diet. And indicated that increased leanness produce bellies that are softer and thinner than those from fatter pigs. Thus, under these circumstances backfat depth can be used as a predictor of belly firmness and thickness.

Improvest Bellies

Several studies have reported that Improvest managed pigs produce bellies that are on average 10.3 cm firmer (as measured by flop distance) and 0.5 cm thicker than those from entire males (Boler et al., 2011; Kyle et al., 2014). However, bellies from IC barrows (26.4 cm, 3.8 cm) are on average intermediate to those from PC barrows (35.9 cm, 4.1 cm) and gilts (22.9 cm, 3.6 cm) in regards to firmness and thickness (Kyle et al., 2014; Lowe et al., 2014a).

In Improvest managed pigs, there is the potential to improve belly quality as the time interval between second dose and slaughter is increased. Belly flop distance was increased in IC barrows from 11.9 cm at 4 weeks to 15.3 cm at 6 weeks after second dose; while thickness remained unchanged during that interval (Boler et al., 2012). Similarly, in IC barrows slaughtered at 5 and 7 week after second dose, belly thickness was increased from 3.4 cm to 4.0 cm and flop distance from 14.7 cm to 16.1 cm. At 5 weeks, belly thickness in IC barrows was 0.3 cm less than PC barrows, but at 7 weeks, the two castration methods differ by only 0.1 cm. While flop distance of IC barrows did increased from 5 to 7 weeks, flop distance of PC barrows also increased (from 16.7 to 18.97 cm)(Tavárez et al., 2014a). Therefore, the difference in flop distance between the two castration methods was unchanged over this interval.

The underlying cause for these improvements is thought to be increased *de novo* synthesis of fat as a consequence of increase in feed intake. This increase in feed intake with a concomitant increased in fat deposition has been previously documented in IC barrows raised outside the US at lighter market weight (Dunshea et al., 2008; Dunshea et al., 2001; Lealiifano et al., 2011). Figure 1.4 displays this increase in feed intake in IC barrows raised in the US using data adapted from Asmus et al. (2014). Immunological castrated barrows, although having consumed less feed than PC barrows until second dose, increased their feed intake by 46% from 0 to 7 weeks after second dose. During that time, PC barrows feed intake was increased by only 18%. The increased in IC barrows feed intake was most pronounced from 3 to 5 weeks after second dose. Feed intake increased 27% during this time compared with just a 5% increase in feed intake in PC barrows during the same interval. Also, during this interval, IC barrows feed intake began to exceed PC feed intake. At 5 and 7 weeks, IC barrows consumed 9% and 11% more feed compared to PC barrows.

Excess carbohydrates consumed as a result of this increased feed intake will be fat. Briefly, in adipocytes glucose are obtained from the plasma, transformed to acetyl-Coa, and synthetized to fatty acids (Bauman, 1976).These fatty acids are quickly process in the cell because free fatty acids are detergent and potentially toxic to the cell. Once processed, fatty acid can be oxidized or used for biosynthetic purposes, including synthesis of phospholipids, cholesterol esters, and triglycerides (major storage lipid). The main fatty acids produced from *de novo* synthesis are the saturated fatty acids palmitic and stearic acids (Mersmann and Smith, 2005). Thus, as the pigs continue to deposit fatty acids and adipocytes fills with triglycerides from *de novo* synthesis, the proportion of unsaturated fatty acids in adipose is reduced, especially linoleic acid (Wood et al., 2008). Consequently, this *de novo* synthesis is reflected in increased lipid content (71.75% at 4 weeks to 77.21% at 8 week after second dose in IC) and reduced IV of belly adipose tissue (63.98 at 4 weeks to 60.85 at 8 weeks after second Improvest dose in IC). While in PC, lipid content was also increased (81.67 at 4 weeks to 84.88 at 8 weeks) and IV of the belly adipose tissue unchanged (61.53 at 4 weeks to 61.64 at 8 weeks) (Tavárez et al., 2014b).

Fresh belly characteristics from Improvest managed pigs are summarized in Table 1.1. This Table contains data from 882 pigs (441 per castration method). Immunologically castrated barrows were 3.7 kg heavier and had 2.1 mm less backfat than PC barrows. Additionally, flop distance and thickness were reduced 7.1 cm and 0.3 cm, respectively in IC compared to PC barrows. Belly adipose tissue lipid content was reduced by 8.9 percentage units in IC barrows, and linoleic acid concentration (14.5 vs. 13.3) and Iodine value (66.2 vs. 65.7) were greater compared to PC barrows. It is important to note the effect of DDGS inclusion on fresh belly quality. Belly flop distance and IV were considerably worse in those studies were DDGS were present in the diet (Boler et al., 2012; Tavárez et al., 2014a). For example, the difference in flop distance between PC barrows fed a corn-soy diet (29.9 cm) and those fed a DDGS diet (17.4 cm) was 12.1 cm. While, between PC and IC barrows this difference was only 7.1 cm. This finding implies that diet has a greater impact on fresh belly characteristics than castration method. Additionally, fresh belly quality in IC barrows is best later (> 6 wk) rather than early after second dose. These improvements are thought to be related to changes in quantity and type of fat deposited with increasing time after second dose.

BACON PROCESSING

Generalities about Bacon Processing

Pork bellies are typically injected with brine and allow to equilibrate for distributions of the curing ingredients. Bellies are then cooked and tempered at temperature close to freezing. Subsequently, cooked bellies are pressed, flank end cut (unusable end) anterior to the inguinal lymph nodule and blade ends squared resulting in a trimmed belly. This trimmed belly is sliced.

Unusable ends, incomplete, and removed slices are summed and classified as ends and pieces. Sliced bacon is the final product originated from the belly primal, which served as the main raw material. Thus, slicing yield is of most importance for the bacon manufacturer as it directly relates to product sell at a premium price compare with ends and pieces.

Discussion of bacon processing data will focus on pump uptake, cooked yield, and slicing yield. Pump uptake indicates amount of brine retained in the belly after injection expressed as a percentage of belly green weight (weight of belly before processing). It is calculated with the following equation: $\left(\frac{Pump\ wt}{green\ wt}\right) \times 100\%$. Cooked yield relates weight of the belly after thermal processing with green weight and is calculated with the following equation: $\left(\frac{cooked\ wt}{green\ wt}\right) \times 100\%$. Slicing yield relates weight of bacon slices with either green weight or cooked weight and is calculated with the following equations: $\left(\frac{sliced\ wt}{green\ wt}\right) \times 100\%$ or $\left(\frac{sliced\ wt}{cooked\ wt}\right) \times 100\%$. Slicing yield, expressed as percentage of green weight carries inherent variation due to pump uptake and cooked weight. In contrast, slicing yield expressed as percentage of cooked weight carries only inherent variation due to cooked weight. Thus, yield as percentage of cooked weight is less variable.

Leanness and Bacon Slicing Yields

The effects of increased of leanness on belly flop distance and thickness were already established in a previous section. Thus, the logical next step would be to determine how increased leanness or reduced fatness relates to bacon slicing yields. To accomplished this goal, pigs from a previous trial (Tavárez et al., 2014a) were segregated according to backfat depth measured at the level of the 10^{th} rib into lean (< 17 mm), ideal (18 -24 mm), and fat (> 25 mm). Next, slicing yields from each class were plotted and compared (Fig. 1.5). From this Fig., bacon from lean pigs had 4 and 3.3 percentage units less slicing yields than ideal and fat pigs. This finding is in line with those observed for fresh bellies. This implies that pigs do not need to be fed until fat to increase bacon slicing yields. This has very important economic implications because one would expect that as fatness increased, the yield of lean sellable meat from the rest of the carcass is decreased.

Bacon Production from Improvest Managed Pigs

Considerations about site for processing. Bacon processing data obtained thus far originate from two facilities, a commercial site and the University of Illinois Meat Science Laboratory (U of I Meat Science Lab). It is important to acknowledge that processing conditions are different between sites. Some of the differences between processing sites are explained below.

At the U of I Meat Science Lab, the starting raw material for bacon manufacturing is an IMPS #408 belly (teat line removed and flank end squared; Fig. 1.6.B) as described by the North American Meat processors Association (2010). Bellies are injected with a cure solution to target 110% of original green weight and allowed to equilibrate for 48 hours. Next, bellies are cooked to an ending internal temperature of 55°C. Cured bellies are placed in a cooler for 24 hours and allowed to cool to 4°C. After chilling, rind is removed and cooked bellies are slice.

However, in a commercial site, the starting raw material is an IMPS #409 skinless pork belly (teat line attached without flank end squared; Fig. 1.6.A) also referred as a natural fall belly. Bellies are injected with a cure solution to target 113% of original green weight and allowed to equilibrate. Bellies are then cooked to target 100% of green weight. Cured bellies are chilled for approximately 48 hours to an internal temperature of -5°C. After chilling, bellies are pressed and sliced according to commercial plant standard operations procedures.

Overall, the process of bacon production is more control at the U of I Meat Science Lab than in a commercial setting. The U of I Meat Science Lab is a small scale operation and labor responsible for slicing and sorting slices are graduate students. Slicing and sorting of slices can take as much time as needed, because research is the main objective. While a commercial setting, is a great scale production process and labor responsible for slicing and sorting of slices are skilled workers. Cooked bellies are sliced with high speed commercial slicers (800 – 1,400 revolutions per minutes or 10 – 20 revolutions per second) and sorting is made at line speed (Toldrá, 2010). In a commercial setting, speed of the slicing and sorting operations is important because workers are evaluated on efficiency. For example, number of sliced bellies per hour.

Based on the above differences, caution should be taken to compare processing data between studies conducted at different sites.

U of I Meat Science Lab Studies. An initial study to determine the effects of increasing concentration of lysine on further products from IC barrows reported that cured bellies from IC barrows are more similar to those from PC barrows than to intact males (Boler et al., 2011). Furthermore, pump uptake and cooked yield were similar between IC fed 1% SID lysine (9.9%, 96.7%) and PC fed 0.7% SID lysine (8.7%, 97.0%). In that study, pump uptake (11.4%) was greater and cooked yield (95.1%) was less in intact males compared to IC and PC barrows. In another study, pump uptake (12.9% vs. 11.3%) and cook loss (11.1% vs. 10.0%) were greater in IC barrows, but cooked yields were similar (97.4% vs. 97.5%) compared to PC barrows (Boler et al., 2012). Similar results were reported by (Lowe et al., 2014a).

Leaner raw materials, such as those originating from IC barrows, have greater concentration of protein and thus retain more brine than less lean counterparts. Proteins in meat have the ability to hold brine due to their electric chargers, while fat does not have this ability.

These leaner raw materials also have more inherent water, therefore lose more water during cooking. However, the final product should be of similar cooked yield.

In pigs raised in a commercial operation and slaughtered at a target weight of 130 kg, slicing yield expressed both as a percentage of green weight (86.3% vs. 85.6%) and cooked weight (96.8% vs. 96.6%) were similar between IC and PC barrows (Lowe et al., 2014a).

Bacon processing data for the studies conducted at the U of I Meat Science Lab were summarized in Table 1.2. Briefly, in heavy weight (> 130 kg BW) pigs with similar backfat (IC, 20.9 mm vs. PC, 22.4 mm); pump uptake was 1.3 percentage units greater in IC barrows. Cooked belly yield and slicing yield were similar compared to PC barrows. However, lipid content of bacon was 5.0 percentage units less in IC barrows.

Commercial studies. Two commercial bacon studies have been conducted to determine cured belly characteristics of Improvest managed pigs. In the first study, IC barrows were slaughtered between 4.5 and 7.5 weeks after second dose. Additionally, pigs were slaughtered at approximately 130 kg BW (Kyle et al., 2014). Although backfat was similar between IC (28.5 mm) and PC (28.9) barrows, lipid content of bacon was 4.8 percentage units less in IC barrows. Slicing yields in IC barrows expressed as a percentage of green weight were 4.8 and 4.6 percentage units less than PC barrows and gilts, respectively. However, feeding ractopamine to IC improved slicing yields by 2.76 percentage units to 93.6% compared to IC barrows not fed ractopamine at 96.4%. The increased slicing yields due to ractopamine may be explained by greater secondary lean area of the slice (Kyle et al., 2014; Scramlin et al., 2008). This increased in secondary lean area is thought to help stabilize structural integrity of the bacon slice. This was evidenced by a reduction of 48% in the number of shatters (breaks in the fat that occur perpendicular to the length of the slice) in IC fed ractopamine compared to those not fed ractopamine.

In the second study, pigs were slaughtered at 5 and 7 weeks after second Improvest dose to evaluate strategies of feeding DDGS to IC barrows (Tavárez et al., 2014a). At 5 weeks, pigs were slaughtered at an average body weight of 119 kg and 19.6 mm of backfat depth. Slicing yields expressed as a percentage of green weight and as a percentage of cooked weight were 6.1 (green) and 4.4 (cooked) percentage units less in IC compared to PC (Fig. 1.7. A, 1.7.B). While at 7 weeks, in pigs slaughtered at an average body of 135.3 kg and 24.2 mm of backfat depth, differences in slicing yields were reduced to 4.6 (green) and 4.3 (cooked) percentage units. Increase in slicing yield in IC from 5 to 7 weeks is likely due to a greater rate of lipid deposition in IC barrows compared to PC barrows. From 5 to 7 weeks, this was evidenced by 7.6 percentage units increase in bacon slice lipid content in IC while the increase in PC was only 4.3 percentage units (Fig.1.7.C). From 5 to 7 weeks after second dose, IC barrows become fatter. This results in flop distance and lipid content in bacon becoming statistically similar between IC and PC. However, while slicing yields did increase from 5 to 7 weeks after second dose in IC barrows, it remained 5 percentage units less than that of PC barrows.

In the same study, it is important to notice the effect of DDGS feeding strategy on slicing yields. In IC barrows, withdrawal of DDGS from the diet increased slicing yields by 5.1 and 5.9 percentage units to 88.6% compared to corn-soy at 83.5% and 30% DDGS at 82.7% average over time after second dose. While in IC barrows, slicing yields remained unchanged in corn-soy at 90.3% compared to 30% DDGS at 90.3% and withdrawal at 90.5%. It is also important to notice, at 5 weeks, flop distance was decreased in IC barrows fed corn-soy by 2.3 cm compared to PC fed corn-soy, but increased in IC barrows fed 30% DDGS by 0.6 cm compared to PC fed

30% DDGS. Similarly, at 7 weeks, flop distance was decreased in IC barrows fed corn-soy by 4.5 cm compared to PC fed corn-soy, but increased in IC barrows fed 30% DDGS by 1.1 cm compared to PC fed 30% DDGS. At all times slicing yield were consistently less in IC barrows.

Bacon processing data from commercial studies are summarized in Table 1.2. On average IC barrows were 3.3 kg heavier than PC with similar backfat (22.8 mm vs. 23.7 mm). Pump uptake was similar, but cured belly cooked yields were 1.6 percentage units less in IC compared to PC barrows. Slicing yields, expressed both as percentage of green weight and cooked weight, were on average 5.3 and 4.0 percentage units greater in PC compare to IC barrows. Lipid content of bacon was 4.8 percentage units in less in IC.

The difference in slicing yields between PC and gilts was 0.2 percentage units, while between PC and IC barrows was 5.3 percentage units; and between pigs fed corn-soy and 30% was 0.4 percentage units (Kyle et al., 2014; Tavarez et al.,.2014a). Reduced slicing yields represent the greatest challenge for adoption of Improvest. Although slicing yields can be improve with increasing time between second dose and slaughter, sellable meat yield can be reduced. It is important to determine the economic implication of this reduction in meat yield compared to improvements in slicing yields.

Predictors of Bacon Sliceability

Bacon data from commercial studies suggest that traditional traits associated with fresh belly quality such as flop distance, thickness, linoleic acid content, and IV may not be good predictors of slicing yields. The association between those traits with slicing yields is presented in Tables 1.3 and 1.4. This association is obtained with a person correlation coefficient (r). This coefficient is bounded by -1 and 1, where r = -1 denotes a negative association between two variables, A and B. Such association is interpreted as the levels of variable A increases, B decreases. The opposite is true if the association were to be positive, r = 1. An r = 0 is interpreted as no association between the two variables.

Data used to calculate correlation coefficients were obtained from the two commercial slicing yields study already presented in this section, which encompassed 380 carcasses. Given the results, prediction of bacon slicing yields appears dependent on sex class. Overall, the best predictor of slicing yields expressed as a percentage of green weight was belly thickness (r = 0.45) in IC barrows; yet, this only accounts for 20.0% of the total variation associated with slicing yields (Table 1.3). For slicing yields expressed as a percentage of cooked weight, bacon lipid content (r = 0.48) was the best predictor in intact males and this only account for 23.0% of the total variation (Table 1.4).

Reduction of slicing yield due to soft and thin bellies has been partially addressed in the pork industry by modifying their manufacturing practices. Most companies segregate bellies by weight and length. This allows for removal of a proportion of thin and soft bellies. Additionally, tempering cooked bellies to temperatures close to freezing before slicing, followed by pressing and squaring has also become common. Tempering takes advantage of the lower melting point of polyunsaturated fatty acids in thinner and softer bellies. Thus, fat does not liquefied and remained in tissue during slicing. Pressing and squaring helps maintain the overall integrity and structure of bacon during slicing.

CONCLUSIONS

In general, Improvest managed pigs produce fresh bellies that are of intermediate quality between gilts and PC barrows. However, as time after second Improvest dose progresses and pigs become heavier and fatter, fresh bellies from IC barrows become more similar to those of PC barrows in terms of firmness, and IV. However, though slicing yields also improved with increasing time after second dose, these did not reach those observed in PC. This would imply that traditional methods to evaluate fresh belly quality are not good predictors of slicing yields, and thus the need continue to investigate other factors. For instance, the process of bacon manufacturing seems to carry a great proportion of inherent variability because of the observed reduction in the difference in slicing yields between IC and PC barrows when these are expressed as percentage of cooked weight as supposed to green weight. Thus leading us to believe that there is a need for a better understanding of the manufacturing process. This coupled with more commercial studies should help improve our understanding of the variability surrounding slicing yields.

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FIGURES

Figure 1.1. Belly thickness measurement locations

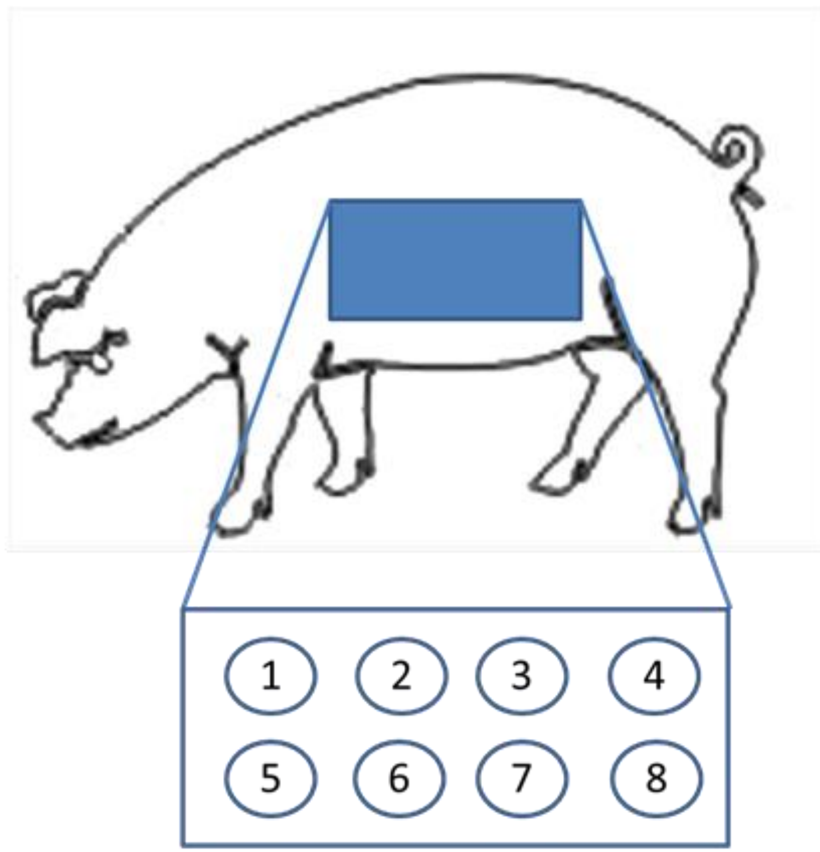


Figure 1.2. Person correlation coefficient (**r**) between traits used to measure fresh belly quality: **A.** Adipose tissue lipid content and thickness; **B.** Adipose tissue lipid content and thickness; **C**. Thickness and flop distance; **D**. Adipose tissue lipid content and iodine value; **E**. Iodine value and flop distance; and **F**. Linoleic acid and flop distance. Adapted from Kyle et al. (2014) and Lowe et al. (2014a).

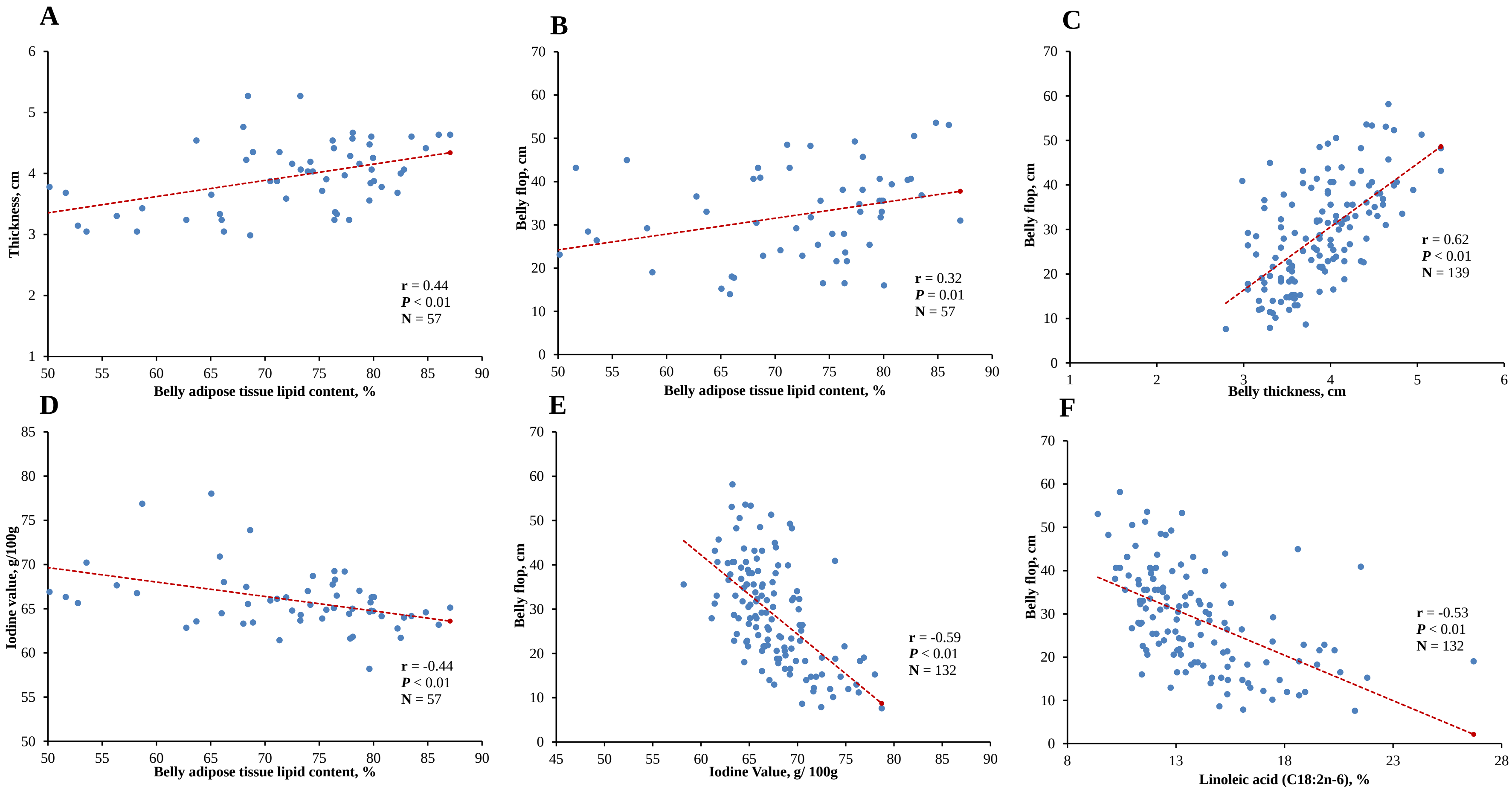


Figure 1.3. Effects of leanness on belly flop distance (**A**) and thickness (**B**) in a population pigs segregated into lean (< 17 mm), ideal (18 -24 mm), and fat (> 25 mm) according to backfat depth measured at the level of the 10th rib. Adapted from Lowe et al. (2014a) and Kyle et al. (2014).

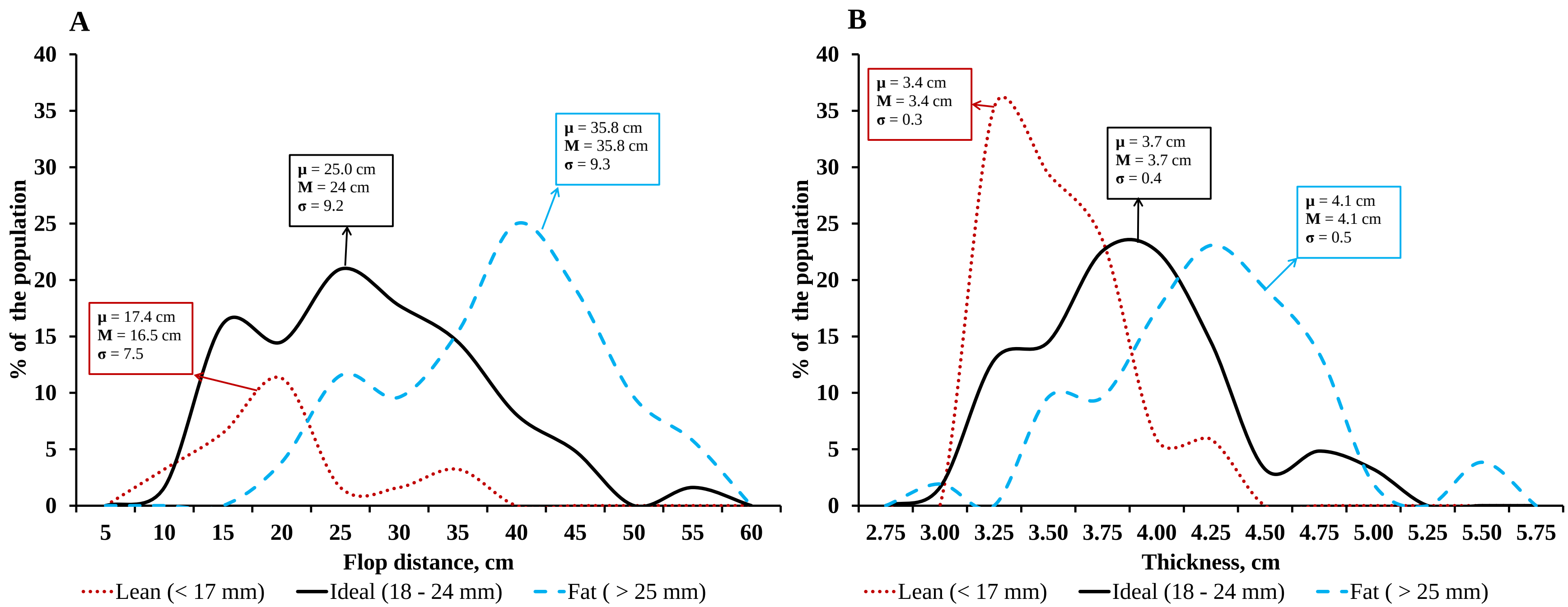


Figure 1.4. Changes in average daily feed intake (**ADFI**) after second Improvest dose on immunologically castrated (**IC**) barrows and physically castrated (**PC**) barrows. Immunological castrated barrows, although having consumed less feed than PC barrows until second dose, increased their feed intake by 46% from 0 to 7 weeks after second dose. During that time, PC barrows feed intake was increased by only 18%. The increased in IC barrows feed intake was most pronounced from 3 to 5 weeks after second dose. Feed intake increased 27% during this time compared with just a 5% increase in feed intake in PC barrows during the same interval. Also, during this interval, IC barrows feed intake began to exceed PC feed intake. At 5 and 7 weeks, IC barrows consumed 9% and 11% more feed compared to PC barrows. Adapted from Asmus et al. (2014).

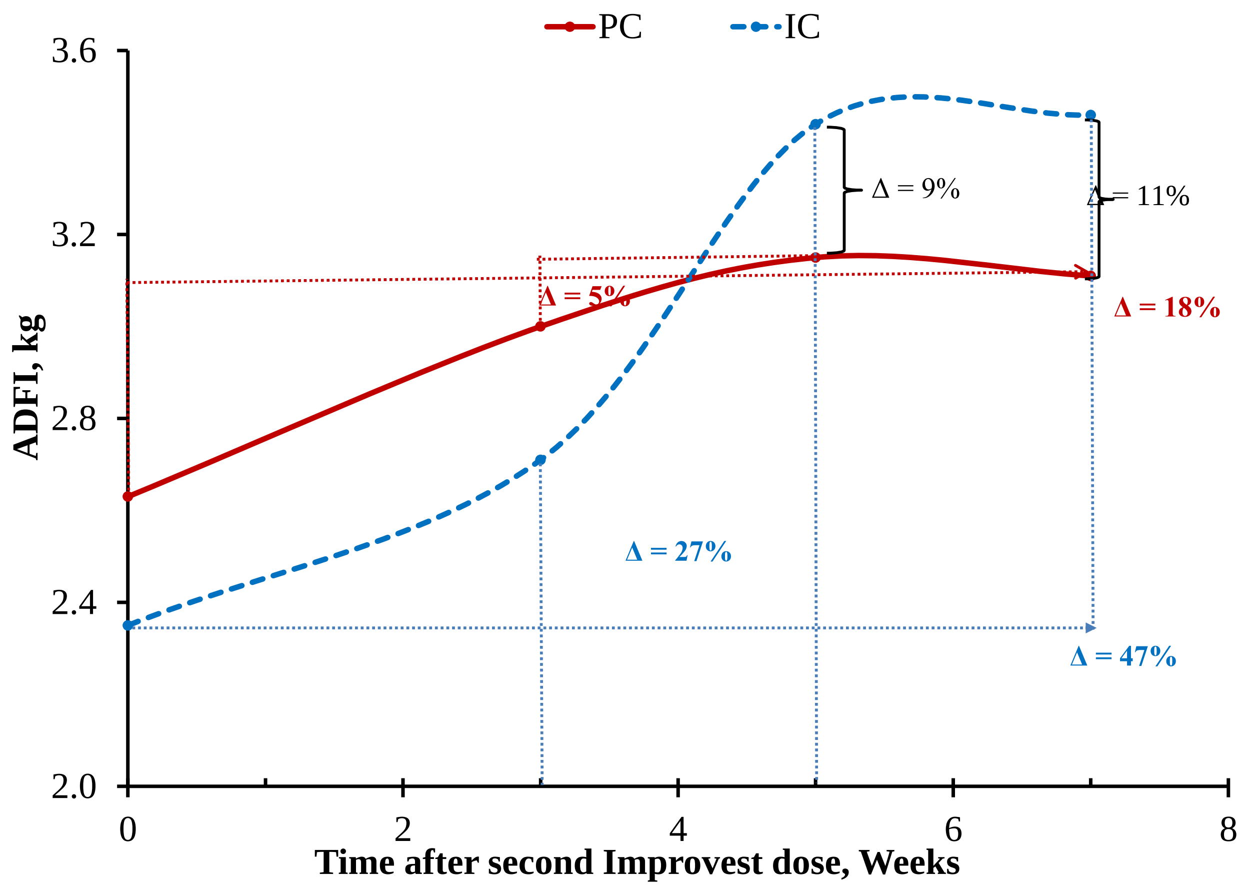


Figure 1.5. Effects of leanness on bacon slicing yield (percentage of belly green weight) in pigs segregated into lean (< 17 mm), ideal (18 -24 mm), and fat (> 25 mm) according to backfat depth measured at the level of the 10th rib. Adapted from Tavárez et al. (2013a).

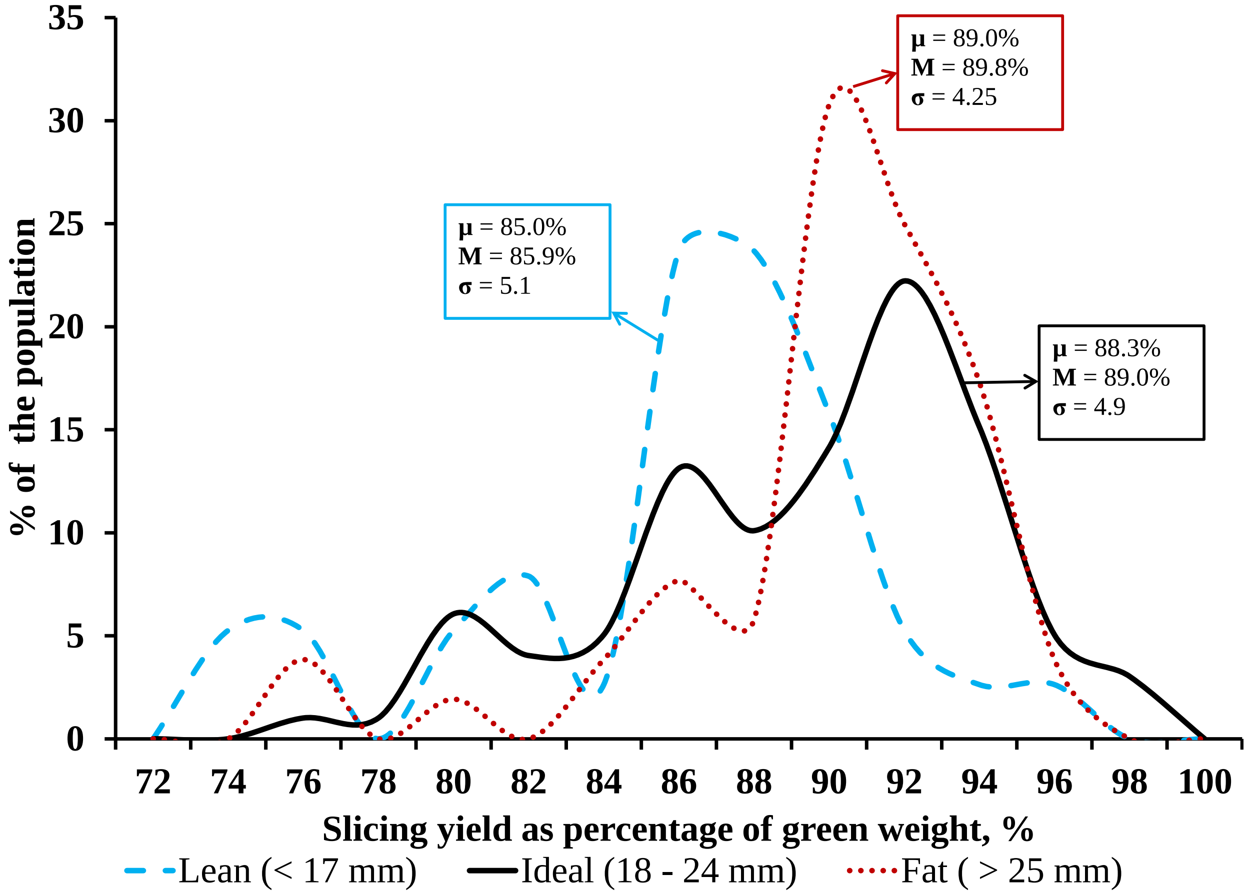
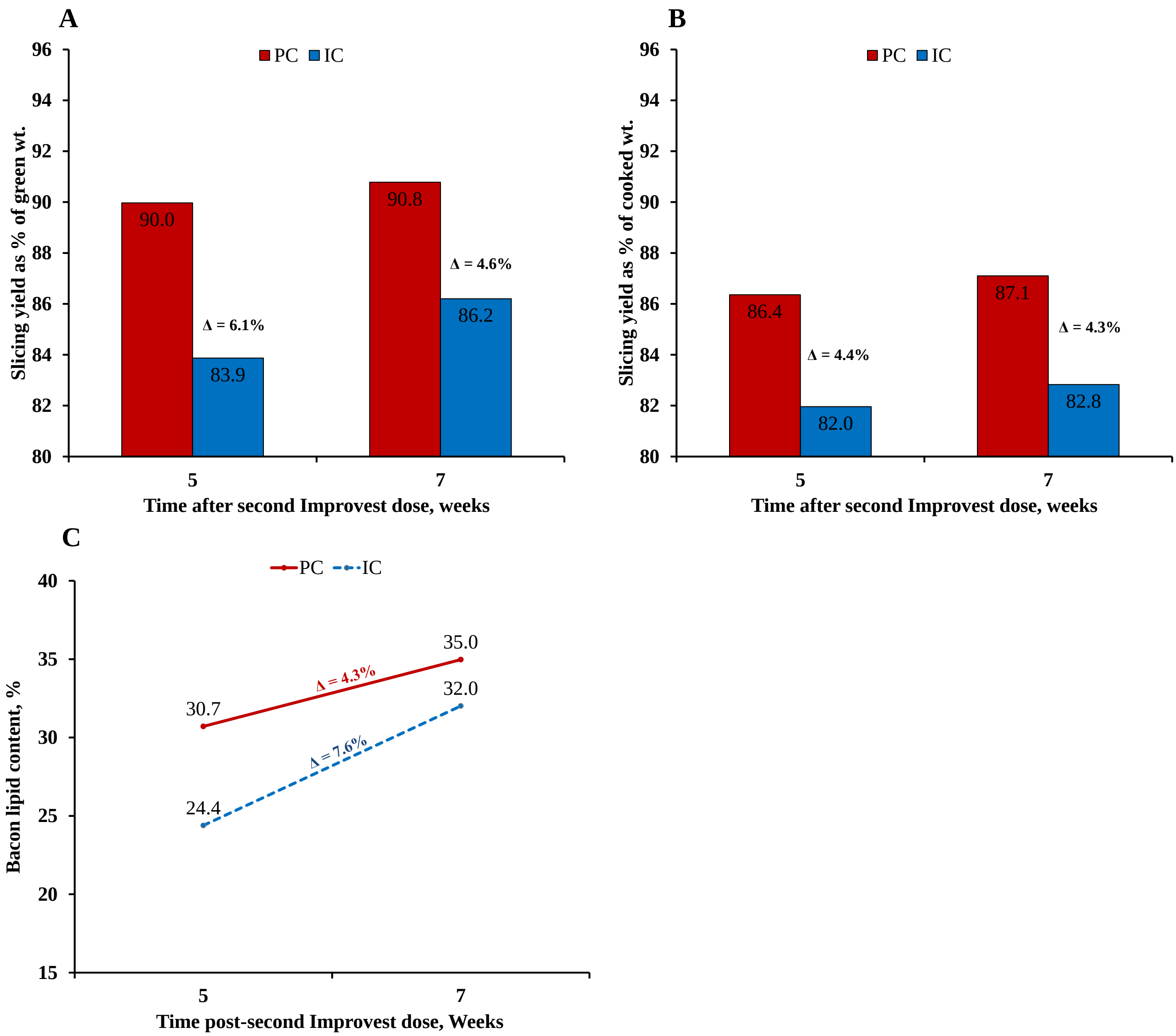


Figure 1.6. Pork belly with teat line attached without flank end squared referred as natural fall belly (**A**) typical in a commercial bacon facility compared with belly (**B**) with teat line attached and flank end squared commonly fabricated at the University of Illinois Meat Science Laboratory.

Figure 1.7. Bacon slicing yields expressed as both percentage of green weight (**A**) and cooked weight (**B**) and slice lipid content (**C**) in physically castrated (**PC**) and immunologically castrated (**IC**) barrows slaughtered at 5 and 7 week after second Improvest dose. Adapted from Tavárez et al. (2013a)



TABLES

Table 1.1 Summary of fresh belly characteristics from Immunologically castrated (**IC**) and physically castrated (**PC**) barrows

Study	Age (wk)		Time after D2 (wk)	Samples per trt	Slaughter weight (kg)		HCW (kg)		10th rib backfat (mm)		Estimated Lean (%)			Belly flop Distance (cm)			Belly thickness (cm)			Adipose tissue lipid content (%)			Linoleic acid-C18:2n-6 (%)			Iodine value (g/100g)		
	D2	**Slaughter**			**PC**	**IC**	**PC**	**IC**	**PC**	**IC**	**PC**	**IC**	**Δ**	**PC**	**IC**	**Δ**	**PC**	**IC**	**Δ**	**PC**	**IC**	**Δ**	**PC**	**IC**	**Δ**	**PC**	**IC**	**Δ**
Boler et al., 2011 (corn soy diet)[1]	20	25	5	16	125.7	130.3	92.0	93.3	19.0	16.0	55.2	57.5	2.3	31.9	19.2	-12.7	3.8	3.4	-0.4	.	.	.	12.6	12.1	-0.4	64.3	63.2	-1.2
Boler et al., 2012 (Step-down diet)[2]	19	23	4	39	122.7	126.3	91.4	91.0	17.7	16.3	55.6	56.2	0.6	18.3	11.9	-6.4	3.3	3.3	0.0	.	.	.	19.4	21.5	2.1	74.6	76.6	1.9
Boler et al., 2012 (Step-down diet)[2]	19	25	6	39	124.0	131.5	92.6	94.0	17.6	16.3	55.7	56.3	0.6	19.8	15.5	-4.3	3.5	3.2	-0.4	.	.	.	18.3	19.6	1.3	73.8	74.5	0.7
Lowe et al., 2013 (corn soy diet)	20	24	4	59	.	.	102.2	104.8	27.9	23.8	.	.	.	39.5	27.5	-12.0	4.2	3.9	-0.3	76.7	67.2	-9.5	11.4	14.5	3.1	64.5	65.3	0.9
Tavárez et al., 2013 (corn soy diet)	20	22	2	6	122.2	118.5	96.4	90.3	.	.	.	.	.	.	.	.	.	.	.	82.8	75.7	-7.1	12.1	15.9	3.8	61.7	67.0	5.4
Tavárez et al., 2013 (corn soy diet)	20	24	4	6	124.9	134.2	97.6	101.5	.	.	.	.	.	.	.	.	.	.	.	81.7	71.8	-9.9	12.6	13.2	0.6	61.5	64.0	2.5
Tavárez et al., 2013 (corn soy diet)	20	26	6	6	134.7	144.5	105.3	111.2	.	.	.	.	.	.	.	.	.	.	.	81.6	76.7	-5.0	15.3	14.0	-1.3	62.7	63.8	1.1
Tavárez et al., 2013 (corn soy diet)	20	28	8	6	142.6	147.3	114.4	116.3	.	.	.	.	.	.	.	.	.	.	.	84.9	77.2	-7.7	13.1	14.4	1.3	61.6	60.9	-0.8
Lowe et al., 2013 (corn soy diet)	18	22.5-25.5	4.5-7.5	144	137.8	140.6	100.7	100.2	25.3	23.9	50.4	50.5	0.04	35.2	26.6	-8.6	4.1	3.8	-0.3	.	.	.	10.1	10.8	0.7	61.5	61.8	0.3
Kyle et al., 2013 (corn soy diet)	20	24.7-25.7	4.7-5.7	24	131.4	133.0	103.4	102.9	28.9	28.5	48.3	48.2	-0.1	32.2	25.3	-7.0	3.9	3.7	-0.2	.	.	.	13.4	13.9	0.5	67.6	68.3	0.7
Tavárez et al., 2013 (corn soy diet)	20	25	5	16	118.2	120.7	89.0	89.0	20.4	17.8	54.6	56.0	1.4	18.2	15.9	-2.3	3.8	3.5	-0.4	.	.	.	11.2	13.7	2.6	61.6	63.2	1.7
Tavárez et al., 2013 (corn soy diet)	20	27	7	16	134.3	137.4	101.9	102.5	26.1	24.7	50.9	52.0	1.1	22.5	18.0	-4.5	4.2	4.1	0.0	.	.	.	10.8	11.7	0.8	61.8	62.2	0.3
Tavárez et al., 2013 (30% DDGS diet)[3]	20	25	5	16	118.4	120.5	87.2	86.1	21.3	19.8	53.9	54.6	0.7	13.8	14.4	0.6	3.7	3.4	-0.3	.	.	.	18.3	19.3	1.1	71.5	71.9	0.5
Tavárez et al., 2013 (30% DDGS diet)[3]	20	27	7	16	133.5	139.4	101.0	103.2	24.1	23.8	52.5	52.5	0.0	13.8	15.0	1.1	4.1	3.7	-0.4	.	.	.	18.6	18.6	-0.1	71.4	69.7	-1.7
Tavárez et al., 2013 (withdrawal diet)[4]	20	25	5	16	117.4	118.9	88.2	86.9	20.8	17.7	54.4	56.2	1.8	18.1	13.8	-4.3	3.8	3.5	-0.3	.	.	.	15.6	16.2	0.6	67.5	66.3	-1.2
Tavárez et al., 2013 (withdrawal diet)[4]	20	27	7	16	130.2	136.9	98.5	101.6	21.9	24.8	53.7	51.9	-1.8	20.6	15.4	-5.2	4.0	4.0	0.0	.	.	.	14.7	13.6	-1.2	66.7	64.5	-2.2
Overall Weighted Averages[5]				***441***	**130.4**	**134.1**	**98.0**	**98.5**	**23.5**	**21.9**	**52.4**	**52.8**	**0.4**	**28.5**	**21.4**	**-7.1**	**3.9**	**3.7**	**-0.3**	**78.5**	**69.6**	**-8.9**	**13.3**	**14.5**	**1.2**	**65.7**	**66.2**	**0.5**

[1]Immunological castrate fed a diet containing 1% SID Lysine

[2]Pigs were fed a diet containing 20% DDGS from 6 weeks of age until 19 weeks; and then switched to 10% DDGS until slaughter

[3]Pigs were fed a diet containing 30% DDGS from 6 weeks of age until slaughter 25 and 27 weeks

[4]Pigs were fed a diet containing 30% DDGS from 6 weeks of age until 20 weeks; and then switched to a corn soy diet until slaughter

[5]Averges were weighted, meaning that from each study the number of samples per treatments was accounted in the calculation of the overall average

Table 1.2. Summary of bacon slicing yields from Immunologically castrated (**IC**) and physically castrated (**PC**) barrows

Study site	Age (wk) D2	Age (wk) Slaughter	Time after D2 (wk)	Samples per trt	Slaughter weight (kg) PC	Slaughter weight (kg) IC	HCW (kg) PC	HCW (kg) IC	10th rib backfat (mm) PC	10th rib backfat (mm) IC	Natural fall belly as % of chilled side weight PC	Natural fall belly as % of chilled side weight IC	Pump uptake[1] (%) PC	Pump uptake[1] (%) IC	Cured belly cooked yield[2] (%) PC	Cured belly cooked yield[2] (%) IC	Bacon lipid content (%) PC	Bacon lipid content (%) IC	Slicing yield (% of Green weight)[3] PC	Slicing yield (% of Green weight)[3] IC	Slicing yield (% of Green weight)[3] Δ	Slicing yield (% of cooked Weight)[4] PC	Slicing yield (% of cooked Weight)[4] IC	Slicing yield (% of cooked Weight)[4] Δ
U of I Meat Lab																								
Boler et al., 2011 (corn soy diet)[5]	20	25	5	16	125.7	130.3	92.0	93.3	19.0	16.0	15.1	15.0	8.7	9.9	97.0	96.7	38.0	30.5	.	.	.	.	.	.
Boler et al., 2012 (Step-down diet)[6]	19	23	4	39	122.7	126.3	91.4	91.0	17.7	16.3	14.8	14.5	10.1	12.8	96.8	97.0	37.3	31.6	.	.	.	.	.	.
Boler et al., 2012 (Step-down diet)[6]	19	25	6	39	124.0	131.5	92.6	94.0	17.6	16.3	14.8	14.3	12.5	13.0	98.1	97.7	37.3	30.8	.	.	.	.	.	.
Lowe et al., 2013 (corn soy diet)	18	22.5-25.5	4.5-7.5	144	137.8	140.6	100.7	100.2	25.3	23.9	16.4	15.9	7.0	8.1	91.3	91.2	39.4	35.2	85.6	86.3	0.0	96.6	96.8	-0.15
Weighted averages[7]				***238***	***132.3***	***136.1***	***97.3***	***97.2***	***22.4***	***20.9***	***15.8***	***15.4***	***8.5***	***9.8***	***93.7***	***93.6***	***38.6***	***33.6***	***85.6***	***86.3***	***0.0***	***96.6***	***96.8***	***-0.15***
Commercial Studies																								
Kyle et al., 2013 (corn soy diet)	20	24.7-25.7	4.7-5.7	24	131.4	133.0	103.4	102.9	28.9	28.5	14.8	14.6	14.9	17.2	106.0	103.8	37.0	32.2	98.4	93.6	-4.8	92.9	90.2	-2.7
Tavárez et al., 2013 (corn soy diet)	20	25	5	16	118.2	120.7	89.0	89.0	20.4	17.8	13.6	13.6	11.9	11.6	104.0	101.5	30.0	23.6	90.3	81.4	-8.9	86.8	80.2	-6.6
Tavárez et al., 2013 (corn soy diet)	20	27	7	16	134.3	137.4	101.9	102.5	26.1	24.7	13.3	13.7	10.5	11.4	104.2	103.1	37.5	33.1	90.4	85.6	-4.8	87.6	82.7	-4.9
Tavárez et al., 2013 (30% DDGS diet)[8]	20	25	5	16	118.4	120.5	87.2	86.1	21.3	19.8	14.3	13.8	13.4	12.7	104.6	102.3	31.3	26.0	89.6	82.4	-7.1	85.6	80.5	-5.2
Tavárez et al., 2013 (30% DDGS diet)[8]	20	27	7	16	133.5	139.4	101.0	103.2	24.1	23.8	14.0	13.8	13.5	12.6	105.2	103.4	34.7	30.9	91.1	83.1	-8.0	86.5	80.8	-5.7
Tavárez et al., 2013 (withdrawal diet)[9]	20	25	5	16	117.4	118.9	88.2	86.9	20.8	17.7	14.0	13.5	12.0	12.4	103.9	103.0	30.8	23.3	90.1	87.8	-2.3	86.7	85.2	-1.5
Tavárez et al., 2013 (withdrawal diet)[9]	20	27	7	16	130.2	136.9	98.5	101.6	21.9	24.8	13.8	13.3	12.2	12.6	104.0	104.5	32.8	32.0	90.9	89.4	-1.5	87.2	85.0	-2.2
Weighted averages[7]				***120***	***126.5***	***129.8***	***96.1***	***96.5***	***23.7***	***22.8***	***14.0***	***13.8***	***12.8***	***13.2***	***104.7***	***103.1***	***33.7***	***28.9***	***92.0***	***86.7***	***-5.3***	***88.0***	***84.0***	***-4.0***

[1]Pump uptake = (pump wt/green wt) × 100%

[2]Cooked yield = (cooked wt/green wt) × 100%

[3]Slicing yield= (slice wt/green wt) × 100%

[4]Slicing yield= (slice wt/cooked wt) × 100%

[5]Immunological castrate fed a diet containing 1% SID Lysine

[6]Pigs were fed a diet containing 20% DDGS from 6 weeks of age until 19 weeks; and then switched to 10% DDGS until slaughter

[7]Averges were weighted, meaning that from each study the number of samples per treatments was accounted in the calculation of the overall average

[8]Pigs were fed a diet containing 30% DDGS from 6 weeks of age until slaughter 25 and 27 weeks

[9]Pigs were fed a diet containing 30% DDGS from 6 weeks of age until 20 weeks; and then switched to a corn soy diet until slaughter

Table 1.3 Pearson correlation coefficient (r) of carcass, fresh belly, and cooked belly traits with bacon slicing yields expressed as a percentage of green weight

	Kyle et al., 2013			Tavárez et al., 2013	
Trait	PC[1] and Gilts	IC[2]	Intact male	PC	IC
Carcass					
Backfat	0.11	0.00	0.15	0.14	**0.34**
Boneless cutting yields[3]	**-0.37**	0.02	-0.18	**-0.20**	**-0.28**
Fresh belly					
Flop distance	**0.36**	-0.01	0.25	0.11	**0.21**
Thickness	**0.32**	-0.08	0.16	**0.30**	**0.45**
Linoleic acid (C18:2n6)	**-0.21**	-0.22	-0.04	-0.01	**-0.25**
Iodine value (IV)	**-0.23**	-0.09	0.02	0.03	**-0.29**
Cooked belly					
Moisture content	-0.19	**-0.38**	**-0.41**	**-0.18**	**-0.40**
Lipid content	0.17	**0.41**	**0.48**	**0.19**	**0.42**

[1]Physically castrated barrows

[2]Immunologically castrated barrows

[3]Boneless lean cutting yield = [(ham + canadian back + sirloin + tenderloin + Boston + picnic) / right chilled side wt] × 100

Font in dark red indicates $P \leq 0.05$
Font in dark blue indicates $0.05 \leq P \leq 0.10$

Table 1.4. Pearson correlation coefficient (r) of carcass, fresh belly, and cooked belly traits with bacon slicing yields expressed as a percentage of cooked weight

	Kyle et al., 2013			Tavárez et al., 2013	
Trait	PC and Gilts	IC	Intact Male	PC	IC
Carcass charactaristics					
Backfat	-0.08	-0.18	**0.44**	0.07	**0.22**
Boneless cutting yields	**-0.21**	0.11	**-0.32**	-0.15	**-0.18**
Fresh belly characteristics					
Flop distance	0.13	-0.18	**0.44**	0.14	0.17
Thickness	0.10	**-0.36**	**0.54**	**0.20**	**0.33**
Linoleic acid (C18:2n6)	-0.08	-0.03	-0.26	-0.11	**-0.20**
Iodine value (IV)	-0.11	0.18	-0.17	-0.07	**-0.24**
Cooked belly characteristics					
Moisture content	-0.08	**-0.42**	**-0.45**	-0.12	**-0.29**
Lipid content	0.09	**0.40**	**0.48**	0.12	**0.31**

[1]Physically castrated barrows

[2]Immunologically castrated barrows

[3]Boneless lean cutting yield = [(ham + canadian back + sirloin + tenderloin + Boston + picnic) / right chilled side wt] × 100

Font in dark red indicates $P \leq 0.05$

Font in dark blue indicates $0.05 \leq P \leq 0.10$

Chapter 2

EFFECT OF IMMUNOCASTRATION AND TIME AFTER SECOND IMPROVEST DOSE ON FATTY ACID PROFILE OF FINISHING PIGS

ABSTRACT

The effect of immunocastration and time after second Improvest dose on proximate composition and fatty acid profile of adipose tissue from belly and jowl of finishing barrows was determined. Physically castrated (PC) and immunologically castrated (IC) barrows were assigned treatments at birth. Within 5 d of age, PC barrows were physically castrated and IC barrows were administered Improvest (GnRF analog; Zoetis, Kalamazoo, MI) at 16 and 20 wk of age. Diets were formulated with corn and soybean meal and did not contain ethanol co-products. Subsequently, PC (n=23) and IC (n=24) barrows were slaughtered biweekly from 22 to 28 wk of age, 2 to 8 wk following second Improvest dose. Adipose tissue samples were collected from the jowl and belly. Main effects of castration method and time after second Improvest dose, and their interaction were analyzed with the MIXED procedure of SAS. In jowl adipose tissue, IC barrows had less lipid than PC barrows (72.9 vs. 77.1%; $P = 0.04$). Lipid content was increased ($P = 0.06$) from 64.7 at 2 wk to 77.0% at 8 wk. Total MUFA content was reduced (42.5 vs. 44.8%; $P = 0.04$) and PUFA content was greater (16.9 vs. 14.8%; $P < 0.01$) in IC compared to PC barrows. Increasing time after second dose reduced ($P = 0.04$) PUFA content from 17.5 at 2 wk to15.4% at 8 wk. There was an interaction ($P = 0.03$) between castration method and time for IV of the jowl. In PC barrows, IV was unchanged over time ($P > 0.05$), but, in IC barrows, IV was reduced ($P < 0.01$) from 68.9 at 2 wk to 61.9 g/100g at 8 wk. Meanwhile, in belly adipose tissue, IC barrows had less lipid content than PC barrows (75.3 vs. 82.7%; $P < 0.01$). Lipid content was unchanged over time ($P = 0.34$) in either PC or IC barrows. Total SFA and MUFA

content of the belly were similar for both IC and PC barrows. Belly adipose tissue from IC barrows had greater concentrations of PUFA than PC barrows (16.2 vs. 14.7%; $P < 0.01$). In IC barrows, PUFA concentration tended to decrease ($P = 0.09$) from 18.4 at 2 wk to 15.4% at 8 wk, but was unchanged ($P > 0.17$) with time in PC barrows. From 2 wk to 8 wk, IV of PC was unchanged ($P > 0.56$; average 61.9) while IV of IC barrows decreased ($P < 0.01$) from 67.0 to 60.1 over the same period. Results indicate that as time after second Improvest dose progressed, IV of jowl and belly was reduced. This was accompanied by an increase in lipid deposition in jowl, while lipid content remained constant in belly.

Key words: belly, iodine value, jowl, Improvest, pork

INTRODUCTION

In 2011, the FDA approved the use of Improvest in entire males as a means to control boar taint. Improvest management also allows producers to takes advantage of the reduced feed consumption with greater or similar rates of gain, and increased leanness and cutability of boars compared to physically castrated (PC) barrows (Boler et al., 2011; Dunshea et al., 2001). Therefore, at equal carcass weights, immunologically castrated (IC) barrows are leaner than PC barrows. However, one disadvantage of leaner pigs is that as they deposit less fat and this fat is generally more unsaturated in nature, the risk of fat quality issues such as softer belly fat (Correa et al., 2008) and severe lean-fat separation in loins and hams are increased (Cliplef and McKay, 1993). Softer belly fat may also lead to problems during bacon slicing and poor appearance of slices after packaging (Enser et al., 1984). Furthermore, bacon slicibility was reduced in IC compared to PC barrows, but improved over time as bacon from IC barrows became compositionally more similar to bacon from PC barrows (Tavárez et al., 2014).

A review by Wood et al. (2008) reported that as lipid deposition was increased, concentration of unsaturated fatty acids in subcutaneous adipose tissue was decreased. In a similar manner, increasing time between second Improvest dose and slaughter has been reported to increase lipid deposition (Lealiifano et al., 2011) and reduce concentrations of polyunsaturated fatty acids (Boler et al., 2012) in IC barrows. However, data are limited regarding changes beyond 6 wk after second dose and in the jowl adipose tissue, a preferred tissue for analyses by packers because of ease of access.

Our hypothesis was that in Improvest managed barrows, lipid deposition would increase with increasing time after second Improvest dose. This would be accompanied by reductions in unsaturated fatty acid in adipose tissue of jowl and belly. Therefore, the objective of the present study was to determine the effect of increasing the interval after second Improvest dose on chemical composition and fatty acid profile of adipose tissue from jowl and belly of finishing barrows.

MATERIALS AND METHODS

Animal use during this study was approved by the University of Illinois Animal Care and Use Committee.

Animals, Housing, and Diets

Forty seven pigs (Genetiporc G-performer sires × Fertilis 25 dams; Genetiporc, Alexandria, MN) were used during the live phase of the study. At birth, male pigs within a litter were randomly allotted to one of two castration methods. Pigs in PC group were physically castrated according to US production guidelines within 5 d of age. Intact males in the IC group were immunologically castrated by administering one dose (2 mL; subcutaneous into the postauricular region of the neck) of Improvest (GnRF analog; Zoetis, Kalamazoo, MI) at 16 wk of age and another 2 mL dose at 20 wk of age. Pigs were blocked by farrowing date (2). Before allotment in the finishing barn, pigs within each sex category were individually weighed and assigned to pens so that pen means within each sex category were equal. There were 4 pens per block and each pen contained approximately 6 pigs, and the final allotment consisted of 8 pens (n = 4 pens for each castration method) with a minimum floor space of 0.96 m^2/ pig, a two-space dry box feeder and a cup type water drinker. The finisher barn was mechanically ventilated with part-hard, part-slatted concrete floors. Pigs had free access to feed and water. Diets used were formulated to meet the nutrient requirement of entire males as proposed by NRC (1998) and did not contain ethanol co-products.

Marketing and Slaughter Procedures

At the farm, pigs were weighed individually every wk from the time of second Improvest dose to end of the study. On the wk before slaughter, pigs were ranked within castration method by weight. The six heaviest pigs from each castration method were identified to be later transported to the University of Illinois Meat Science Laboratory. This process was repeated until completion of the study. Pigs were slaughtered biweekly from 22 to 28 wk of age, 2 to 8 wk following second Improvest dose. Upon arrival at the slaughter facility, pigs had free access to water, but had no access to feed; therefore, pigs were fasted for approximately 12 to 15 hours before slaughter. Immediately before slaughter, pigs were weighed to determine ending live weight. After weighing, pigs were electrically stunned using a head-to-heart method and exsanguinated under the inspection of the United States Department of Agriculture. Pigs were scalded, dehaired, and singed to remove all hair from the carcass. Immunologically castrated barrows slaughtered at 2 wk after second Improvest dose did not enter the food chain as these pigs did not comply with labeling requirements for Improvest.

Following slaughter, HCW were collected, and carcasses were chilled for approximately 20 h at 4°C. After chilling, on the hanging carcasses, adipose tissue samples (~8 g/tissue) from the most anterior tip of the jowl and from the dorsal anterior edge of the belly were collected using a coring device.

Fatty acids analysis

Initially, samples, free of lean tissue and skin, were cut into pieces. Pieces were frozen in liquid nitrogen before being pulverized in a blender (Warin Products, Torrington, CT) for 10 s. The resulting powder was collected and used obtain fatty acid methyl esters (FAME) according to the methodology described by AOCS official method Ce 2-66 (1998). Subsequently, FAME were analyzed using a gas chromatograph (Hewlett Packard 5890 series II) equipped with an auto-sampler and a DB-wax capillary column (30 m × 0.25mm × 0. 25 µm film coating, Agilent Technologies, Santa Clara, CA).The equipment was operated under a constant pressure at 1.30 Kg/cm^2 using helium as the carrier gas and a 99:1 split ratio. Temperatures of the injector and of the flame-ionization detector were held constant at 250^0C and 260^0C, respectively. The oven was operated at 170°C for 2 min (programmed temperature to increase 4^0C /min up to 240°C and then held constant for 12.5 min). Chromatographs from FAME were integrated using Agilent Chemstation software for gas chromatograph systems (Version B.01.02, ®Agilent Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 68 from Nu-check-prep, Elysian, Mn). Fatty acids were normalized so that the area of each peak was represented as a percentage of the total area. Iodine values (IV) were calculated using fatty acid profile data with the following AOCS (1998) equation: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.785).

Proximate Composition

Pulverized adipose tissue samples were also analyzed for proximate composition (moisture and lipid). Approximately 2 g of tissue were oven dried at 110° C for approximately 24 h. Dried samples were washed multiple times in an mixture of warm chloroform:methanol (4:1) as described by Novakofski et al. (1989) to determine total extractable lipid. Moisture and lipid were determined by weight differences after drying (moisture) and extraction (lipid).

Statistical Analysis

Data were analyzed using the mixed procedure in SAS (SAS Institute Inc., Cary, NC) and Individual pig (N=47) was the experimental unit for all traits measured. Data were analyzed as a randomized complete block design with a 2 × 4 factorial arrangement of treatments. The fixed effects in the model were castration method (PC or IC) and time after second dose (2 wk, 4 wk, 6 wk, and 8 wk) and their interaction. Blocks and blocks within pen were analyzed as random variables in the model. Homogeneity of variance was tested with the Levene's test or Brown and Forsythe in the case of non-normal data using the GLM procedure of SAS. Normality of the residuals was tested in the Univariate procedure of SAS with normal probability plots. Least square means were separated with the PDIFF option and adjusted with Tukey's multiple comparison procedure. Statistical differences were accepted as significant at $P < 0.05$ using a two-tailed test. Trends were noted at $0.05 < P < 0.10$.

RESULTS

Slaughter Weight, HCW, and Dressing Percentage

Immunologically castrated barrows had greater slaughter weight (136.1 vs. 131.1 kg; $P < 0.01$) and similar HCW (104.8 vs. 103.4 kg; $P = 0.28$) compared with PC barrows. However, for both traits, interactions ($P < 0.01$) were observed between castration method and time after second Improvest dose (Fig. 2.1.A, Fig. 2.1.B). From 2 to 8 wk, the magnitude of the increase in slaughter weight was greater in IC barrows (28.8 kg) compared to PC barrows (20.4 kg). During the same period of time, the magnitude of the increase in HCW was also greater in IC barrows (25.9 kg) compared to PC barrows (18.0 kg). Dressing percentage was reduced ($P < 0.01$) in IC barrows (76.8%) compared to PC barrows (78.8%). From 2 to 8 wk, averaged over both castration methods, dressing percentage was increased by 1.3 percentage units ($P < 0.01$). No interaction was observed between castration method and time after second Improvest dose for dressing percentage ($P = 0.62$; Fig. 2.1.C).

Jowl Adipose Tissue

There was an interaction ($P = 0.01$) between castration method and time after second Improvest dose for moisture content of jowl adipose tissue (Fig. 2.2.A). In IC barrows, moisture content was decreased ($P = 0.03$) from 27.5% at 2 wk to 18.1% at 8 wk. But moisture was unchanged ($P = 0.98$) in PC barrows (from 15.9% at 2 wk to 18.2% at 8wk). Lipid content of jowl adipose tissue was, on average, decreased by 4.2 percentage units in IC barrows compared to PC barrows (72.9 vs. 77.1%; $P = 0.04$) (Fig. 2.2.B). Interestingly, at 2 wk, jowl adipose tissue from IC barrows had 15.5 percentage units less lipid compared to that of PC barrows (64.7 vs. 80.2%; $P < 0.01$). However, at 4, 6, and 8 wk, lipid content was similar between castration methods ($P > 0.75$). Furthermore, in IC barrows, lipid content tended to increase ($P = 0.06$) 12.3

percentage units from 2 to 8 wk, but was unchanged (*P* > 0.25) in PC barrows during that time interval.

Jowl adipose tissue fatty acid concentrations are reported in Table 2.1. In IC barrows, myristic acid (14:0) was increased (*P* = 0.03) and myristoleic acid (14:1) tended (*P* = 0.09) to increase compared to PC barrows. Myristic acid decreased (*P* = 0.02) and γ-linolenic acid (18:3n-6) tended to decreased (*P* = 0.10) with time after second Improvest dose in both IC and PC barrows. In general, the rest of fatty acids analyzed were unaffected by castration method (*P* ≥ 0.15) and time after second Improvest dose (*P* ≥ 0.19). Jowl adipose tissue SFA content was similar between IC and PC barrows (*P* = 0.90). However, the magnitude of the change in SFA tended to be greater in IC compared to PC barrows (3.7 vs. -2.7 percentage units; Inter. *P* = 0.08). Total MUFA content was, on average, 2.2 percentage units less in IC barrows compared to PC barrows and was not affected by time after second dose (*P* = 0.27). Although PUFA content and PUFA:SFA were reduced (*P* = 0.04) with time after second Improvest dose, both PUFA (16.9% vs. 14.8%; *P* = 0.04) and PUFA:SFA (0.42 vs. 0.37; *P* = 0.01) were increased in IC barrows compared to PC barrows. The magnitude of the change in UFA:SFA with time after second dose tended to decrease in IC barrows compared to PC barrows (-0.2 vs. 0.1; Inter. *P* = 0.06). There was an interaction (*P* = 0.03) of castration method and time after second Improvest dose for IV of jowl adipose tissue (Fig. 2.2.C). In IC barrows, IV decreased (*P*<0.01) from 68.9 g/100 g at 2 wk to 61.9 g/100 g at 8 wk, but was unchanged (*P* > 0.94) in PC barrows during the same time interval.

Belly Adipose Tissue

Changes in belly adipose tissue proximate composition are presented in Fig. 2.3.A and Fig. 2.3.B. In IC barrows, moisture (18.8 vs. 13.6%) was increased (*P* < 0.01) and lipid (75.3 vs.

82.8%) was decreased ($P < 0.01$) compared to PC barrows. Neither measurement was affected ($P > 0.23$) by increasing time after second Improvest dose.

Belly adipose tissue fatty acid concentrations are reported in Table 2.2. In IC barrows, linoleic acid (18:2n-6) and linolenic acid (18:3n-3) were increased ($P < 0.01$) compared to PC barrows. These fatty acids were also decreased ($P < 0.03$) with increasing time after second dose in both IC and PC barrows. All other fatty acids analyzed were not affected by castration method ($P > 0.14$) or time after second Improvest dose ($P > 0.16$).

Total SFA, MUFA, and ratio of UFA:SFA were all similar ($P \geq 0.26$) between castration methods. Total MUFA tended to increase ($P = 0.09$) with time after second dose. Total PUFA was, on average, greater in IC compared to PC barrows (16.2 vs. 14.7%; $P < 0.01$). From 2 to 8 wk, PUFA:SFA was decreased ($P = 0.04$) from 0.47 to 0.35 in IC barrows while it was unchanged ($P = 0.99$) in PC barrows. In the same time interval, IV in PC barrows remained constant at an average of 61.9 g/100g ($P > 0.56$) while in IC barrows decreased from 67.0 at 2 wk to 60.1 g/100g at 8 wk ($P < 0.01$) (Fig. 2.3.C).

DISCUSSION

The objective of this study was to characterize changes in chemical composition of adipose tissue from jowl and belly of IC and PC barrows with increasing time after second Improvest dose (increasing age) at slaughter. In jowl adipose tissue, increasing time resulted in reduced moisture content with a concomitant increase in lipid deposition. Furthermore, IV was reduced in IC barrows with increasing time after second dose. In belly adipose tissue, although moisture and lipid content remained constant with increasing time after second dose, unsaturation level was reduced in IC barrows. In both tissues, chemical composition and IV remained constant in PC barrows with increasing age. These changes in fat deposition and level of unsaturation took place while also increasing slaughter and carcass weight in both IC and PC barrows.

In Improvest managed pigs, there is the potential to increase lipid deposition as the time interval between second dose and slaughter is increased (Dunshea et al., 2008; Dunshea et al., 2001; Lealiifano et al., 2011; Tavárez et al., 2014). The underlying cause for these increases is thought to be increased *de novo* synthesis of fatty acids as a consequence of increased feed intake in IC barrows after second dose of Improvest. Both increased in feed intake and increased fat deposition has been previously documented in IC barrows raised in the US (Asmus et al., 2014) and outside the US (Dunshea et al., 2008; Dunshea et al., 2001; Lealiifano et al., 2011). For example in a study by Asmus et al. (2014), feed intake was reduced in IC barrows compared with PC barrows prior to second dose, but feed intake was increased in IC barrows by 46% from 0 to 7 weeks after second dose. During that time, feed intake in PC barrows was increased by only 18%. The increase in IC barrows feed intake was most pronounced from 3 to 5 weeks after second dose. Feed intake increased 27% during this time compared with just a 5% increase in feed intake in PC barrows during the same interval.

Excess carbohydrates consumed as a result of this increased feed intake will be stored as lipid. In adipocytes, glucose is obtained from the plasma, transformed to acetyl-Coa, and synthetized to fatty acids (Bauman, 1976). The main fatty acids produced from *de novo* synthesis are the saturated fatty acids palmitic and stearic acids (Mersmann and Smith, 2005). Thus, as pigs continue to deposit fatty acids and adipocytes fill with triglycerides from *de novo* synthesis, the proportion of saturated fatty acids in adipose tissue is increased (Wood et al., 2008). In the present study, evidence of *de novo* synthesis was reflected in reduced PUFA content and reduced IV of jowl and belly adipose tissue. While in PC barrows, PUFA content was also decreased and

IV of the belly and jowl adipose tissue unchanged. Similar changes in level of saturation were attributed to increased *de novo* synthesis by Boler et al. (2012) in IC barrows slaughtered at 4 and 6 wk after second dose.

CONCLUSIONS

Increasing age or the time interval between second Improvest dose and slaughter changed chemical composition of adipose tissue. These changes were more pronounced in IC barrows compared to PC barrows in both jowl and belly. Compositional changes included increased lipid deposition and reduced IV in the jowl, but no change in lipid deposition despite reduced IV in the belly. These results would indicate that meat characteristics that depend on adipose tissue composition, such as firmness and oxidative stability should improve with time after second Improvest injection. Additionally, as this time is increased, adipose tissue from IC barrows becomes compositionally more similar to that of PC barrows.

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FIGURES

Figure 2.1. Effect of castration method (cast.) and time after second Improvest dose (TASD) on slaughter weight (A), HCW (B), and dressing percentage (C) of immunologically castrated (IC) and physically castrated (PC) barrows. Pigs in IC group were immunologically castrated with Improvest at 16 and 20 wk of age.

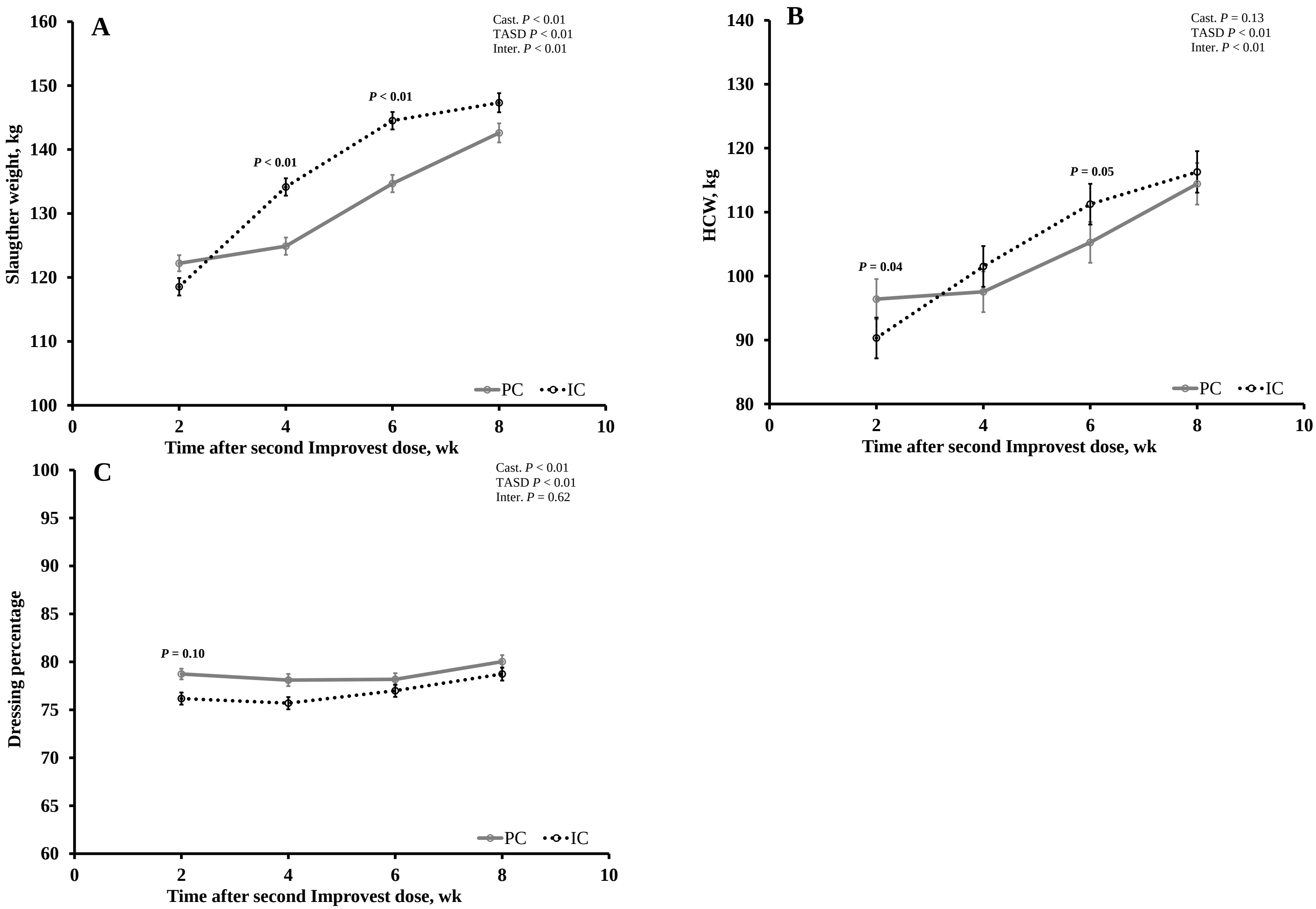


Figure 2.2. Effect of castration method (cast.) and time after second Improvest dose (TASD) on jowl adipose tissue moisture content (A), lipid content (B), and iodine value (C) of immunologically castrated (IC) and physically castrated (PC) barrows. Pigs in IC group were immunologically castrated with Improvest at 16 and 20 wk of age.

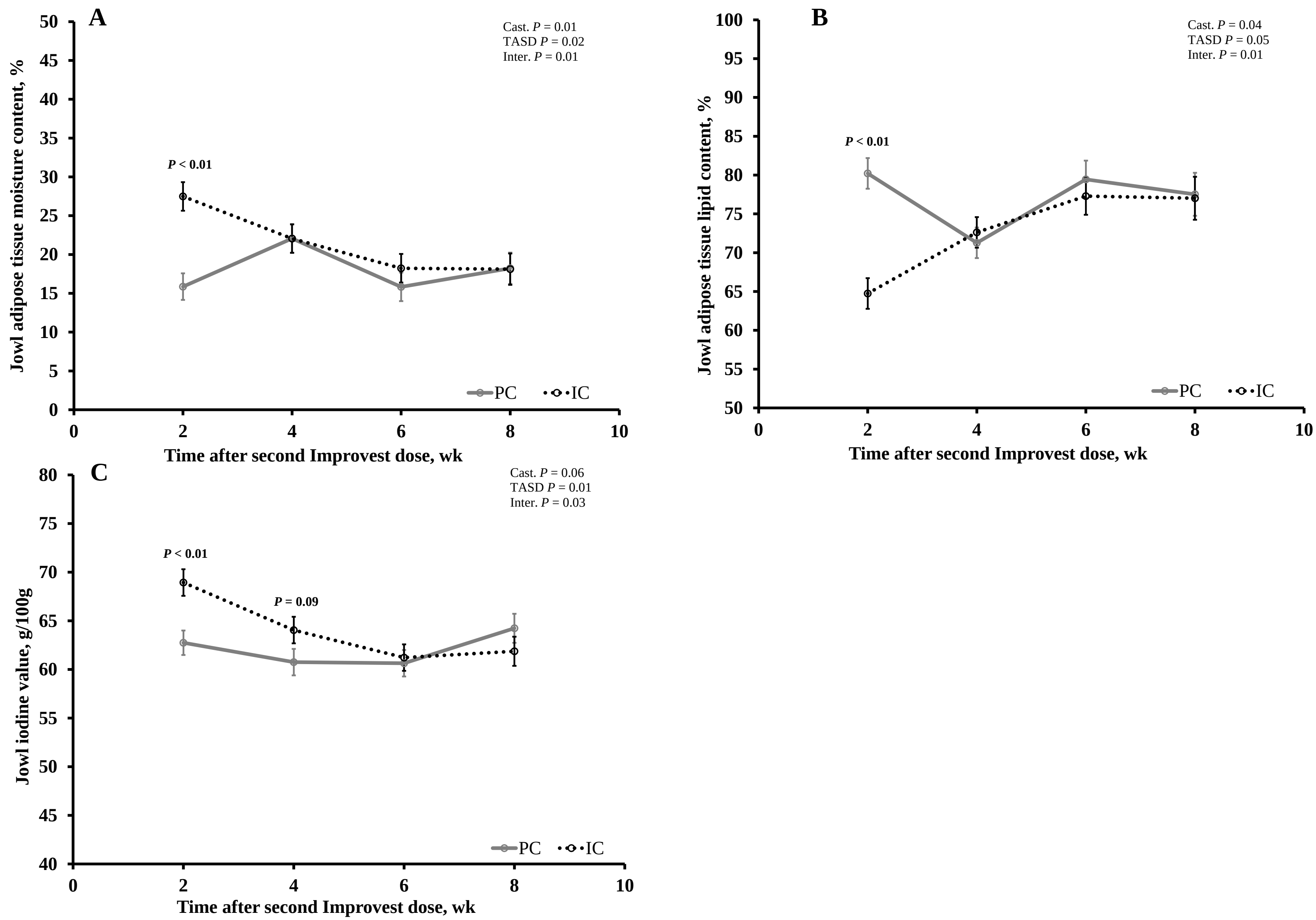
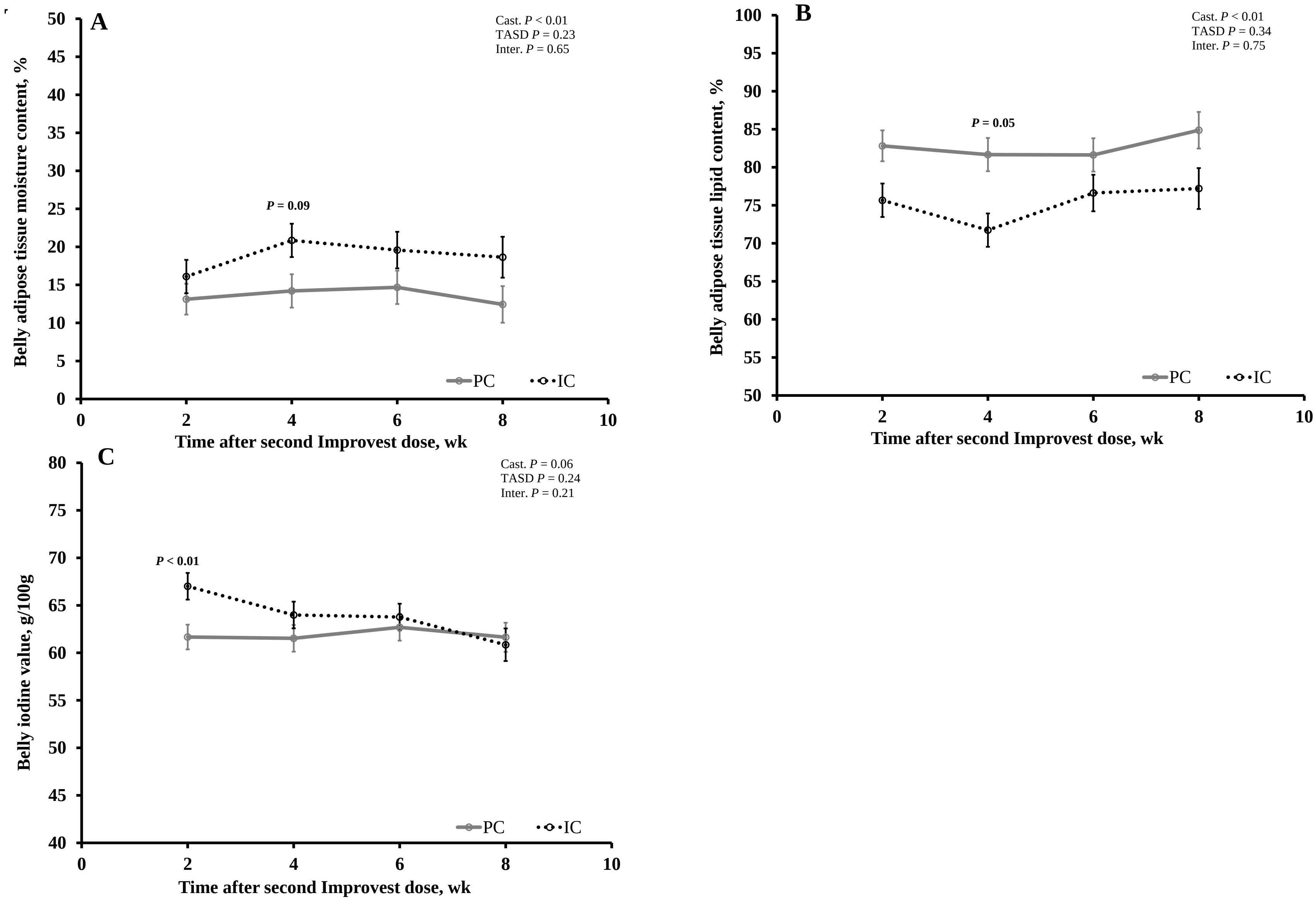


Figure 2.3. Effect of castration method (cast.) and time after second Improvest dose (TASD) on belly adipose tissue moisture content (A), lipid content (B), and iodine value (C) of immunologically castrated (IC) and physically castrated (PC) barrows. Pigs in IC group were immunologically castrated with Improvest at 16 and 20 wk of age.



TABLES

Table 2.1. Effect of castration method and time after second Improvest dose on jowl fatty acid profile (g/100g FAME)

	PC[1]				IC[2]							
Item	2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk	SEM	Cast.	TASD[3]	Inter.
Myristic acid (14:0)	1.62	1.46	1.51	1.56	1.71	1.52	1.58	1.77	0.71	0.03	0.02	0.68
Myristoleic acid (14:1)	0.02	0.02	0.02	0.01	0.03	0.03	0.02	0.02	0.01	0.09	0.46	0.97
Palmitic acid (16:0)	26.27	24.63	24.92	27.61	27.53	25.69	25.48	22.52	1.84	0.70	0.70	0.34
Palmitoleic acid (16:1)	3.68	3.44	3.68	3.37	3.97	3.28	3.58	3.05	0.32	0.74	0.19	0.76
Margaric acid (17:0)	0.36	0.39	0.41	0.36	0.40	0.45	0.36	0.41	0.08	0.67	0.90	0.84
Stearic acid (18:0)	12.44	11.62	11.35	12.63	12.52	12.18	13.88	12.69	1.70	0.43	0.94	0.75
Oleic acid (18:1n-9)	40.14	39.77	37.86	38.41	36.00	38.77	40.09	41.21	2.33	0.98	0.88	0.35
Linoleic acid (18:2n-6)	12.09	12.62	15.32	13.08	15.90	13.20	13.99	14.36	2.55	0.42	0.81	0.59
α-Linolenic acid (18:3n-3)	0.53	0.59	0.87	0.64	0.71	0.79	0.62	0.67	0.15	0.66	0.78	0.29
γ-Linolenic acid (18:3n-6)	0.19	0.13	0.13	0.05	0.18	0.15	0.14	0.13	0.04	0.28	0.10	0.61
Arachidic acid (20:0)	0.24	0.31	0.21	0.32	0.20	0.17	0.22	0.24	0.08	0.31	0.82	0.70
Gadoleic acid (20:1)	1.19	1.18	1.04	1.25	0.94	1.74	1.07	1.12	0.29	0.88	0.45	0.38
Eicosadienoic acid (20:2)	0.85	0.98	0.97	0.96	0.77	1.26	0.74	0.71	0.26	0.71	0.60	0.72
Dihomo-γ-Linolenic acid (20:3n-3)	0.13	0.44	0.19	0.17	0.11	0.14	0.10	0.14	0.12	0.15	0.38	0.52
Arachidonic acid (20:4n-6)	0.44	0.78	0.56	0.50	0.29	0.44	0.27	0.36	0.21	0.15	0.68	0.95
Total SFA[4]	40.29	41.45	42.30	37.62	37.92	39.68	42.94	41.59	1.35	0.90	0.03	0.08
Total MUFA[5]	44.32	43.39	43.55	47.78	42.47	43.84	41.68	42.14	1.59	0.04	0.49	0.27
Total PUFA[6]	15.39^{b}	15.16^{b}	14.15^{b}	14.60^{b}	19.62^{a}	16.48^{ab}	15.39^{ab}	16.27^{ab}	1.05	< 0.01	0.04	0.34
UFA:SFA[7]	1.49	1.42	1.37	1.68	1.66	1.53	1.34	1.41	0.09	0.94	0.04	0.06
PUFA:SFA[8]	0.39^{b}	0.37^{b}	0.33^{b}	0.39^{ab}	0.52^{a}	0.42^{ab}	0.36^{b}	0.39^{ab}	0.03	0.01	0.01	0.15

[1]Physically castrated

[2]Immunologically castrated. Pigs in this group were immunologically castrated by administering Improvest at 16 and 20 wk of age

[3]Time after second Improvest dose

[4]Total SFA = ([C14:0] + [C16:0] + [17:0] + [C18:0] + [C20:0] + [C24:0]); brackets indicate concentration

[5]Total MUFA = ([C14:1] + [C16:1] + [18:1n-7] + [18:1n-9] + [20:1]); brackets indicate concentration

[6]Total PUFA = ([C18:2n-6] + [C18:3n3] + [C18:3n-6] + [C20:2] + [C20:3] + [C20:4n-6]); brackets indicate concentration

[7]UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[8]PUFA:SFA ratio = total PUFA / total SFA.

[a-b] Different superscripts within the same row indicate $P < 0.05$.

Table 2.*2* Effect of castration method and time after second Improvest dose on belly fatty acid profile (g/100g FAME)

	PC[1]				**IC[2]**							
Item	2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk	SEM	Cast.	TASD[3]	Inter.
Myristic acid (14:0)	1.61	1.60	1.38	1.50	1.39	1.58	1.73	1.78	0.19	0.34	0.80	0.22
Myristoleic acid (14:1)	0.01	0.00	0.02	0.01	0.00	0.03	0.02	0.02	0.02	0.53	0.83	0.66
Palmitic acid (16:0)	27.35	26.55	25.85	26.87	27.76	26.02	25.48	22.52	1.99	0.14	0.85	0.69
Palmitoleic acid (16:1)	3.70	3.40	3.55	3.52	3.37	3.72	3.58	3.05	0.52	0.79	0.92	0.84
Margaric acid (17:0)	0.48	0.41	0.35	0.36	0.43	0.39	0.39	0.37	0.08	0.95	0.56	0.91
Stearic acid (18:0)	13.90	14.02	11.41	11.66	13.08	11.55	14.62	12.48	1.86	0.85	0.77	0.21
Oleic acid (18:1n-9)	37.42	39.14	41.45	38.55	37.79	39.05	40.09	41.21	2.20	0.79	0.44	0.82
Linoleic acid (18:2n-6)	13.40	12.76	12.12	12.92	16.29	13.85	13.35	14.31	0.62	< 0.01	0.02	0.49
α-Linolenic acid (18:3n-3)	0.63	0.58	0.55	0.57	0.72	0.64	0.60	0.66	0.04	< 0.01	0.03	0.88
γ-Linolenic acid (18:3n-6)	0.12	0.14	0.12	0.17	0.18	0.18	0.14	0.13	0.03	0.42	0.86	0.56
Arachidic acid (20:0)	0.25	0.24	0.23	0.26	0.22	0.21	0.21	0.25	0.02	0.07	0.16	0.93
Gadoleic acid (20:1)	1.00	0.45	1.08	1.08	0.81	0.81	0.91	0.98	0.26	0.84	0.20	0.48
Eicosadienoic acid (20:2)	0.65	0.74	0.76	0.71	0.66	0.60	0.74	0.71	0.11	0.62	0.79	0.88
Dihomo-γ-Linolenic acid (20:3n-3)	0.14	0.13	0.16	0.12	0.14	0.13	0.12	0.16	0.02	0.94	0.88	0.29
Arachidonic acid (20:4n-6)	0.36	0.35	0.33	0.36	0.43	0.33	0.32	0.40	0.05	0.41	0.41	0.69
Total SFA[4]	42.54	41.92	39.76	42.04	39.48	40.55	39.97	43.60	1.67	0.51	0.28	0.41
Total MUFA[5]	42.15	43.38	46.20	43.13	42.10	43.73	44.76	41.04	1.77	0.45	0.09	0.84
Total PUFA[6]	15.31^{a}	14.70^{ab}	14.04^{b}	14.82^{ab}	18.43^{ab}	15.73^{ab}	15.27^{ab}	15.37^{a}	0.80	< 0.01	0.01	0.24
UFA:SFA[7]	1.37^{b}	1.40^{ab}	1.52^{a}	1.39^{ab}	1.55^{ab}	1.47^{ab}	1.54^{ab}	1.30^{b}	0.08	0.46	0.26	0.50
PUFA:SFA[8]	0.36^{b}	0.35^{b}	0.36^{b}	0.35^{b}	0.47^{a}	0.39^{b}	0.39^{b}	0.35^{b}	0.03	0.01	0.06	0.14

[1]Physically castrated

[2]Immunologically castrated. Pigs in this group were immunologically castrated by administering Improvest at 16 and 20 wk of age

[3]Time after second Improvest dose

[4]Total SFA = ([C14:0] + [C16:0] + [17:0] + [C18:0] + [C20:0] + [C24:0]); brackets indicate concentration

[5]Total MUFA = ([C14:1] + [C16:1] + [18:1n-7] + [18:1n-9] + [20:1]); brackets indicate concentration

[6]Total PUFA = ([C18:2n-6] + [C18:3n3] + [C18:3n-6] + [C20:2] + [C20:3] + [C20:4n-6]); brackets indicate concentration

[7]UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[8]PUFA:SFA ratio = total PUFA / total SFA.

[a-b] Different superscripts within the same row indicate $P < 0.05$.

Chapter 3

EFFECTS OF IMMUNOLOGICAL CASTRATION AND DISTILLER'S DRIED GRAINS WITH SOLUBLES ON CARCASS CUTABILITY AND COMMERCIAL BACON SLICING YIELDS OF BARROWS SLAUGHTERED AT TWO TIME POINTS

ABSTRACT

Male pigs were randomly assigned to a castration method at birth and allotted to 48 pens (28 pigs/pen). Physically castrated (PC) barrows were castrated at 2 d of age; immunologically castrated (IC) barrows were administered Improvest (GnRF analog; Zoetis, Kalamazoo, MI) at 16 and 20 wk of age. Distiller's dried grains with solubles (DDGS) feeding strategies included either 0% DDGS (control), 30% DDGS (30% DDGS) fed from 6 wk of age to slaughter, or 30% DDGS fed from 6 wk of age to second dose and then fed 0% DDGS until slaughter (withdrawal). Four barrows closest to the median pen weight at 4.5 wk after second dose were selected for evaluation; two were randomly selected and slaughtered at 5 wk and the other two at 7 wk after second dose. Data from each slaughter time were analyzed independently as a 2 × 3 factorial design with pen as the experimental unit. At 5 wk after second dose: Bone-in lean cutting yields were 2.63 percentage units greater ($P < 0.01$) in IC when compared to PC. Bellies were thicker ($P < 0.01$) and tended to have greater belly flop distances ($P = 0.07$) in PC compared to IC, however iodine values (IV) were not altered ($P = 0.84$). Carcass traits ($P \geq 0.10$), cutting yields ($P \geq 0.43$) and fresh belly characteristics ($P \geq 0.08$) were minimally affected by DDGS feeding strategy. Bacon slicing yields (percentage of green weight) were 6.10 percentage units less ($P < 0.01$) in IC compared with PC. At 7 wk after second dose: Bone-in lean cutting yields were 1.57 percentage units greater ($P = 0.03$) in IC compared with PC. Distiller's grains feeding strategy had no effect ($P \geq 0.83$) on boneless carcass cutting yields in IC; while in PC, these yields were 2.32 percentage units less ($P < 0.02$) in control fed barrows when compared to other feeding strategies (castration method × feeding strategy; $P = 0.03$). Bellies from PC tended to be thicker ($P = 0.07$), have similar flop distances ($P = 0.44$) and IV ($P = 0.54$) when compared with IC. Iodine value was greater ($P = 0.03$) in 30% DDGS fed barrows compared with control fed barrows. Bacon slicing yields (percentage of green weight) were 4.27 percentage units less ($P = 0.05$) in IC compared with PC. These data suggested that while bacon slicing yield was reduced in IC barrows fed control and 30% DDGS compared with PC barrow counterparts, withdrawal of DDGS improved bacon slicing yields of IC barrows.

Key words: bacon, cutting yields, DDGS, Improvest, pig

INTRODUCTION

Improvest (GnRF analog; Zoetis, Kalamazoo, MI) is for the temporary immunological castration and reduction of boar taint in intact male pigs intended for pork (Font i Furnols et al., 2008; Font i Furnols et al., 2009; Kubale et al., 2013). Immunologically castrated (IC) barrows had improved growth rates (Dunshea et al., 2001; Fàbrega et al., 2010) and cutability (Boler et al., 2012), along with greater leanness in comparison to physically castrated (PC) barrows. Leaner barrows tended to have thinner bellies (Person et al., 2005) that contained softer fat (Correa et al., 2008), both of which may reduce bacon slicing yield. Bellies of IC barrows were generally thinner, had greater concentrations of unsaturated fatty acids (Boler et al., 2012), and reduced bacon slicing yields (Kyle et al., 2014) when compared to PC barrows.

Inclusion of 30% distiller’s dried grains with solubles (DDGS) in swine diets increased concentrations of unsaturated fatty acids in pork fat (Whitney et al., 2006; Stein and Shurson, 2009), but had little effect on lean percentage of the carcass (Leick et al., 2010). The shift to a greater degree of unsaturation of the belly often resulted in bellies that were more difficult to slice and reduced bacon slicing yields (Seman et al., 2013). Belly firmness was improved and saturation of fat increased when DDGS were removed from the diet of finisher pigs as early as three weeks before slaughter compared with a continuous DDGS inclusion until slaughter (Xu et al., 2010). Therefore, while DDGS inclusion in swine diets was generally thought to reduce belly quality, these effects may be mitigated by removal of DDGS for a time prior to slaughter. Therefore, the objective of this study was to evaluate strategies for feeding DDGS to Improvest managed barrows slaughtered at two times after second dose of Improvest.

MATERIALS AND METHODS

Experimental procedures during the live phase of the experiment were approved by the Kansas State University Institutional Animal Care and Use Committee (IACUC) and followed the guidelines stated in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). No approval was obtained from the University of Illinois or The Ohio State University IACUC for this experiment because only carcasses were used in the experiment. Carcasses were obtained from a federally inspected facility.

Allotment and Assignment to Treatments

Pigs for slaughter and carcass evaluation were selected from a larger experiment that involved approximately 1,360 finisher barrows (PIC 337 × 1050, Pig Improvement Company, Hendersonville, TN). Odd-numbered barrows from each litter were left intact and assigned to Improvest management and even-numbered barrows from each litter were physically castrated with standard farm protocols and assigned to physical castration management when barrows were 2 d old. Barrows assigned to Improvest management were administered two 2-mL doses of Improvest subcutaneously at 16 and 20 wk of age. No placebo injection was administered to PC barrows at either administration time point. All treatments were fed the same nursery diets until barrows were 6 wk of age, after which barrows were switched to one of the following DDGS feeding strategies: a corn and soybean meal based diet with no DDGS (control), 30% DDGS inclusion through second dose followed by a control diet with no DDGS (withdrawal), or 30% DDGS inclusion until slaughter (30% DDGS). The combination of castration method and DDGS feeding strategies resulted in a 2 x 3 factorial with 6 treatment groups. Barrows were housed in pens of 28 barrows per pen of the same castration method. Diets were formulated to meet the lysine requirement of IC barrows. Further diet information can be found in Asmus et al. (2014).

Animal Selection

Barrows from each pen were weighed as individuals at approximately 4.5 wk after second dose. The 4 barrows closest to the pen median (192 total) were selected for carcass evaluation and tattooed on the left shoulder and ham for identification in the plant. Two of those barrows per pen (96 total) were randomly selected and slaughtered at 5 wk after second dose (25 wk of age). The other two barrows (96 total) were slaughtered at 7 wk after second dose (27 wk of age). Hot carcass weight was collected at slaughter. Dressing percentage was calculated by dividing HCW by ending BW recorded 48 h before slaughter. Carcasses were chilled for approximately 24 h and the left sides were delivered to the University of Illinois Meat Science Laboratory for further data collection.

Carcass Evaluation

Carcass measurements and loin quality data were collected in the same manner described by Boler et al. (2011b). The left sides of carcasses were separated between the 10^{th} and 11^{th} rib to measure LM area, back fat depth, and LM quality. Loin depth and back fat thickness measured with a Fat-o-Meater at the slaughter facility were used to calculate estimated percent lean with the following equation developed and used with Fat-O-Meater data: $\text{Calculated Lean} = 58.86 - (\text{back fat} \times 0.61) + (\text{LM depth} \times 0.12)$. The left side of each carcass was fabricated into primal and subprimal pieces. Sides were fabricated in a similar manner described in (Boler et al., 2012) with the exception of the belly primal. The belly primal was fabricated as an NAMP #408 pork belly (teat line attached without flank end squared) also referred as a natural fall belly. Carcass cut-out data were expressed as a percentage of chilled side weight to account for the variability in BW and HCW across treatments. Loin quality measurements included ultimate pH, drip loss, objective color, subjective color, marbling, and firmness scores.

Cutting Yield Equations

The following equations were used to determine cutting yields:

$$\text{Bone} - \text{in lean cutting yield} = \left[\frac{\text{trimmed ham} + \text{trimmed loin} + \text{Boston butt} + \text{picnic}}{\text{chilled left side weight}}\right] \times 100$$

$$\text{Bone} - \text{in carcass cutting yield} \left[\frac{\text{Bone}-\text{in lean cutting yield components} + \text{natural belly}}{\text{chilled left side weight}}\right] \times 100$$

$$\text{Boneless lean cutting yield} = \left[\frac{5-\text{piece ham} + \text{Canadian back} + \text{sirloin} + \text{tenderloin} + \text{Boston butt} + \text{picnic}}{\text{chilled left side weight}}\right] \times 100.$$

$$\text{Boneless carcass cutting yield} = \left[\frac{\text{Boneless lean cutting yield components} + \text{natural belly}}{\text{chilled left side weight}}\right] \times 100.$$

Fresh Belly Characteristics

Natural fall bellies were placed on a table, covered, and allowed to equilibrate for approximately 18 h at 4 °C. After chilling, belly measurements (length, width, thickness at eight points, skin-on untrimmed weight, and flop distance) were obtained. Fresh belly characteristic data were collected in a similar manner to Boler et al. (2012). Iodine values (**IV**) were calculated with fatty acid profile data from Asmus et al. (2014) with the following equation: $\text{IV} = \text{C16:1}(0.95) + \text{C18:1}(0.86) + \text{C18:2}(1.732) + \text{C18:3}(2.616) + \text{C20:1}(0.785 +$

C22: 1(0.723) (AOCS, 1998). After fresh evaluation, bellies were vacuumed packaged (two bellies per bag), boxed, and stored frozen at -20 °C for 30 d for later bacon production.

Bacon Production

Skin-on bellies (n=192) were transported frozen from the University of Illinois to the meat science laboratory at The Ohio State University for further processing. Skin-on belly weights were recorded after bellies were allowed to thaw for 72 h at approximately 4 °C. Bellies were skinned using a hand-held skinner (Model S-1011; Best and Donovan, Cincinnati, Ohio). Bellies were processed at a commercial bacon processing facility in same manner described by Kyle et al. (2014) with the only exception being that after pressing (rather than during fabrication), flank ends were cut anterior to the inguinal lymph nodule and blade ends were squared. Briefly, bellies were sliced using standard operation protocols of the commercial facility. Unusable ends, incomplete, and removed slices were summed and classified as ends and pieces. Sliced bellies were boxed individually maintaining anatomical orientation (blade to flank end) and transported back to the meat science laboratory at The Ohio State University for further evaluation.

Bacon Slice Characteristics

Sliced bellies were kept at approximately 4 °C during bacon slice counting and shatter determination. Sliced weights were collected for each individual belly to determine a bacon slicing yield. Two slicing yield equations were used; one was based on green weight, which accounted for variability due to raw materials and variability due to the manufacturing process and the other was based on cooked weight, which removed the variability due to the manufacturing process.

$$\text{Slicing Yield based on green wt.} = \left(\frac{\text{sliced wt}}{\text{green wt}}\right) \times 100\%$$

$$\text{Slicing Yield based on cooked wt.} = \left(\frac{\text{sliced wt}}{\text{cooked wt}}\right) \times 100\%$$

Slices were counted to determine the number of saleable slices. Slices were separated into five equal portions, modified from Robles (2004), based on anatomical orientation (zone A, B, C, D, and E) with zone A representing the anterior (blade) end and zone E representing the posterior (flank) end (Fig. 3.1). The first two slices of each zone were used for shatter determination and proximate composition (moisture and lipid). Shatters were defined only as a vertical break in a bacon slice across the fat, not the breaks between lean and fat (Pérez, 2002). Shatter numbers from each zone were summed and reported as the number of shatters per ten slices of each belly. Moisture content was determined in the same manner described in Boler et al. (2011a). Lipid was removed from the dried samples by washing the samples numerous times with heated petroleum ether. Image analysis was conducted to determine lean:fat ratio. Slices were collected from the middle of zones A, C, and E and were representative of the blade, middle, and flank of the belly (Fig. 3.1). Bacon slice percent lean was collected in a similar manner to Boler et al. (2011).

Statistical Analyses

Slaughter time after second dose was analyzed as two separate experiments (5 and 7 wk). Ending BW (118.99 vs. 135.30 kg) and age of the pigs (25 vs. 27 wk) likely influenced differences between slaughter groups and thus, justified two separate analyses. Pen (N = 48) was designated as the experimental unit, and data were averaged between the two pigs from each pen for all parameters. Data were analyzed in the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 2 × 3 factorial arrangement in a complete randomized design. Therefore, the model included the fixed effects of castration method, DDGS feeding strategy, and their interactions. Homogeneity of variances was tested with Levene's test and Brown and Forsythe in the case of non-normal data with GLM. Normality of residuals was tested using the CAPABILITY procedure of SAS. Comparisons among means were considered significantly different if $P \leq 0.05$. Comparisons were considered trending towards significance if $0.05 < P \leq 0.10$. Data were presented as interaction means of castration method × DDGS feeding strategy as these most represent the objectives of the study.

RESULTS

Carcass Characteristics

Results for carcass characteristics from both slaughter groups are presented in Table 3.1.

At 5 wk after second dose: Body weight, HCW, and dressing percentage were not different ($P \geq 0.11$) between IC barrows (120.02 kg, 87.36 kg, 72.78%; respectively) and PC barrows (117.98 kg, 88.11 kg, 74.51%; respectively). Loin depth and LMA were not different ($P \geq 0.31$) between IC barrows (66.48 mm, 49.49 cm^2; respectively) and PC barrows (67.69 mm, 48.71 cm^2; respectively). Distiller's grains feeding strategy had no effect ($P \geq 0.13$) on BW, dressing percentage, loin depth, and LMA. Hot carcass weight tended to be greater ($P = 0.09$) in control fed barrows (89.00 kg) compared with barrows fed 30% DDGS (86.65 kg), while HCW of barrows fed the withdrawal strategy (87.56 kg) was not different ($P \geq 0.39$) compared with control and barrows fed 30% DDGS. Back fat thickness was less ($P < 0.01$) in IC barrows (18.42 mm) compared with PC barrows (20.83 mm). Calculated percent lean was 1.33 percentage units greater ($P = 0.03$) in IC barrows compared with PC barrows.

***At 7 wk after second dose*:** Body weight and HCW was 5.25 kg and 1.96 kg greater ($P \leq 0.05$) in IC barrows (137.93 kg, 102.42 kg; respectively) compared with PC barrows (132.68 kg, 100.46 kg; respectively). Dressing percentage was 1.46 percentage units greater ($P < 0.01$) in PC barrows (74.26%) compared with IC barrows (75.71%). Back fat thickness, loin depth, LMA, and calculated percent lean were not different ($P \geq 0.69$) between castration methods. These traits along with BW, HCW, and dressing percentage were not different ($P \geq 0.12$) among DDGS feeding strategies.

Loin Quality

Results for loin quality from both experiments are presented in Table 3.2.

***5 wk after second dose*:** L* values (lightness) tended to be greater ($P = 0.06$) in IC barrows (47.88) compared with PC barrows (46.51), yet a* values (redness) and b* values (yellowness) were not different ($P \geq 0.31$) between IC and PC barrows. Marbling scores were 0.30 units greater ($P < 0.01$) in PC barrows compared with IC barrows. Firmness scores tended to be greater ($P = 0.10$) in PC barrows (2.65) compared with IC barrows (2.16). Moisture and fat percentage were not different ($P \geq 0.28$) between castration methods, but drip loss was 0.57 percentage units greater ($P = 0.03$) in IC barrows compared with PC barrows. All loin quality traits were the same ($P \geq 0.22$) among DDGS feeding strategies. A trend was observed for an interaction ($P = 0.09$) between castration method and DDGS feeding strategies for a*. The magnitude of the difference in a* of PC barrows when feeding 30% DDGS was 0.83 units compared with PC barrows fed control; while the magnitude of the difference in a* of IC barrows fed 30% DDGS was 0.35 units compared with control fed barrows (Cast x DDGS; $P = 0.09$). An interaction ($P = 0.02$) was observed between castration method and DDGS feeding strategies for subjective color evaluation. Color scores were not different ($P = 0.94$) among

DDGS feeding strategy in PC barrows. Color score was darker (P = 0.04) in IC barrows fed DDGS compared with IC barrows fed the withdrawal strategy, but these two strategies were not different ($P \geq 0.15$) to IC barrows fed the control strategy. Furthermore, marbling scores of PC barrows fed withdrawal had a 0.37 magnitude of increase compared with PC barrows fed 30% DDGS. Marbling scores of IC barrows fed withdrawal had a 0.07 magnitude of decrease compared with IC barrows fed the 30% DDGS strategy (Cast × DDGS; $P < 0.05$).

***7 wk after second dose*:** Loin quality traits were not different ($P \geq 0.15$) between castration methods. Additionally, DDGS feeding strategy had no effect ($P \geq 0.21$) on the majority of loin quality traits, with the exception of b* values and marbling scores. Values for b* were greater (P = 0.05) in control fed barrows (3.71) compared with barrows fed 30% DDGS (3.11), with withdrawal fed barrows (3.21) being intermediate and not different ($P \geq 0.14$) compared with the other two strategies. Marbling scores were greater ($P \leq 0.04$) in control fed barrows (2.38) compared with both barrows fed 30% DDGS (1.58) and barrows fed the withdrawal strategy (1.44). An interaction (P = 0.02) was detected for drip loss percentage. Drip loss of PC barrows fed 30% DDGS had 0.49 percentage units magnitude of increase compared with PC barrows fed the control strategy. Drip loss of IC barrows fed 30% DDGS had a 0.16 percentage unit decrease compared with IC barrows fed the control strategy.

Cutting Yields

Results for cutting yields from both experiments are presented in Table 3.3.

***5 wk after second dose*:** Carcasses from IC barrows had 1.87 percentage unit greater ($P < 0.01$) bone-in lean cutting yields, 1.57 percentage unit greater ($P < 0.01$) bone-in carcass cutting yields, 1.51 percentage unit greater ($P < 0.01$) boneless lean cutting yields, and 1.18 percentage unit greater ($P < 0.01$) boneless carcass cutting yields compared with carcasses from PC barrows.

No differences among DDGS feeding strategies ($P \geq 0.43$) or interactions between castration method and DDGS feeding strategies ($P \geq 0.15$) were observed in cutting yields.

7 wk after second dose: While carcass characteristics (back fat thickness and calculated lean; Table 3.2) between IC and PC barrows were not different at 7 wk after second dose, cutting yield advantages still tended to be greater ($P \leq 0.06$) in IC barrows compared with PC barrows. However, numerically, the advantage of IC barrows over PC barrows in cutting yields was reduced at 7 wk after second dose compared with 5 wk after second dose. Nevertheless, carcasses from IC barrows had 0.94 percentage unit greater ($P = 0.03$) bone-in lean cutting yields, tended to have 0.80 percentage unit greater ($P = 0.06$) bone-in carcass cutting yields, 0.93 percentage unit greater ($P = 0.02$) boneless lean cutting yields, tended to have 0.79 percentage unit greater ($P = 0.06$) boneless carcass cutting yields compared with carcasses from PC barrows. Bone-in lean cutting yields were similar ($P = 0.20$) among DDGS feeding strategies. Control fed barrows ($P = 0.08$; 75.95 %) tended to have less bone-in carcass cutting yields compared to those fed a withdrawal (76.96 %) and 30% DDGS (76.98 %) diets, respectively. Boneless lean cutting yields of control fed barrows (39.97%) were less ($P < 0.04$) compared with withdrawal fed barrows (41.18%) and barrows fed 30% DDGS (41.08%). An interaction ($P = 0.03$) was detected between castration method and DDGS feeding strategy for boneless carcass cutting yields. Boneless carcass cutting yields of PC barrows were at least 2.32 percentage units less ($P < 0.02$) in control fed barrows compared with withdrawal and barrows fed 30% DDGS. Boneless carcass cutting yields of IC barrows were not different ($P \geq 0.83$) among DDGS feeding strategy.

Fresh Belly Characteristics

Results for fresh belly quality from both experiments are presented in Table 3.4.

***5 wk after second dose*:** Belly width was greater (*P* = 0.05) in IC barrows (25.79 cm) than PC barrows (25.00 cm). Belly thickness was less (*P* < 0.01) in IC barrows (3.44 cm) compared with PC barrows (3.78 cm). Belly flop distance (an indication of firmness) tended to be less (*P* = 0.07) in IC barrows (14.72 cm) compared with PC barrows (17.29 cm). Barrows fed 30% DDGS (25.89 cm) tended to have wider (*P* = 0.06) bellies than control fed barrows (24.81 cm), and withdrawal fed barrows (25.50 cm) were not different (*P* ≥ 0.32) from the other DDGS feeding strategies. Belly thickness (*P* = 0.26) and belly flop distance (*P* = 0.49) was not different among DDGS feeding strategies. An interaction (*P* < 0.01) between castration method and DDGS feeding strategy was detected for belly length. Belly length was 2.25 cm greater (*P* = 0.02) in PC barrows fed 30% DDGS compared with PC barrows fed withdrawal, but both feeding strategies were not different (*P* ≥ 0.47) from PC barrows fed control. Belly length was 2.28 cm less (*P* = 0.02) in IC barrows fed 30% DDGS compared with IC barrows fed control, and both feeding strategies were not different (*P* ≥ 0.12) to IC barrows fed withdrawal. Iodine value was not different between castration method (*P* = 0.63), but was 4.51 units greater (*P* < 0.01) in withdrawal fed barrows compared with control fed barrows and 9.28 units greater (*P* < 0.01) in 30% DDGS fed barrows compared with control fed barrows.

***7 wk after second dose*:** Belly width, thickness and flop were similar (*P* ≥ 0.44) between IC and PC barrows, however, bellies of IC barrows tended (*P* = 0.07) to be thinner (3.95 cm) than PC barrows (4.05 cm). Bellies tended (*P* < 0.06) to be longer in control fed barrows (70.97 cm) compared with barrows fed 30% DDGS (69.22 cm) and withdrawal fed barrows (69.67 cm) being intermediate but not different (*P* ≥ 0.22) from other feeding strategies. Bellies were wider (*P* ≤ 0.02) in control fed barrows (25.03 cm) compared with withdrawal fed barrows (26.51 cm) and barrows fed 30% DDGS (27.40 cm), while withdrawal and 30% DDGS fed barrows were not different ($P = 0.21$). Belly thickness tended to be greater ($P = 0.10$) in control fed barrows (4.15 cm) compared with withdrawal fed barrows (3.95 cm), yet barrows fed 30% DDGS (3.96 cm) were not different ($P \geq 0.11$) from either DDGS feeding strategy. Belly flop distance was greater ($P < 0.01$) in control fed barrows (20.25 cm) compared with barrows fed 30% DDGS (14.41 cm) and tended ($P = 0.10$) to be greater compared with withdrawal fed barrows (18.51 cm). Iodine value was not different between castration method ($P = 0.21$), but was 2.67 units greater ($P = 0.03$) in withdrawal fed barrows compared with control fed barrows and 7.50 units greater ($P < 0.01$) in 30% DDGS fed barrows compared with control fed barrows. Interactions of castration method and diet were not significant for any fresh belly characteristic at 7 wk after second dose.

Bacon Production

Results for cured belly characteristics from both experiments are presented in Table 3.5.

5 wk after second dose: Skin-on untrimmed weights (5.71 vs. 5.95 kg), green weights (4.90 vs. 5.17 kg), pumped weights (5.50 vs. 5.81 kg), cooked weights (5.04 vs. 5.38 kg), trimmed cooked weight (4.44 vs. 4.97 kg), and sliced weights (4.14 vs. 4.65 kg) were lighter ($P < 0.01$) in IC barrows compared with PC barrows. Pump uptake was not different ($P = 0.61$) in IC barrows compared to PC barrows. Cooked yield was 1.91 percentage units less ($P < 0.01$) in IC barrows (102.24%) compared with PC barrows (104.15%). Ends and pieces weights were heavier ($P = 0.02$) in IC barrows (0.62 kg) compared with PC barrows (0.39 kg). Processing weights and yields were not different ($P \geq 0.10$) among DDGS feeding strategy, with the exception of pump uptake and ends and pieces weights. Pump uptake was 1.26 percentage units greater ($P = 0.03$) in 30% DDGS fed barrows (13.01%) compared to bellies from control fed barrows (11.75%), with withdrawal fed barrows (12.19%) intermediate and not different ($P \geq$

0.23) from other feeding strategies. Ends and pieces weights tended to be less (P = 0.10) in IC barrows fed withdrawal (0.36 kg) compared with IC barrows fed control (0.81 kg), but not different ($P \geq 0.19$) than IC barrows fed 30% DDGS (0.70 kg) or PC barrows fed any feeding strategy. There was a significant interaction ($P \leq 0.04$) between castration method and DDGS feeding strategy for slicing yields, both as a percentage of green and cooked weight. For both green and cooked weight calculations, slicing yields did not differ ($P > 0.05$) between feeding strategies in PC barrows. However, slicing yield as a percentage of green weight was 5.35 percentage units greater (P = 0.04) in withdrawal fed IC barrows compared with IC barrows fed 30% DDGS and 6.36 percentage units greater (P = 0.01) in withdrawal fed IC barrows compared with IC barrows fed control. Similarly, slicing yields as a percentage of cooked weight was 4.79 percentage units greater (P = 0.02) in withdrawal fed IC barrows compared with IC barrows fed 30% DDGS and 5.04 percentage units greater (P = 0.01) in withdrawal fed IC barrows compared with IC barrows fed control.

7 wk after second dose: Skin-on untrimmed weights, green weights, pumped weights, pump uptake, and cooked weights were not different ($P \geq 0.48$) in IC barrows compared with PC barrows, however, cooked yield was 0.83 percentage units less (P = 0.02) in IC barrows (103.67%) compared with PC barrows (104.50%). Trimmed cooked weights and sliced weights were lighter ($P \leq 0.01$) in IC barrows (5.29 kg, 4.95 kg; respectively) compared with PC barrows (5.60 kg, 5.28 kg; respectively). Slicing yield expressed as a percentage of green weight was 4.77 percentage units less (P = 0.05) in IC barrows compared with PC barrows (86.01 vs. 90.78%). Slicing yields expressed as a percentage of cooked weight were 4.27 percentage units less ($P < 0.01$) in IC barrows compared with PC barrows (82.82 vs. 87.09%). Skin-on trimmed weight and pump weight tended to be greater (P =0.10) in barrows fed 30% DDGS compared with barrows fed withdrawal, while barrows fed control were intermediate and not different (P > 0.10) than other feeding strategies. Pump uptake was greater (P < 0.01) in barrows fed 30% DDGS (13.68%) than control fed barrows (11.44%), with withdrawal fed barrows (12.38%) being intermediate and not different (P > 0.05) to either DDGS feeding strategy. Slicing yield expressed as a percentage of green weight was not different (P = 0.33) among DDGS feeding strategies. Interactions (P < 0.05) were observed between castration method and DDGS feeding strategy for cooked yields and end and pieces weights. Cooked yield was less (P = 0.03) in IC fed 30% DDGS compared to PC fed 30% DDGS; however, cooked yield was not different ($P \geq$ 0.45) between PC and IC barrows for the other feeding strategies. Distiller's grains feeding strategy had no effect ($P \geq 0.97$) on weight of ends and pieces in PC barrows, while IC barrows fed withdrawal had less ($P \leq 0.05$) ends and pieces weight compared to IC barrows fed control and 30% DDGS (0.19 kg, 0.33 kg; respectively). No interaction (P = 0.30) was detected for slicing yield as percentage of green weight, yet a trending interaction (P = 0.08) between castration method and DDGS feeding strategy was detected for slicing yield as a percentage of cooked weight. Slicing yield was not affected by DDGS feeding strategy in PC barrows, while in withdrawal fed IC barrows slicing yield was greater (P < 0.01) than control and 30% DDGS fed IC barrows.

Bacon Slice Characteristics and Composition

Results for bacon slice characteristics and composition from both experiments are presented in Table 3.6.

5 wk after second dose: Number of slices was 3.89 less (P = 0.01) in IC barrows compared with PC barrows. Moisture percentage was greater (P < 0.01) and extractable lipid was less (P < 0.01) in IC barrows (56.70%, 24.27%; respectively) compared with PC barrows

(52.04%, 30.71%; respectively). Differences in composition were also evident with image analysis, as lean:fat in IC barrows was greater ($P \leq 0.01$) in the blade-end portion (61.18 vs. 55.99%), middle (60.13 vs. 55.69%), flank-end (66.24 vs. 63.07%), and average across all three locations (62.52 vs. 58.25%) compared with PC barrows. Number of slices tended to be less ($P = 0.10$) in barrows fed 30% DDGS (105.38) compared with withdrawal fed barrows (109.14), while control fed barrows (106.22) were intermediate and not different ($P \geq 0.25$) than either DDGS feeding strategy. Feeding strategy, however, did not alter composition of bacon slices. The interaction of castration method and feeding strategy trended towards significance ($P = 0.09$) for shatters. Total shatters were similar ($P \geq 0.16$) between IC and PC barrows fed withdrawal and 30% DDGS, but were reduced ($P < 0.01$) in IC barrows compared to PC barrows fed control.

7 wk after second dose: Composition evaluated chemically and with image analysis was not different (P > 0.20) between IC and PC barrows, nor was there an effect of castration method for shatters. No differences ($P \geq 0.35$) between DDGS feeding strategy were detected in chemical composition; however average lean:fat was at least 3.02 units less ($P \leq 0.05$) in control fed barrows compared with other DDGS feeding strategies. There was an interaction ($P = 0.05$) between castration method and DDGS feeding strategy for number of slices. Number of slices was not affected ($P \geq 0.27$) by DDGS feeding strategy within each castration method. However, slice number was reduced in IC barrows fed control diets compared to PC barrows fed the same. Within barrows fed withdrawal and 30% DDGS, castration methods did not differ in slice number.

DISCUSSION

Feeding co-products such as DDGS to pigs is increasingly common given the constraints of increased grain prices. Therefore, the effect of feeding DDGS on lean meat yield and bacon slicing yield of IC barrows must be determined. While diets containing DDGS at levels up to 30% have not altered carcass leanness or lean meat yield in PC barrows, IC barrows have nutritional requirements that differ from PC barrows (Dunshea et al., 2013). In the present study, however, DDGS inclusion in IC barrow diets was not detrimental to HCW, dressing percentage, LM depth or area, or calculated lean percentage. Lean and carcass cutting yields did not differ between DDGS feeding strategies at 25 wk of age. However, at 27 wk of age, boneless lean cutting yields were improved in withdrawal and 30% DDGS fed PC and IC barrows while boneless carcass cutting yields were improved with DDGS inclusion in PC barrows and unchanged in IC barrows. The reduction in boneless carcass cutting yields at 27 wk in control fed PC barrows was most likely due to increased fatness of this treatment group compared to all others. Furthermore, inclusion of DDGS had only minimal impacts on loin quality characteristics with only slight reductions in marbling and b* when DDGS was included in the 7 wk slaughter group. While statistically significant, changes in loin quality in the present study were of little practical significance. The lack of effect of DDGS feeding strategies on overall carcass characteristics was in agreement with previous reports (Stein and Shurson, 2009). Notably, in the present study, the lack of interactions between castration method and DDGS feeding strategy indicated that IC and PC barrows had similar responses to DDGS feeding strategies from a carcass characteristics standpoint and that DDGS can be included in the diet of IC barrows at 30% without harm to carcass leanness, yields, or loin quality.

Given the possibility of increased leanness leading to increased unsaturated fatty acid content of adipose tissue from IC barrows in comparison to PC barrows, it was important to understand whether diets with increased unsaturated fatty acids from DDGS inclusion would further exacerbate this condition. At both 5 and 7 wk after second dose, IV was increased in IC and counterpart PC barrows fed 30% DDGS through slaughter compared with withdrawal and control-fed barrows similar to previous reports (Leick et al, 2010; Xu et al., 2010). Withdrawing DDGS prior to slaughter improved IV suggesting an improvement in belly quality. Despite differences in IV and flop distance among feeding strategies, DDGS feeding strategy alone had minimal effects on bacon slicing yields. All three DDGS feeding strategies (0%, 30% and withdrawal) resulted in similar slicing yields in PC barrows. In fact, DDGS inclusion reduced the number of shatters at 25 wk but did not alter shatters at 27wk. These data would suggest that flop distance and IV were poor predictors of bacon slicing yields in this population of PC barrows.

The effect of immunological castration on belly characteristics was similar to previous reports. Boler et al. (2012) reported IC barrows had thinner and wider bellies with reduced flop distances and greater IV compared to PC barrows. Kyle et al. (2014) reported IC barrows had bellies of similar thickness, width, and IV compared to PC barrows, yet bellies from IC barrows had narrower flop distances compared to bellies from IC barrows. In the present study, IC barrows slaughtered 5 wk after second dose had thinner and wider bellies with narrower flop distances, yet similar IV compared with PC barrow counterparts. Furthermore, IC barrows slaughtered 7 wk after second dose had thinner bellies with of similar width, flop distance, and IV compared with PC barrow counterparts. Nevertheless, bacon slicing yields were reduced in IC barrows fed control and 30% DDGS diets through slaughter at both 25 and 27 wk of age. Withdrawal of DDGS from IC barrows diets at both time points normalized slicing yields of IC barrows to that of PC barrow counterparts. Similarly, Kyle et al. (2014) reported IC barrows had reduced bacon slicing yields compared with PC barrows. Generally, IV has been used to identify potential fat quality issues and ultimately predict bacon slicing yield. Although, IV was similar between castration methods; bacon slicing yields were reduced in IC barrows compared to PC barrow counterparts. This suggests the need to explore other factors that may play a role in determining bacon slicing yields.

Extending time after second dose in IC barrows had obvious impacts on some carcass characteristics (BW, HCW), because of the method of pig selection and increased age of the pigs, therefore comparisons between the two times after second dose needed to be made with caution. Dressing percentage of IC barrows was less than PC barrows in both times after second dose, but was improved by 1.41percentage units in IC barrows slaughtered at 5 wk after second dose compared with IC barrows slaughtered at 7 wk after second dose, while PC barrows were improved 1.03 percentage units over the same time period. Back fat thickness was less and calculated lean was greater in IC barrows slaughtered 5 wk after second dose compared with PC barrow counterparts; conversely, back fat thickness and calculated lean was similar between IC barrows slaughtered 7 wk after second dose compared with PC barrow counterparts. Cutting yields were greater in IC barrows at both times compared with PC barrows, yet were greater in magnitude at 5 wk after second dose than 7 wk after second dose. Bellies of IC barrows slaughtered at 5 wk after second dose were 0.51 cm thinner and had 1.43 units greater IV compared with IC barrows slaughtered at 7 wk after second dose. Bacon slicing yields of bellies of IC barrows slaughtered 7 wk after second dose were improved (2.15% units of green wt; 0.85% units of cooked wt) compared with bellies of IC barrows slaughtered 5 wk after second dose.

CONCLUSIONS

Immunologically castrated barrows had advantages in cutting yields compared to PC barrows whether measured on a bone-in or boneless basis. The advantages in cutting yields remained at 7 wk after second dose even when IC barrows became heavy (138 kg) and had the same back fat thickness as PC barrow counterparts. Bellies from IC barrows were thinner at both time points, and IV did not differ at either time point. Nevertheless, bacon slicing yield was reduced in both control-fed and DDGS-fed IC barrows compared to PC barrow counterparts. Withdrawal of DDGS from IC barrows corrected bacon slicing yields to that of PC barrows. Therefore, these data suggest that IV was not well associated with bacon slicing yields. The combination of increasing time after second dose, age of the pig, BW, and DDGS withdrawal warrants further research to best determine management and marketing strategies of IC barrows.

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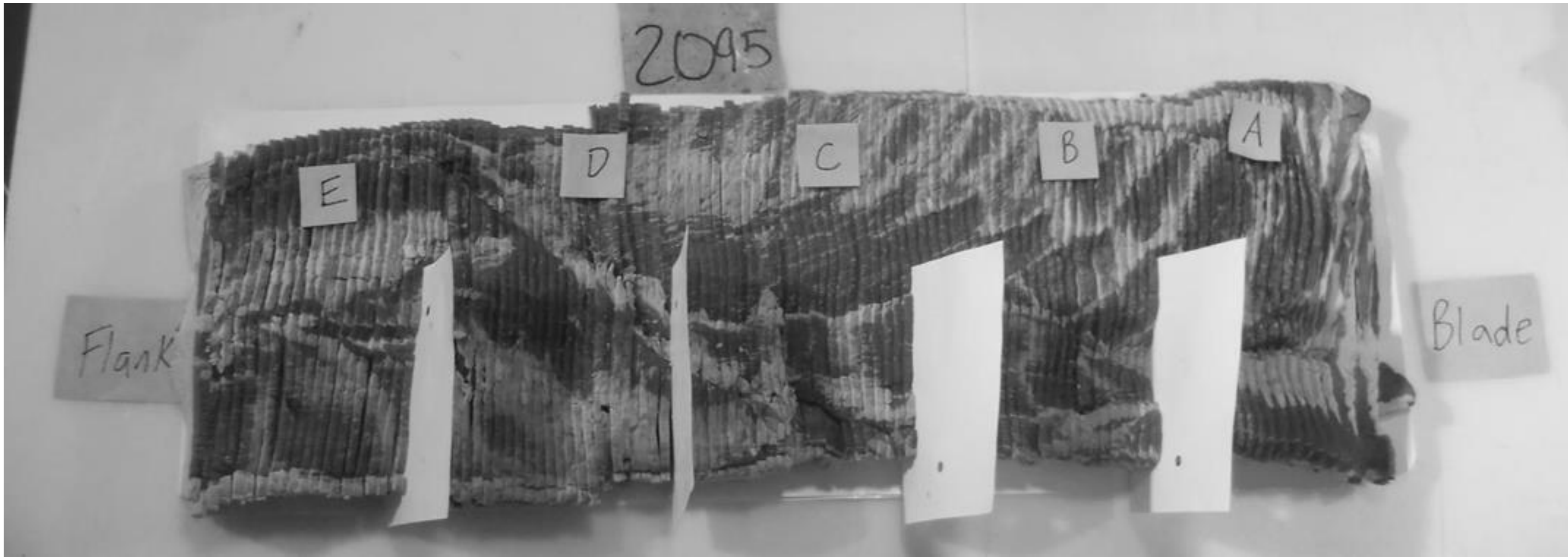
FIGURES

Figure 3.1. Sampling zones in a cured and sliced belly.



TABLES

Table 3.1. Effect of Immunological castration and DDGS feeding strategies[1] on carcass characteristics of barrows slaughtered at 5 and 7 wk after second Improvest injection

	5 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
BW, kg	118.14	117.42	118.37	120.68	118.88	120.49	2.26	0.45	0.85	0.97
HCW, kg	88.97	88.20	87.16	89.02	86.90	86.13	1.09	0.40	0.10	0.80
Dressing, %	75.26	75.21	73.65	73.89	73.12	71.54	0.87	0.11	0.19	0.85
Loin depth, mm	68.38	68.19	66.50	66.44	67.63	65.37	1.44	0.31	0.37	0.89
Back fat thickness, mm	20.44	20.81	21.25	17.75	17.69	19.81	1.08	<0.01	0.35	0.72
Loin muscle area, cm^2	49.77	48.06	48.30	51.40	48.60	48.49	1.24	0.44	0.13	0.83
Calculated lean[2], %	54.60	54.35	53.88	56.00	56.19	54.62	0.72	0.03	0.26	0.75
	7 wk after second Improvest dose									
	Physical Castrate			**Physical Castrate**				***P* - value**		
	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
BW, kg	134.26	130.21	133.56	137.44	136.93	139.42	1.46	<0.01	0.12	0.45
HCW, kg	101.87	98.50	101.02	102.46	101.61	103.20	1.20	0.05	0.15	0.57
Dressing, %	75.87	75.67	75.64	74.55	74.22	74.01	0.35	<0.01	0.54	0.91
Loin depth, mm	66.31	67.69	69.06	68.44	67.50	67.94	0.71	0.74	0.50	0.27
Back fat Thickness, mm	26.13	21.85	24.06	24.65	24.75	23.81	1.28	0.69	0.25	0.22
Loin muscle area, cm^2	55.42	53.79	55.46	54.85	54.02	55.07	1.26	0.84	0.50	0.95
Calculated lean[2], %	50.88	53.68	52.47	52.01	51.86	52.47	0.80	0.74	0.23	0.19

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet = 30% DDGS inclusion 6 wk of age-slaughter.

[2]Calculated lean = 58.86 - (back fat × 0.61) + (LM depth × 0.12)

Table 3.2. Effect of Immunological castration and DDGS feeding strategies[1] on loin quality of barrows slaughtered at 5 and 7 wk after second Improvest dose

	5 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
pH	5.52	5.51	5.55	5.45	5.43	5.51	0.07	0.48	0.52	0.87
Minolta L*	46.65	46.55	46.32	47.96	48.95	46.75	0.85	0.06	0.36	0.51
Minolta a*	7.58	7.44	6.75	7.57	7.14	7.92	0.39	0.31	0.67	0.09
Minolta b*	2.76	2.76	2.05	3.12	3.00	3.03	0.74	0.54	0.92	0.96
Subjective Color[3]	2.81[a]	2.75[ab]	2.63[ab]	2.31[ab]	2.19[b]	2.81[a]	0.14	0.02	0.22	0.02
Subjective marbling[3]	2.63[a]	2.56[ab]	2.19[ab]	2.25[ab]	2.06[b]	2.13[ab]	0.13	<0.01	0.49	0.05
Subjective firmness[4]	2.75	2.75	2.44	2.13	2.31	2.32	0.32	0.10	0.95	0.62
Moisture, %	74.23	74.27	74.52	74.50	74.66	74.46	0.22	0.28	0.83	0.59
Lipid, %	2.00	1.71	1.78	1.77	1.68	1.71	0.30	0.51	0.99	0.57
Drip loss, %	1.38	1.66	1.69	2.00	2.06	1.94	0.22	0.03	0.73	0.70
	7 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
pH	5.68	5.63	5.66	5.66	5.63	5.66	0.03	0.77	0.33	0.95
Minolta L*	45.08	45.55	45.15	46.14	45.38	46.27	0.70	0.25	0.94	0.59
Minolta a*	9.27	8.25	8.40	8.40	8.25	7.75	0.71	0.56	0.22	0.48
Minolta b*	3.78	3.30	3.22	3.64	3.13	3.00	0.26	0.39	0.05	0.99
Subjective Color[3]	3.63	3.44	3.38	3.56	3.38	3.13	0.27	0.66	0.55	0.88
Subjective marbling[3]	2.50	1.63	1.63	1.69	1.44	1.38	0.37	0.15	0.02	0.68
Subjective firmness[4]	3.00	2.44	2.56	2.50	2.38	2.44	0.29	0.37	0.57	0.79
Moisture, %	73.35	73.90	73.94	73.86	74.16	73.70	0.23	0.38	0.21	0.27
Lipid, %	2.83	1.85	2.10	2.26	2.02	2.15	0.52	0.67	0.42	0.73
Drip loss, %	1.40	1.24	1.89	1.53	1.84	1.37	0.19	0.66	0.68	0.02

[a-b]Means within a row without a common superscript differ ($P \leq 0.05$)

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet = 30% DDGS inclusion 6 wk of age-slaughter

[2]L*, greater value indicates a lighter color; a*, greater value indicates a redder color; b*, greater value indicates a more yellow color

[3,4]Subjective evaluations based on National Pork Producers Council (Des Moines, IA) standards, 1991 and 1999

Table 3.3. Effect of Immunological castration and DDGS feeding strategies[1] cutting yields of barrows slaughtered at 5 and 7 wk after second Improvest dose

Item	Physical Castrate: Control	Physical Castrate: Withdrawal	Physical Castrate: 30% DDGS	Immunological Castrate: Control	Immunological Castrate: Withdrawal	Immunological Castrate: 30% DDGS	SEM	*P* - value: Cast.	*P* - value: DDGS	*P* - value: Cast. × DDGS
5 wk after second Improvest dose										
Chilled side wt, kg	43.54	43.09	42.24	43.44	42.26	41.84	0.52	0.30	0.03	0.79
Bone-in										
Lean cutting yield[2], %	63.10	63.57	63.35	65.73	65.52	64.40	0.54	<0.01	0.43	0.36
Carcass cutting yield[3], %	76.74	77.53	77.60	79.28	79.04	78.21	0.48	<0.01	0.72	0.15
Boneless										
Lean cutting yield[4], %	40.93	41.04	41.09	42.91	42.98	41.70	0.51	<0.01	0.44	0.32
Carcass cutting yield[5], %	54.57	55.01	55.35	56.46	56.51	55.50	0.48	<0.01	0.77	0.17
7 wk after second Improvest dose										
Chilled side wt, kg	49.45	48.06	49.24	49.84	49.48	50.42	0.65	0.07	0.23	0.71
Bone-in										
Lean cutting yield[2], %	61.68	63.04	62.80	63.25	63.74	63.35	0.52	0.03	0.20	0.57
Carcass cutting yield[3], %	74.98	76.88	76.82	76.91	77.04	77.14	0.50	0.06	0.08	0.17
Boneless										
Lean cutting yield[4], %	39.03	41.18	40.63	40.91	41.17	41.53	0.45	0.02	0.02	0.13
Carcass cutting yield[5], %	52.33[b]	55.02[a]	54.65[a]	54.58[a]	54.47[a]	55.32[a]	0.50	0.06	<0.01	0.03

[a-b]Means within a row without a common superscript differ ($P \leq 0.05$)

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet = 30% DDGS inclusion 6 wk of age-slaughter.

[2]Bone-in lean cutting yield = [(trimmed ham + trimmed loin + Boston + picnic) / right chilled side wt] × 100

[3]Bone-in carcass cutting yield = [(bone-in lean cutting yield components + natural belly) / right chilled side wt] × 100

[4]Boneless lean cutting yield = [(5-piece ham + Canadian back + sirloin + tenderloin + Boston + picnic) / right chilled side wt] × 100

[5]Boneless carcass lean cutting yield = [(boneless lean cutting yield components + natural belly) / right chilled side wt] × 100

Table 3.4. Effect of Immunological castration and DDGS feeding strategies[1] on fresh belly characteristics of barrows slaughtered at 5 and 7 wk after second Improvest dose

	5 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Length, cm	67.85^{abc}	66.63^{bc}	68.88^{a}	68.42^{ab}	67.88^{abc}	66.14^{c}	0.48	0.43	0.18	<0.01
Width, cm	24.02	25.32	25.9	25.59	25.64	26.12	0.47	0.05	0.08	0.36
Thickness[2], cm	3.84	3.81	3.67	3.47	3.51	3.35	0.10	<0.01	0.26	0.94
Flop distance, cm	18.19	18.11	13.84	15.92	13.81	14.43	1.71	0.07	0.49	0.65
Iodine Value[3], g/ 100 g	61.59^{c}	67.54^{b}	71.46^{a}	63.25^{c}	66.33^{b}	71.93^{a}	0.76	0.63	<0.01	0.18
	7 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Length, cm	71.39	69.44	69.31	70.55	69.91	69.12	0.81	0.77	0.06	0.7
Width, cm	24.40^{b}	27.00^{a}	27.23^{a}	25.66^{ab}	26.02^{ab}	27.58^{a}	0.54	0.63	<0.01	0.11
Thickness[2], cm	4.17^{a}	3.96^{ab}	4.14^{ab}	4.12^{ab}	3.95^{ab}	3.70^{b}	0.10	0.07	0.07	0.14
Flop distance, cm	22.49^{a}	20.59^{ab}	13.84^{b}	18.00^{ab}	15.44^{b}	14.97^{b}	1.80	0.44	<0.01	0.14
Iodine Value[3], g/ 100 g	62.52^{d}	66.76^{bc}	71.00^{a}	63.21^{cd}	64.31^{cd}	69.71^{ab}	0.99	0.21	<0.01	0.29

[a-b]Means within a row without a common superscript differ ($P \leq 0.05$)

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet = 30% DDGS inclusion 6 wk of age-slaughter.

[2]Thickness is the average of 8 measurements collected on along the belly, where location 1 to 4 is from the anterior to posterior position of the dorsal edge of the belly and location 5 to 8 is from the anterior to posterior position of the ventral edge of the belly

[3]Calculated as IV value (IV; AOCS, 1998) = C16:1 × (0.95) + C18:1 × (0.86) + C18:2 × (1.732) + C18:3 × (2.616) + C20:1 × (0.785) + C22:1 × (0.723)

Table 3.5. Effect of Immunological castration and DDGS feeding strategies[1] on belly processing of barrows slaughtered at 5 and 7 wk after second Improvest dose

	5 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Skin-on untrimmed wt, kg	5.93	5.95	5.97	5.77	5.64	5.71	0.10	<0.01	0.85	0.77
Purge loss[2], %	0.97^{ab}	1.08^{ab}	0.82^{b}	1.47^{a}	1.33^{ab}	1.23^{ab}	0.14	<0.01	0.32	0.70
Green wt, kg	5.18	5.17	5.17	4.97	4.84	4.89	0.10	<0.01	0.74	0.81
Pump wt, kg	5.80	5.79	5.85	5.55	5.44	5.50	0.11	<0.01	0.81	0.86
Pump uptake, %	11.91	12.00	13.35	11.59	12.38	12.66	0.49	0.61	0.04	0.55
Cooked wt, kg	5.35	5.37	5.41	5.05	5.07	5.00	0.11	<0.01	0.99	0.86
Cooked yield, %	104.03^{a}	103.87^{ab}	104.56^{a}	101.45^{b}	102.96^{ab}	102.31^{ab}	0.59	<0.01	0.41	0.34
Trimmed cooked wt, kg	5.01^{a}	4.96^{a}	4.96^{a}	4.30^{b}	4.73^{ab}	4.30^{b}	0.11	<0.01	0.12	0.07
Ends and pieces wt, kg	0.33	0.39	0.45	0.81	0.36	0.70	0.09	0.02	0.10	0.08
Sliced wt, kg	4.65^{a}	4.66^{a}	4.63^{a}	4.06^{b}	4.32^{ab}	4.05^{b}	0.12	<0.01	0.36	0.47
Slicing yield (green wt)[3], %	90.28^{a}	90.06^{a}	89.57^{a}	81.41^{b}	87.77^{a}	82.42^{b}	1.24	<0.01	0.03	0.03
Slicing yield (cooked wt)[4], %	86.79^{a}	86.70^{a}	85.63^{a}	80.21^{b}	85.24^{a}	80.45^{b}	1.04	<0.01	0.01	0.04
	7 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Skin-on untrimmed wt, kg	6.56	6.54	6.80	6.60	6.53	6.83	0.13	0.85	0.09	0.98
Purge loss[2], %	1.58	1.52	1.47	1.75	1.07	1.78	0.52	0.98	0.77	0.77
Green wt, kg	5.78	5.71	5.92	5.74	5.65	5.91	0.13	0.74	0.18	0.98
Pump wt, kg	6.44	6.41	6.72	6.39	6.36	6.66	0.15	0.67	0.09	1.00
Pump uptake, %	11.50^{b}	12.17^{ab}	13.53^{a}	11.38^{b}	12.59^{ab}	12.63^{ab}	0.41	0.55	<0.01	0.28
Cooked wt, kg	6.02	5.95	6.23	5.92	5.91	6.11	0.15	0.48	0.21	0.96
Cooked yield, %	104.24^{ab}	104.00^{ab}	105.24^{a}	103.11^{b}	104.53^{ab}	103.36^{b}	0.44	0.02	0.27	0.02
Trimmed cooked wt, kg	5.58	5.50	5.73	5.21	5.39	5.27	0.15	0.01	0.77	0.44
Ends and pieces wt, kg	0.44^{b}	0.45^{b}	0.49^{b}	0.71^{a}	0.52^{b}	0.85^{a}	0.05	<0.01	<0.01	0.01
Sliced wt, kg	5.28	5.19	5.38	4.90	5.03	4.92	0.13	<0.01	0.88	0.51
Slicing yield (green wt)[3], %	90.40	90.86	91.08	85.61	89.38	83.05	1.94	0.05	0.33	0.30
Slicing yield (cooked wt)[4], %	87.57^{a}	87.24^{a}	86.46^{a}	82.65^{b}	85.01^{a}	80.79^{b}	0.82	<0.01	0.01	0.08

$^{a\text{-}b}$Means within a row without a common superscript differ ($P \leq 0.05$)

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet =

[2]Purge loss = [(natural belly weight – skin-on untrimmed weight) / natural belly weight] × 100

[3]Slicing yield [green wt] = (sliced weight / green weight) × 100

[4]Slicing yield [cooked wt] = (sliced weight / cooked weight) × 100

Table 3.6. Effect of Immunological castration and DDGS feeding strategies[1] on bacon characteristics of barrows slaughtered at 5 and 7 wk after second Improvest dose

	5 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Number of slices, #	108.63	109.88	108.06	103.81	108.4	102.69	1.87	0.01	0.1	0.52
Composition										
Moisture, %	52.62	52	51.51	57.18	57.48	55.43	0.95	<0.01	0.24	0.7
Fat, %	29.97	30.84	31.33	23.57	23.26	25.99	1.26	<0.01	0.26	0.66
Image analysis										
Blade lean:fat	55.71	55.85	56.41	62.64	61.04	59.87	1.9	<0.01	0.85	0.64
Middle lean:fat	57.44	54.02	55.62	60.44	61.02	58.93	1.68	<0.01	0.55	0.4
Flank lean:fat	64.41	62.86	61.93	65.3	66.2	67.22	1.53	0.01	0.97	0.33
Average lean:fat	59.19	57.58	57.98	62.79	62.75	62.01	1.34	<0.01	0.73	0.83
Total shatters	21.68[b]	15.94[ab]	12.69[a]	12.69[a]	10.25[b]	11.13[a]	1.67	<0.01	0.01	0.09
	7 wk after second Improvest dose									
	Physical Castrate			**Immunological Castrate**				***P* - value**		
Item	Control	Withdrawal	30% DDGS	Control	Withdrawal	30% DDGS	SEM	Cast.	DDGS	Cast. × DDGS
Number of slices, #	114.87[b]	114.31[b]	111.88[ab]	107.06[a]	111.25[ab]	109.81[ab]	1.25	<0.01	0.23	0.05
Composition										
Moisture, %	46.41	50.87	48.47	49.59	50.95	51.89	2.05	0.2	0.35	0.62
Fat, %	37.48	32.75	34.7	33.14	31.97	30.94	2.56	0.32	0.58	0.77
Image analysis										
Blade lean:fat	49.36	55.02	53.78	50.03	55.99	54.38	1.4	0.51	<0.01	0.99
Middle lean:fat	48.05	52.47	50.23	53.92	48.57	53.77	2.11	0.29	0.77	0.06
Flank lean:fat	59.27	63.31	62.3	59.83	63.26	64.65	1.6	0.46	0.03	0.74
Average lean:fat	52.23	56.93	55.43	54.6	55.94	57.6	1.28	0.26	0.03	0.34
Total shatters	26.51	13.81	24.55	25.38	21.15	19.45	5.3	0.92	0.24	0.39

[a-b]Means within a row without a common superscript differ ($P \leq 0.05$)

[1]Distiller's Dried Grains with Solubles (DDGS) feeding strategies: control = no DDGS; withdrawal = 30% DDGS inclusion 6 wk of age-second dose followed by no DDGS (control) diet; 30% DDGS diet = 30% DDGS inclusion 6 wk of age-slaughter

Chapter 4

EFFECTS OF TIME AFTER SECOND IMPROVEST DOSE INDEPENDENT OF AGE AT SLAUGHTER ON COMMERCIAL BACON SLICIBILITY IN IMMUNOLOGICALLY CASTRATED BARROWS

ABSTRACT

The objective of the present study was to quantify both the effects of age at slaughter and time after second Improvest (GnRF analog; Zoetis, Kalamazoo, MI) dose on fresh belly characteristics and commercial bacon production in immunologically castrated (IC) barrows compared with physically castrated (PC) barrows and gilts. The study was conducted as a randomized complete block design with 12 treatments. Pigs (N=278) were slaughtered at 24, 26, and 28 wk of age. Within each slaughter age, IC barrows, PC barrows, and gilts were represented. For pigs slaughtered at 24 wk, administration of the second Improvest dose was staggered so that IC barrows were slaughtered at 4, 6, 8, and 10 wk after second dose. In pigs slaughtered at 26 and 28 wk, IC barrows were slaughtered at 6 and 8 weeks after second dose, respectively. Pigs served as the experimental units. Data were analyzed with the mixed procedure in SAS and the model included the main effects of treatment, and the random effects of block (farrowing date = 4) and block within replication. Single DF contrasts were obtained to test for linear (L) and quadratic (Q) effects and to conduct pairwise comparison of interest. In pigs slaughtered at 24 wk of age, belly thickness, flop distance, and bacon lipid content were increased (L; $P < 0.04$) and iodine value (IV) tended to decrease (L; $P = 0.08$) with time after second dose in IC barrows. Bacon slicing yields (as percent of green and cooked weight) were also increased with time after second dose (Q; $P < 0.05$), but were similar ($P > 0.14$) between sex classes. In pigs slaughtered from 24 to 28 wk of age, fatness (last rib and bacon) was increased

(L; $P < 0.01$) and IV reduced (L; $P < 0.01$) in IC barrows with age at slaughter, but not (L; $P > 0.11$) in PC barrows and gilt combined. Slicing yields (green and cooked weight) were increased (L; $P < 0.01$) with age at slaughter in IC barrows. Both yields were superior ($P < 0.01$) in IC barrows compared to PC and gilts at 28 wk. Increasing both age at slaughter and the time after second Improvest dose improved fresh and cured belly characteristics in IC barrows, however age at slaughter seemed to have a greater effect on the belly.

Keywords: Immunological castration, age at slaughter, bacon production

INTRODUCTION

Advances in animal genetics coupled with technologies to improve feed efficiency and muscle growth, such as immunological castration, have increased leanness in pigs. One disadvantage of leaner pigs, however, is that adipose tissue of lean pigs have increased amounts of unsaturated fatty acids (UFA) (Correa et al., 2008). This is a cause for concern to packers and processors because it is thought to increased issues with fat characteristics (increased soft and oily fat), especially that of the belly. Bellies with soft and oily fat produce bacon that is difficult to slice (Person et al., 2005).

Historically, immunologically castrated (IC, Improvest; Zoetis, Kalamazoo, MI) barrows were generally leaner, and bellies were thinner (Boler et al., 2012), had greater concentrations of UFA, had greater iodine value (IV) (Boler et al., 2011a), and reduced bacon slicing yields compared to physically castrated (PC) barrows (Kyle et al., 2014; Tavárez et al., 2014a). However, IV of the belly and bacon slicing yields, were improved in IC barrows with increasing time after second Improvest dose (Tavárez et al., 2014a; Tavárez et al., 2014b). However, this improvement in belly quality attributed to increasing time after second dose cannot be separated from the effects of age as this also increased. Therefore, the objectives of the present study were to quantify both the effects of time after second dose and age at slaughter on fresh belly characteristics and commercial bacon production in IC barrows compared with PC barrows and gilts. A study by Lealiifano et al. (2011) reported at a constant slaughter age increasing time after second of Improvest led to increased fat deposition in IC barrows. Thus, our hypothesis was that increasing time after second Improvest dose, without increasing age would improve belly characteristics and bacon slicing yields due to increased fatness. These improvements will be of similar magnitude compared to the effect of increasing both age and time after second dose.

MATERIALS AND METHODS

Animals used during this study were cared for in accordance with University of Illinois Animal Care and Use Committee guidelines. Animals were transported to and slaughtered at a USDA Food Safety and Inspection Service-inspected slaughtering facility. Samples were transported to the University of Illinois Meat Science Laboratory.

Study Design, Animals, and Treatments

The live phase of the study was conducted as a randomized complete block design with 12 treatments (Table 4.1). Pigs were slaughtered at 24, 26, and 28 wk of age. Within each slaughter age, IC barrows, PC barrows, and gilts were represented. For pigs slaughtered at 24 wk, administration of the second Improvest dose was staggered so that IC barrows were slaughtered at 4, 6, 8, and 10 wk after second dose. In pigs slaughtered at 26 and 28 wk, IC barrows were slaughtered at 6 and 8 weeks after second dose, respectively. This arrangement of treatments allowed for distinguishing the effects of time after second Improvest dose in IC pigs slaughtered at 24 wk and the effects on increasing age slaughter in IC pigs slaughtered from 24 through 28 wk.

Pigs were blocked by farrowing date (4) with 3 pigs per pen and 8 pens per treatment for a total of 288 pigs. Within each group of 12 pens, all treatment groups were present making each set of 12 pens a replication within a block. Pigs used in the study were of commercial genetics (G-Performer sires × Fertilis 25 dams, Génétiporc, Alexandria, MN). Within the first wk of age, male pigs of similar weight were randomly assigned to either PC or IC treatment group. Those pigs in the PC treatment were castrated within the first week of life following farm standard operation procedures. Pigs were assigned to pens upon entering the grow-finish facility so that average pen weights for the three sex class treatments (PC, IC, and gilt) were approximately equal. Pigs assigned to the IC treatment group were administered the first dose of Improvest at 9 wk of age. The second dose was administered no earlier than 5 weeks after the first dose. Pigs assigned to the PC and gilt treatments did not receive placebo injections. Injections (2 ml subcutaneously administered in the post-articular region of the side of the neck) were administered by trained personnel at research farm. Quality assurance evaluation of IC pigs was completed approximately 2 weeks after second injection with Improvest. At this time any pigs displaying boar behavior including, but not limited to, riding, ejaculation, and enlarged testicles were given another 2 ml dose of Improvest.

Pigs had free access to feed and water. Diets were formulated similar to Puls et al. (2014) to meet or exceed the nutrient requirement of intact males over the weight range for the study as recommended by the National Research Council (2012). For more information on the live phase of the study refer to Puls (2013)

Randomization, Marketing, and Data Collection

Pigs were marketed over a period of 6 slaughter events at three target ages: 24, 26, and 28 wk. At each age, all three pigs in a pen were marketed. Pigs were weighed and tattooed on the belly and ham before shipment to the slaughter facility. At the facility, HCW and fat depth at the last rib were measured by University of Illinois Meat Science Laboratory personnel. From these two measurements, estimated percent lean was calculated with the following equation from Burson and Berg (2001):

$$Estimated\ Lean = \left[\frac{(25.568 + 0.503 \times (HCW, lb) - 21.348 \times (back\ fat\ depth, in))}{HCW, lb}\right] \times 100\% \ .$$

Fresh Belly Yield and Quality

Following slaughter and chilling, whole sparerib-in bellies from the right side of each carcass were collected for further evaluation at the University of Illinois Meat Science Laboratory. A total of 278 bellies were collected from the 288 originally targeted. Three bellies corresponded to pigs that died at the farm, one corresponded to a carcass that was retained at the slaughter facility; and the 7 remaining were removed from the study due to excessive trimming at fabrication. Upon arrival, bellies were fabricated as described by the North American Meat Processors Association (NAMP) into NAMP #408 pork belly (teat line attached without flank end squared – also referred as a natural fall belly) and NAMP #416 spareribs. Both pieces were weighed to calculate yields. After fabrication, natural fall bellies were laid flat on a table, covered, and allowed to equilibrate for 24 hours at 4°C.

Bellies were measured for length and width at the midpoint of the longitudinal and cross-sectional axis, respectively. Thickness was measured at 8 locations starting at the anterior end on the dorsal edge of the belly and working to the posterior end for measurements 1 through 4. Measurements 5 through 8 were started at the anterior end of the belly along the ventral edge working toward the posterior end of the belly. Belly flop distance was measured by draping a skin-side down belly over a stationary bar and measuring the distance the 2 skin edges. Next, a fat sample consisting of all three layers was collected from a single location on the dorsal edge of the anterior end of the belly to conduct a fatty acid profile analysis. Samples for fatty acids determination were prepared and analyzed with the methodology described by Tavárez et al. (2012). Data from fatty acids profile were used to calculate IV with the following AOCS (1998) equation: $\mathrm{IV} = \mathrm{C16{:}1}(0.95) + \mathrm{C18{:}1}(0.86) + \mathrm{C18{:}2}(1.732) + \mathrm{C18{:}3}(2.616) + \mathrm{C20{:}1}(0.785 + \mathrm{C22{:}1}(0.723)$.

After evaluation, bellies were individually vacuum packaged, boxed, and frozen (-20°C) for later processing. After frozen storage, bellies were thawed at 4°C for approximately 72 hours. Bellies were skinned using an air skinner to remove less than 3 mm of skin and tissue. Belly fat firmness using a digital durometer (Model RX-DD-000SRB; Electromagnetic Equipment Company, Inc., NY) equipped with a 0.5 inch probe. To determine fat firmness, the durometer was placed at the anterior end of the belly (fat side facing up), at approximately 7 cm from the anterior edge and midway from the dorsal to ventral edges of the belly. Bellies were boxed and shipped under refrigeration to manufacture bacon in a commercial facility (Sugar Creek Packing, Dayton, OH).

Bacon Processing

Upon arrival at the commercial facility, bellies were processed according to their standard operation procedures in the same manner described by Kyle et al. (2014) with the only exception that bellies were trimmed and squared (flank-end) after pressing rather than during fabrication. Flank ends were cut anterior to the inguinal lymph nodule. These pieces of flank were classified as ends. Additionally, slices that did not meet the facility criteria for number 1 slices were removed after slicing and classified as pieces. Sliced bellies were boxed individually maintaining anatomical orientation (blade to flank-end) and transported back to the University of Illinois Meat Science Laboratory for further evaluation.

Bacon Slice Characteristics

Sliced bellies were kept at approximately 4 °C during bacon slice counting and sample collection. Sliced weights were collected for each individual belly to determine bacon slicing yields. Three slicing yields were calculated by dividing the weight of number 1 slices (sliced weight) by green weight, cooked weight, and trimmed cooked weight. The first one was based on green weight, which accounted for variability due to raw materials and variability due to the manufacturing process. The second one was based on cooked weight, which removed the variability due to the manufacturing process. And the third one, based on trimmed cooked weight, which removed the variability due to trimming before slicing.

Slices were counted to determine the number of saleable slices. Then, sliced bellies were separated into five equal portions, modified from Robles (2004), based on anatomical orientation (zone A, B, C, D, and E) with zone A representing the anterior (blade) end, zone C the middle, and zone E representing the posterior end (flank-end). From the center of zones A, C, and E, two slices were removed. One slice was used to determine proximate composition (moisture and lipid) and the other one to conduct image analysis on each of the zones previously mentioned.

For proximate composition, slices were homogenized in a food processor and approximately 5 g of tissue were oven dried at 110° C for approximately 24 h. Dried samples were washed multiple times in an mixture of warm chloroform:methanol (4:1) as described by Novakofski et al. (1989) to determine total extractable lipid. Moisture and lipid were determined by weight differences after drying (moisture) and extraction (lipid).

For image analysis, slices were evaluated for total area, lean area, and secondary lean area with the methodology described by Boler et al. (2011b).

Statistical Analysis

The experimental unit to determine weight at slaughter, HCW, dressing percent, back fat depth, and estimated lean was the individual pig (N = 278). For all other traits including fresh and cured belly characteristics, individual bellies served as the experimental unit. Bellies were considered the experimental unit because one of the primary objectives of this study was to further processing characteristics such as cooked yield and bacon slicing yields where curing solution was applied to a belly. Data were analyzed in the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized complete block design. Therefore, the model included the fixed effect of treatments and the random effects of block and replicate within block. Homogeneity of variances was tested with Levene's test and Brown and Forsythe in the case of non-normal data with GLM. Normality of residuals was tested using the CAPABILITY procedure of SAS. Least squares means were generated using LSMEANS. Additionally, three sets of a priori contrast statements were obtained to compare treatments of interest (Table 4.2). The first set was used to test for linear and quadratic (curvilinear) effects of increasing time after second Improvest dose on IC barrows slaughtered at 24 wk of age. Within this age, pairwise comparisons were determined between IC barrows slaughtered at 4 wk after second Improvest dose (IC24-4) and PC barrows; and IC24-4 and gilts. The second set was used to test for linear effects of age at slaughtered on IC barrows, and PC barrows and gilts combined. Pairwise comparisons within pigs slaughtered at 26 and 28 wk of age were also determined. The third set was used to conduct pairwise comparison between 24-wk-old and 26-wk-old IC barrows, both slaughtered at 6 wk after second dose (IC24-6 vs. IC26-6); and 24-wk-old and 28-wk-old IC barrows, both slaughtered at 8 wk after second dose (IC24-8 vs. IC28-8). The third set was limited to determined differences in fresh belly thickness, flop distance, and IV value; and bacon slicibility (green and cooked weight), and lipid content. Pairwise comparisons were considered significantly different if $P \leq 0.05$. Comparisons were considered trending towards significance if $0.05 \leq P \leq 0.10$.

Data were presented in two sets of tables in accordance with the first two sets of contrast statements previously described. Therefore, Tables 4.3 through 4.6 refer to set 1, while Tables 4.7 through 4.10 refer to set 2.

RESULTS

Pigs Slaughtered at 24 wk of Age

Carcass Characteristics. Overall, carcass traits we unchanged with increasing time after second dose (L and Q; $P > 0.31$; Table 4.3). Weight at slaughter was greater in IC24-4 compared with PC barrows ($P < 0.01$) and gilts ($P < 0.01$). Weight of the carcass was greater in IC24-4 compared with gilts ($P < 0.01$), but similar to PC barrows ($P = 0.17$). Dressing percentage was decreased in IC24-4 compared with PC barrows ($P = 0.04$) and gilts ($P = 0.05$). Last rib backfat depth ($P > 0.70$) and estimated lean ($P > 0.40$) were similar between sex classes.

Belly Yield. Whole belly; both as absolute weight and as a percentage of HCW, natural fall belly weight, and spare ribs as a percentage of HCW were all unchanged ($P > 0.11$; Table 4.3) with increasing time after second dose. However, natural fall as a percentage of HCW tended to increase both linearly ($P = 0.10$) and curvilinearly ($P = 0.10$). Spare ribs weight also tended to increased curvilinearly ($P = 0.09$) with increasing time after second Improvest dose. Whole belly and natural fall weights were greater ($P < 0.05$) in IC24-4 compared with gilts, but similar (*P* > 0.67) to PC barrows. However, when expressed as a percentage of HCW these were similar among sex classes (*P* > 0.16). Spare ribs weight was greater in IC24-4 compared with PC barrows and gilts, but was similar when expressed as a percentage of HCW among sex classes (*P* > 0.29).

Fresh Belly Characteristics. Belly length, average thickness, and flop distance were all increased (*P* < 0.07), while width was reduced linearly (*P* < 0.01) with time after second Improvest dose (Table 4.3). From those, width and flop distance were increased curvilinearly (*P* < 0.06). Fat and lean (flank and medial) firmness were not affected linearly (*P* > 0.16) or curvilinearly (*P* > 0.14) with increasing time after second Improvest dose. Belly length (*P* > 0.93), fat firmness (*P* > 0.18), and lean firmness (*P* > 0.42) were all similar among sex classes. Belly width was greater in IC24-4 compared with PC barrows (*P* < 0.01) and gilts (*P* < 0.01). Average belly thickness and flop distance were reduced in IC24-4 compared to PC barrows (*P* < 0.01), but similar to gilts (*P* > 0.77).

Belly Adipose Tissue Fatty Acid Profile. Concentration of the essential fatty acids, linoleic acid and α-linolenic acid, was decreased (L and Q; *P* < 0.01) increasing time after second Improvest dose (Table 4.4). Due to this reduction, concentration of total PUFA was also reduced (L and Q; *P* = 0.01). Concentration of total SFA, total MUFA, and ratio of UFA:SFA was not altered (L and Q; *P* > 0.28) but ratio of PUFA:SFA was reduced (L and Q; *P* = 0.04) with increasing time after second Improvest dose in IC barrows. In a similar fashion, IV tended to decrease from 66.04 g/100g at 4 wk to 64.22 at 10 wk after second dose (L; *P* = 0.08).

Iodine value of belly adipose tissue was similar (*P* > 0.38) between IC barrows (66.04 g/100g), PC barrows (65.21 g/100g), and gilts (66.65 g/100g). Thus, with some exceptions, fatty acid concentration was generally similar between sex classes (*P* > 0.12). Concentrations of linoleic acid (*P* = 0.03) and total PUFA (*P* = 0.03) were 0.74 and 0.83 percentage units greater in IC24-4 compared with PC barrows.

Cured Belly Characteristics. Processing characteristics related to absolute weights, with some exceptions, were generally unchanged in IC barrows with time after second dose (L and Q; *P* > 0.12; Table 4.5). Weight of bacon ends was changed 0.31 kg from 4 to 8 wk, while only changing -0.03 kg from 8 to 10 wk after second dose (L and Q; *P* < 0.01). Due to the latter, slicing yields, when expressed as percent of green (Q; *P* = 0.05) and cooked (Q; *P* = 0.02) weight, increased in a similar fashion with increasing time after second Improvest dose. Weight of bacon pieces was reduced (L; *P* = 0.04) from 0.63 at 4wk to 0.47 kg at 10 wk after second dose. This reduction in bacon pieces resulted in a linear increased (2.73 percentage units; *P* = 0.01) in bacon slicing yields, when expressed as percent trimmed cooked weight. Green belly weight tended to increase in IC24-4 compared to gilts (6.42 vs. 5.80; *P* = 0.07), but was no different to PC barrows (6.42 kg; *P* = 0.42). The rest of processing characteristics related to absolute weights and yields were also no different (*P* > 0.13) between IC24-4 and PC barrows, with the exception of pump uptake being greater (*P* < 0.03) and weight of bacon ends being less (*P* < 0.01) in IC24-4 compared with PC barrows. In contrast, pump weight (*P* = 0.08), and cooked weight (*P* = 0.07) all tended to increase in IC24-4 compared to gilts. Additionally, weight of bacon ends was less (*P* < 0.01) in IC24-4 compared to gilts. Thus, trimmed cooked weight was heavier (*P* < 0.01) in IC24-4. However, due to heavier (*P* = 0.01) bacon pieces, slicing yields expressed as percentage of trimmed cooked weight, tended to be less (89.45 vs. 91.23%; *P* = 0.06) in IC24-4 compared to gilts.

Bacon Characteristics. The number of bacon slices with time after second dose followed a curvilinear (Q; *P* < 0.01) pattern as the change in magnitude from 4 wk to 6 wk was -11.57

units, while the change in magnitude from 6 to 10 wk was to 8.71 units (Table 4.6). Moisture content of bacon slice was decreased (L; $P < 0.01$) on average by 3.93 percentage units from 4 to 10 wk after second dose, while lipid content was increased (L; $P < 0.01$) on average by 5.48 percentage units in the same period of time. The number of bacon slices was greater in IC24-4 compared to gilts (161.64 vs. 145.77; $P < 0.01$), but was similar to PC barrows (155.04; $P = 0.12$). As expected, moisture content was on average 6.93 percentage units greater ($P < 0.01$) and lipid content was on average 9.28 percentage units less ($P < 0.01$) in bacon from IC24-4 compared to PC barrows, but similar to gilts ($P > 0.17$).

Bacon slice area, lean area, and secondary lean area; both expressed as absolute value and as proportion of slice area, were on average unaltered ($P > 0.11$; Table 4.6) with time after second dose. These traits were also no different ($P > 0.14$) between IC24-4, PC barrows, and gilts.

Pigs Slaughtered at 24, 26, and 28 wk of Age

Carcass Characteristics. In IC barrows weight at slaughter, HCW, dressing percent, and last rib back fat were all increased (L; $P < 0.03$), but estimated lean was decreased (L; $P = 0.02$) with age at slaughter (Table 4.7). Similar effects were observed in PC barrows and gilts combined, with the exception of dressing percent (L; $P < 0.26$) and last rib backfat depth (L; $P = 0.25$). At 26 and 28 wk of age, weight at slaughter and HCW were greater ($P < 0.01$) in IC barrows compared with gilts, although dressing percentage was similar ($P > 0.22$) between the two. Also at 26 and 28 wk estimated lean tended to decrease ($P < 0.10$) by 1.33 and 1.60 percentage units respectively in IC barrows compared with gilts. Weight at slaughter was greater ($P < 0.01$) at both 26 and 28 wk of age and HCW was greater ($P = 0.03$) at 26 wk in IC barrows compared with PC barrows. However, dressing percentage tended to decrease ($P = 0.10$) by 1.29

and 1.97 percentage units in IC barrows at both ages. Averaged over all ages, PC barrows had heavier slaughter weights (*P* < 0.01) and carcass weight (*P* < 0.01), similar dressing percentage (*P* = 0.23), and were fatter (*P* < 0.01) compared to gilts.

Belly Yield. In all sex classes, whole belly (*P* < 0.04) and natural fall belly (*P* < 0.05) were increased linearly with age at slaughter, when expressed either on a weight basis or as a percentage of HCW (Table 4.7). Additionally, spare ribs were heavier (L; *P* < 0.01) with age, but unaltered (L; *P* > 0.35) when expressed as a percentage of HCW. At 26 and 28 wk, whole belly (*P* < 0.05) and spare ribs (*P* < 0.10) were heavier in IC barrows compared to PC barrows and gilts. Also at 26 and 28 wk, the sub-primal natural fall belly was 1.00 and 1.15 kg heavier (*P* < 0.01) in IC barrows compared to gilts but was similar (*P* > 0.11) to PC barrows. At 28 wk whole belly and natural fall belly, both as a percent of HCW, were 0.94 and 0.69 percentage units greater (*P* < 0.04) in IC barrows compared with gilts. Averaged over all ages, PC barrows had greater (*P* < 0.01) whole belly and natural fall belly weights compared to gilts. However, when expressed as a percent of HCW, whole belly was unchanged (*P* = 0.23) but natural fall was increased (*P* = 0.05) in PC barrows.

Fresh Belly Characteristics. In all sex classes belly length, average thickness, and flop distance were all increased (L; *P* < 0.01), but fat firmness was unchanged (L; *P* > 0.51) with age at slaughter (Table 4.7). Belly width was not altered (L; *P* = 0.64) with age in IC barrows, although was increased (*P* < 0.01) in PC barrows and gilts combined. At 26 wk, belly length was greater (*P* = 0.01) in IC barrows compared with gilts; while width tended to increase (*P* = 0.06) compared to PC barrows. Although average thickness was similar (*P* > 0.42) among sex classes; bellies were softer (25.39 vs. 32.14 cm; *P* = 0.01) in IC barrows compared with PC barrows, but were similar (26.51 cm; *P* = 0.69) to gilts. At 28 wk, bellies tended to be longer (*P* < 0.09) in IC barrows compared with PC barrows and gilts. Bellies were thicker (4.71 vs. 4.10 cm; *P* < 0.01) and firmer (35.54 vs. 25.91 cm; *P* < 0.01) in IC barrows compared with gilts, but were similar (4.66 and 35.85 cm; *P* > 0.61) to PC barrows. At 26 and 28 wk, fat firmness was no different (*P* > 0.50) among sex classes. Averaged over all ages, belly length and width were similar (*P* > 0.31) between PC barrows and gilts. However, bellies were thicker (*P* < 0.01) and firmer (*P* < 0.01) in PC barrows.

Belly Adipose Tissue Fatty Acid Profile. The increased fatness (increased back fat and reduced estimated lean) observed in IC barrows was reflected in the overall fatty acid profile of the belly adipose tissue (Table 4.8). From 24 to 28 wk of age, total SFA were increased (L; *P* = 0.03) by 2.06 percentage units while total PUFA were decreased (L; *P* < 0.01) by 1.40 percentage units. Consequently, ratios of UFA: SFA and PUFA:SFA were also decreased (L; *P* < 0.04), which ultimately resulted in IV being reduced (L; *P* < 0.01) from 66.04 to 63.21 g/100g. In PC barrows and gilts combined, the fatty acid profile was unchanged (*P* > 0.13) with age at slaughter. This was not surprising as back fat thickness was generally not altered with age at slaughter in PC barrows and gilts combined.

At 26 wk of age, total SFA were increased (*P* = 0.04) by 1.96 percentage units and total PUFA (*P* < 0.01) were decreased by 1.18 percentage units in IC barrows compared with gilts. Thus, ratios of UFA:SFA (*P* = 0.06) and PUFA:SFA (*P* < 0.01) along with IV (64.92 vs. 67.44 g/100g; *P* = 0.01) were reduced in IC barrows. The above differences between IC barrows and gilts were persistent at 28 wk of age. Fatty acid composition was not different (*P* > 0.13) between IC barrows and PC barrows at 26 wk. However, at 28 wk total SFA tended to increase (*P* = 0.07) by 1.74 percentage units while MUFA tended to decrease (*P* = 0.08) by 1.48 percentage units, but IV was similar (63.21 vs. 64.76 g/100g; *P* = 0.56) between IC barrows and

PC barrows. Averaged over all ages, PC barrows had more total SFA increased ($P < 0.01$) and reduced ($P < 0.01$) total PUFA, UFA:SFA, PUFA:SFA, and IV compared with gilts.

Cured Belly Characteristics. The observed increased in carcass weights over slaughter ages was reflected in belly processing characteristics. In IC barrows and in PC barrows and gilts combined, green weight, pump weight, cooked weight, cooked yield, trimmed cooked weight, and sliced weight were all increased (L; $P < 0.01$) with age at slaughter (Table 4.9). Pump uptake tended to decreased by 0.79 percentage units (L; $P = 0.06$) in IC barrows, but unchanged (L; $P = 0.65$) in PC barrows and gilts combined over time. This was not surprising given the increased in fatness observed in IC barrows over slaughter ages. It is though that leaner raw materials generally uptake more cure solution than their fatter counterparts. Bacon slicing yields expressed as a percent of green and as percent cooked weight, were increased (L; $P < 0.01$) by 4.04 and 3.06 percentage units with age in IC barrows. In PC barrows and gilts combined, slicing yields expressed as a percent of green weight tended to increase (L; $P < 0.06$) by 1.55 percentage units; but unchanged (L; $P = 0.33$) by 0.72 percentage units when expressed as percent of cooked weight. Slicing yields expressed as a percent of trimmed cooked weight were not altered (L; $P > 0.12$) with age between IC barrows, PC barrows, and gilts.

At 26 wk, green bellies were 0.80 kg heavier ($P < 0.02$) in IC barrows compared with gilts. This advantage in green belly weight, as a result of heavier carcasses, persisted throughout processing as pump weight, cooked weight, trimmed cooked weight, and sliced weight were also heavier ($P < 0.04$), while pump uptake and cooked yield were similar ($P > 0.35$) between IC barrows and gilts. These advantages in weight coupled with less losses at trimming and slicing, reduced weight of bacon ends ($P < 0.01$) and similar ($P = 0.88$) bacon pieces, resulted in a trend to increase ($P < 0.09$) both green and cooked slicing yields by 2.36 and 1.36 percentage units respectively in IC barrows compared with gilts. These advantages in cured belly characteristics IC barrows compared with gilts were persistent (P < 0.01) at 28 wk of age. On the contrary, cured belly characteristics were no different (P > 0.11) between IC barrows and PC barrows at 26 wk. however, at 28 wk, green weights, pump weights, and cooked weights tended to increase (P < 0.10) in IC barrows compared with PC barrows. Trimmed cooked weight and sliced weight were heavier (P < 0.01) in IC barrows. Slicing yields expressed as percent of green (P = 0.01) and cooked (P < 0.01) weight were greater 3.09 and 3.15 percentage units in IC barrows compared with PC barrows. However, slicing yields were reduced (P = 0.02) when expressed as percent of trimmed cooked weight in IC barrows compared with PC barrows. Averaged over all ages, green weight, pump weight, cooked weight, trimmed cooked weight, and sliced weight were all greater (P < 0.01) in PC barrows compared to gilts. Although, pump uptake was reduced (P < 0.02), cooking yield was increased (P = 0.05) in PC barrows. Slicing yields were all similar (P > 0.13) between PC barrows and gilts.

Bacon Characteristics. In IC barrows and in PC barrows and gilts combined, number of bacon slices was increased (L; P < 0.01) with age (Table 4.10). In IC barrows, moisture content was decreased (L; P < 0.01) on average by 6.64 percentage units while lipid content was increased (L; P < 0.01) on average by 9.01 percentage units from 24 to 28 wk of age. On the contrary, moisture and lipid content were generally not altered (L; P > 0.11) in PC barrows and gilt combined in the same period of time. This was consistent with the rates of fat deposition observed in the backfat and the fatty acid composition of the belly adipose tissue reported above. At 26 and 28 wk, number of slices was increased in IC barrows compared with PC barrows (P < 0.01) and gilts (P < 0.01). Bacon composition was similar (P > 0.24) between IC barrows and gilts. However, on average moisture content was 4.36 and 2.7 percentage units greater (P < 0.09) and lipid content was 5.93 and 3.59 percentage units less (*P* < 0.10) in IC barrows compared with PC barrows at 26 and 28 wk respectively. Averaged over all ages, bacon slices were fatter (more lipid and less moisture; *P* < 0.01) regardless of location in PC barrows compared to gilts.

In all sex classes, slice area was increased (L; *P* < 0.01) with age at slaughter regardless of location in the belly (Table 4.10). From 24 to 26 wk of age, lean area was increased (L; *P* = 0.03) on average by 5.84 cm^2, but reduced (L; *P* = 0.05) from 0.59 to 0.54 when expressed as a proportion of slice area in IC barrows. Both traits were unaltered (L; *P* > 0.15) in PC barrows combined with gilts.

At 26 and 28 wk, slice area was on average bacon slices no different (*P* > 0.17) between IC barrows and PC barrows. However, lean area, expressed as absolute value and as a proportion of slice area, was greater (*P* < 0.03) in IC barrows compared with PC barrows at 26 wk. Lean area was also greater (*P* = 0.04) at 28 wk in IC barrows compared with PC barrows. At both slaughter ages, bacon slice characteristics were generally similar (*P* > 0.23) between IC barrows and gilts, with the exception of slice area being greater (*P* < 0.01) in IC barrows at 28 wk. Averaged over all ages, PC had greater (*P* < 0.01) slice area, but less (*P* < 0.08) total lean area and secondary lean areas both expressed as absolute value and a percent of slice area, than gilts on average bacon slice.

Comparative Effects of Increasing Time after Second Improvest Dose and Age at Slaughter

In the present study, 4 groups of IC barrows were selected to compare the effects of time after second Improvest dose with those of increasing age at slaughter on certain fresh and cured belly traits. Therefore, IC barrows slaughtered at a common time after second but differing in age at slaughter were compared (IC24-6 vs. IC26-6 and IC24-8 vs. IC28-8). As far as fresh belly characteristics, thickness was 0.24 and 0.53 cm^2 greater ($P < 0.01$) in IC26-6 and IC28-8 compared with IC24-6 and IC24-8 (Fig. 4.1.A). However, flop distance was similar (24.53 vs. 25.39 cm; $P = 0.75$) between IC24-6 and IC26-6; but reduced (29.70 vs. 35.54 cm; $P = 0.03$) in IC24-8 compared with IC28-8 (Fig. 4.1.B). Iodine value and bacon lipid content was not different ($P > 0.34$; Fig.4.1.C, D) between the 4 groups of IC barrows. Bacon slicing yields, both as a percent of green (Fig.4.1.E) and cooked (Fig.4.1.D) belly weight, were increased ($P < 0.01$), in IC26-6 and IC28-8 compared with IC24-6 and IC24-8, respectively.

DISCUSSION

Belly quality can be evaluated in several ways including yields, fresh characteristics, fat quality, and characteristics of bacon including processing yields. Limited data regarding IC barrows indicate that fresh characteristics such as belly thickness and flop distance in IC barrows have been reported as equal or superior to gilts, but inferior to PC barrows (Boler et al., 2011a; Boler et al., 2012; Kyle et al., 2014; Lowe et al., 2014). Whereas, commercial bacon slicing yields in IC barrows have been reported as inferior to PC barrows and gilts (Kyle et al., 2014; Tavárez et al., 2014a). However, increasing age at slaughter to allow for increased time between second dose and slaughter improved both fresh and cured belly characteristics in IC barrows (Boler et al., 2012; Tavárez et al., 2014a). These improvements are generally driven by a dramatic increase in feed intake observed in IC barrows within the 7 to 14 d following the second dose of Improvest (Dunshea et al., 2013). The complication with these results is that one cannot separate the effects of age from those of time after second dose. Our study not only intended to further quantify both the effects of age and time after second dose but also to differentiate their overall contribution to fresh belly characteristics and commercial bacon production in IC barrows when compared with PC barrows and gilts.

Effects of Increasing Time after Second Dose

In the present study, carcass weight, leanness and belly weights were all unchanged with increasing time after second dose in IC barrows slaughtered at a common age. However, the proportion of the carcass made up of the sub-primal natural fall belly was increased along with improvements in fresh belly characteristics including thickness, flop distance and IV value. To our knowledge, a report by Lealiifano et al. (2011) is the only other study that has reported the effects of time after second dose independent of age in IC barrows. In that study, weight of the carcass and level of fatness were increased linearly with time after second dose from 2 to 6 wk. Pigs from that study were slaughter at a relative younger age (22 vs. 24 wk) and lighter weights (106.3 vs. 137.5 kg) compared to ours. In contrast, the lack of linear response in our study may be due to the difference in initial time point of slaughter. In Lealiifano et al. (2011) carcass traits were initially reported at 2 wk after second dose, whereas in our study traits were reported at 4 wk. As feed intake increased in IC barrows at 7 to 14 d after second dose (Dunshea et al., 2013), changes in carcass composition may not be evident until more than 2 wk after second dose. Thus, the effects of increasing the time between second dose and slaughter are further magnified when the initiation point of data reporting is 2 wk.

The shape of the mean response in bacon slicing yields (green and cooked weight) was described as curvilinear with increasing time after second Improvest dose. This was because the maximum response was observed at 4 wk, while declining at 6 wk, followed by a steady incline at 8 and 10 wk after second dose. The reason behind these results in slicing yields may be attributed to various factors. Weight of bacon ends was gradually increased with time after second dose (From 0.51 kg at 4 wk to 0.79 kg at 10 wk) and this was in part due to bellies becoming longer. While at the same time, weight of bacon pieces was gradually reduced. This reduction in pieces was related to the previously mentioned improvements in belly thickness, flop distance, and IV value with increasing time after second dose. All of those changes in belly characteristics occurred, while green weights remained constant over time. Additionally, changes in bacon composition were observed with time after second dose, as bacon was fatter with time at all location when measured chemically. For the most part, the magnitude of these differences was also observed in the image analysis, but due to larger variation associated with the assay; these differences were not detected statistically.

Effects of Increasing Age at Slaughter

From 24 to 28 wk of age, weight at slaughter was increased in all pigs as expected. Fatness, as measured by last rib fat depth was increased in IC barrows with age at slaughter, but marginally increased in PC barrows and gilts combined. Initially at 24 wk belly weights and yields were no different, but as carcass became heavier, bellies were also heavier in IC barrows compared to both PC barrows and gilts at 26 and 28 wk. The superior weight at slaughter and carcass weight in IC barrows has been reported in numerous studies (Asmus et al., 2014; Boler et al., 2014; Dunshea, 2010; Dunshea et al., 2013; Lowe et al., 2014). These are typically attributed to a marked increase in feed intake at approximately 7 to 14 d after the second dose leading to greater rates of gain when compared to PC barrows (Dunshea et al., 2013).

Fresh belly characteristics including thickness and flop distance were improved in all pigs with age at slaughter. Especially in IC barrows as these characteristics became more similar to PC barrows and superior to gilts at 28 wk. These improvements in fresh characteristics with time after second dose have been reported in numerous studies (Boler et al., 2012; Tavárez et al., 2014a; Tavárez et al., 2014b). The underlying cause for these improvements is thought to be increased *de novo* synthesis of fat as a consequence of increase in feed intake. This increase in feed intake with a concomitant increased in fat deposition has been previously documented in IC barrows (Asmus et al., 2014; Dunshea et al., 2008; Dunshea et al., 2001; Lealiifano et al., 2011). The main fatty acids produced from *de novo* synthesis are the saturated fatty acids palmitic and stearic acids (Mersmann and Smith, 2005). Thus, as the pigs continue to deposit fatty acids and adipose tissue fills with triglycerides from *de novo* synthesis, the proportion of unsaturated fatty acids in adipose is reduced, especially linoleic acid (Wood et al., 2008). This *de novo* synthesis was reflected in increased bacon lipid content (from 28.0% at 24 wk to 37.0% at 28 wk IC barrows) and reduced IV of belly adipose tissue (from 66.04 g/100g at 24 wk to 63.21 g/100g at 28 wk in IC barrows). While in PC barrows and gilts combined, bacon lipid content (from 33.8% at 24 wk to 37.2% at 28 wk) and IV (from 65.9 g/100g at 24 wk to 66.5 at 28 wk) remained unchanged.

In the present study, slicing yield as percent of green weight was improved over slaughter ages in all pigs. But, when expressed as percent of cooked weight only in IC barrows were improved. Both yields were similar between barrows at slaughtered at 24 and 26 wk of age, but greater at 28 wk in IC barrows compared to PC barrows and gilts. This is the first study to report equal or superior slicing yields in favor of IC barrows. Tavárez et al. (2014a) reported similar improvements in both IC barrows and PC barrows over two slaughter ages, although slicing yields in PC barrows (90.4%) were superior to IC barrows (85.0%). In another study, Kyle et al. (2014) reported that slicing yields in IC barrows were 4.8 and 4.5 percentage units less than in PC barrows and gilts, respectively. This disagreement between studies may be related to differences in slaughter weights and ultimately green belly weights. In our study, slaughter weights in IC barrows were on average 8.9 kg and 15.30 kg heavier and green weights were 2.6 kg and 4.6 kg heavier than PC barrows and gilts, whereas in Tavárez et al. (2014a) slaughter weights in IC barrows were 3.6 kg heavier but green weights were 0.4 kg lighter than PC barrows, and in Kyle et al. (2014) slaughter weights in IC barrows were 2.6 kg and 4.0 kg heavier and green weights were 0.2 kg lighter and 0.1 kg heavier than PC barrows and gilts. The latter would suggest that IC barrows most likely need to be raised to heavier finishing weights compared to PC barrows and gilts to obtain heavier bellies and consequently bacon slicing yields won't be compromise.

In the present study, to evaluate the effects of increasing age at slaughter, pigs were slaughtered every two weeks, from 24 through 28 wk of age. Furthermore 24, 26, and 28-wk-old IC barrows were slaughtered at 4, 6, and 8 wk after second dose to mimic a "long on space" marketing strategy, common to US the pork industry. However, a possible limitation is that within each pen, pigs were raised in groups of 3 with 0.96 m^2 per pig as supposed to commercial conditions where pigs are raised in groups of 22 with 0.64 m^2 per pig. Additionally, pigs were sent to market upon reaching a target age, as supposed to an ending live weight. Thus, at each slaughter date the whole pen was sent to market rather than removing the heaviest pigs and leaving the rest for the next marketing date. As a result, 26 and 28-wk-old pigs were considerably heavier than typical in commercial operations. Therefore, our results should be interpreted having these considerations in mind and knowing that the US pork industry is transitioning to heavier finishing weights every year.

Comparative Effects of Time after Second dose and Age at slaughter

In the present study, improvements in fresh belly and bacon processing characteristics have already been established due to increasing both the time between second Improvest dose and slaughter and age at slaughter. Our final objective was to determine which of those two contributed to a greater effect on fresh and cured belly characteristics in IC barrows. To accomplish this objective four groups of IC barrows were selected and then assigned to one of two times after second dose (6 or 8 wk). Within each time after second dose, age at slaughter was altered (24 wk-old and 26 wk-old or 24 wk-old to 28 wk-old) and the effects were measured on specific traits of importance in fresh and cured bellies. In IC barrows slaughtered at older ages belly thickness, flop distance, and slicing yields were superior. Therefore, increasing age at slaughter contributed to greater effects on specific belly traits than increasing time after second dose alone. These differences may be driven by body weight and ultimately belly green weights, as 24-wk-old IC barrows were considerably lighter than 26 and 28-wk-old IC barrows.

CONCLUSIONS

In conclusion fresh belly quality traits including thickness, flop distance, and IV were all improved with increasing time after second Improves dose in IC barrows slaughtered at 24 wk of age. These improvements occurred while slaughter weight and fatness were unchanged over time, but natural fall belly expressed as a percent of HCW was increased in IC barrows. Bacon slicing yields were also improved with increasing time after second dose, but IC24-4 were similar to PC barrows and gilts. Increasing age at slaughter from 24 to 28 wk, increased fat deposition (last rib and bacon) and reduced IV in IC barrows, but not in PC barrows and gilts combined. However, IC barrows had similar bacon lipid content to gilts, but less than PC barrows at all slaughter ages. Bacon slicing yields both, as a percent of green weight and as a percent of cooked weight, were improved in all pigs. However, these yields were superior in IC barrows compared to PC barrows and gilts at 28 wk. Increasing both the time second Improvest dose and slaughter and age at slaughter improved overall fresh and cured belly characteristics. However, increasing age at slaughter had a greater marginal impact on fresh and cured belly characteristics.

Data from this study suggest that at heavier (> 135 kg) finishing weights bellies from IC barrows become more similar to that of PC barrows and superior to gilts and this ultimately leads to improvements in bacon slicing yields. Additionally, increasing both the age at slaughter and the time between second Improvest dose and slaughter is crucial to accomplish these improvements.

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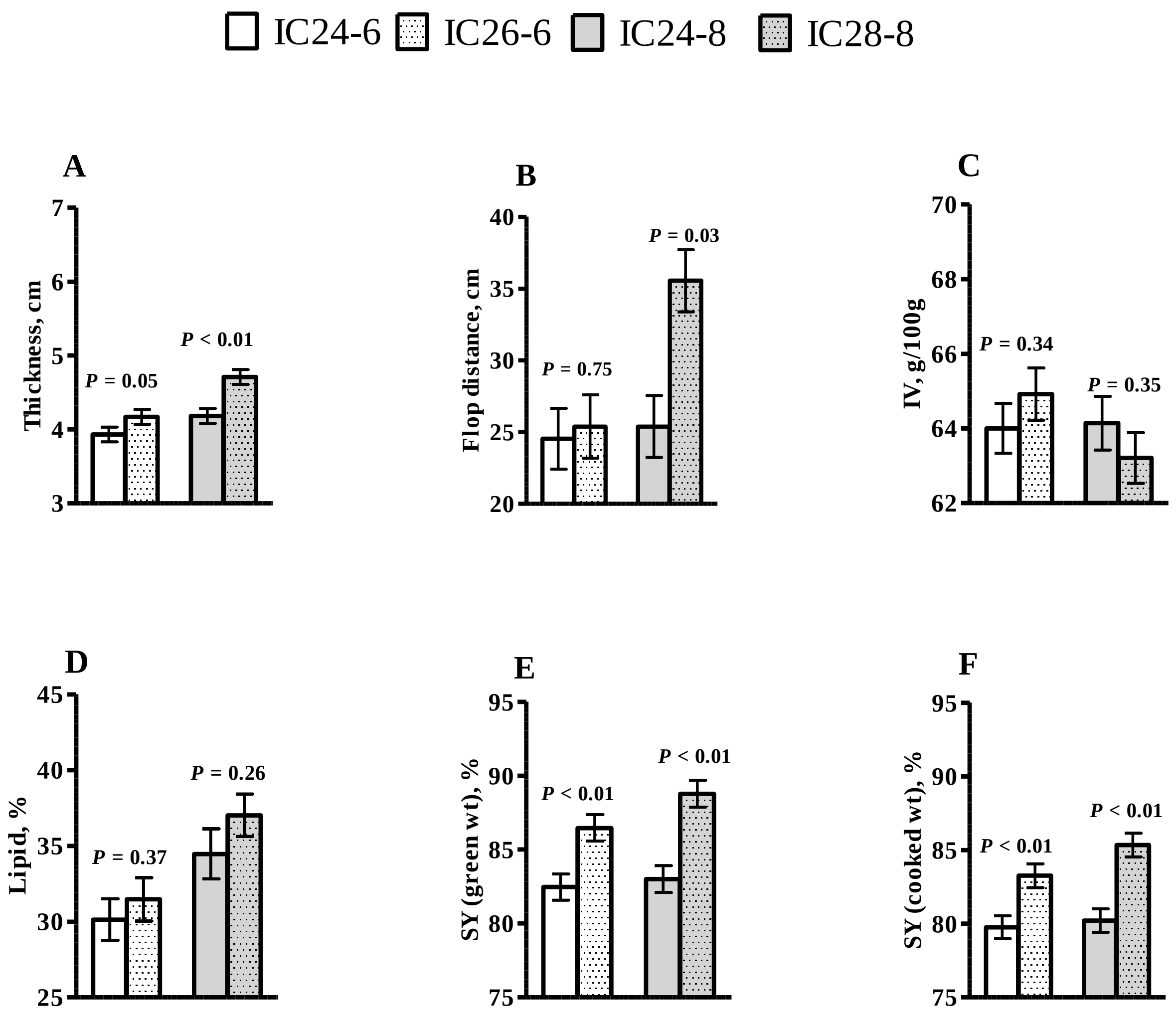
FIGURES

Figure 4.1. Comparative effects of time after second Improvest (GnRF Analog, Zoetis, Kalamazoo, MI) dose and increasing age at slaughter on belly thickness (A), flop distance (B), IV value (C), bacon lipid content (D), and slicing yields expressed as percent of green (E) and cooked (F) weight. In 24-wk-old IC barrows slaughtered at 6 (IC24-6) and 8 (IC24-8) wk after second dose; and 26 and 28-wk-old IC barrows slaughtered at 6 (IC26-6) and 8 wk (IC28-8) after second dose. Single df contrast were used to test statistical differences within each time after second dose.



TABLES

Table 4.1. Arrangement of treatments during live phase of study*

		Improvest[1]				
Trt[2]	Sex class	Age at 1st dose, wk	Age at 2nd dose, wk	Age at slaughter, wk	Time after second dose, wk	Pigs, #
IC24-4	IC barrows	9	20	24	4	24
IC24-6	IC barrows	9	18	24	6	24
IC24-8	IC barrows	9	16	24	8	24
IC24-10	IC barrows	9	14	24	10	24
PC24	PC barrows	.	.	24	.	24
G24	Gilt	.	.	24	.	24
IC26-6	IC barrows	9	20	26	6	24
PC26	PC barrows	.	.	26	.	24
G26	Gilt	.	.	26	.	24
IC28-8	IC barrows	9	20	28	8	24
PC28	PC barrows	.	.	28	.	24
G28	Gilt	.	.	28	.	24
						288

[1]Improvest (GnRF analog; Zoetis, Kalamazoo, MI)

[2]Treatment

*Adapted from Puls (2013)

Table 4.2. Sets of contrast statement used during data analysis*

Set	#	1 DF contrast statement	Age at slaughter, wk
1	1	Linear (L) effect of time after second Improvest dose	24
	2	Quadratic (Q) effect of time after second Improvest dose	24
	3	IC24-4 vs. PC[1]	24
	4	IC24-4 vs. gilt	24
2	5	L effect of time after second Improvest dose coupled with age in IC barrow	24, 26, 28
	6	L effect age in PC and gilt (combined)	24, 26, 28
	7	IC26-6 vs. PC	26
	8	IC26-6 vs. gilt	26
	9	IC28-8 vs. PC	28
	10	IC28-8 vs. gilt	28
	11	PC vs. gilt	24, 26, 28
3	12	IC24-6 vs. IC-26-6	24, 26
	13	IC24-8 vs. IC-28-8	24, 28

[1]Physically castrated barrow

*IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI). The first at 9 wk and the second at 20, 18, 16, or 14 wk of age according to IC treatment group

Table 4.3. Effect of time after second Improvest dose on carcass characteristics and belly yield[1] and quality of finishing pigs slaughtered at 24 wk of age

			Time after second Improvest[2] dose, wk					*Single DF contrasts*			
Item	PC24[*]	G24[*]	IC24-4	IC24-6	IC24-8	IC24-10	SEM	L[3]	Q[3]	IC24-4 vs. PC24	IC24-4 vs. G24
Wt. at slaughter, kg	131.83	124.33	139.73	135.10	136.61	138.50	2.07	0.80	0.11	<0.01	<0.01
HCW, kg	98.23	92.84	101.58	98.35	100.21	101.71	1.80	0.77	0.18	0.17	<0.01
Dressing, %	74.51	74.61	72.59	72.71	73.38	73.47	0.63	0.31	0.98	0.04	0.05
Last rib backfat depth, mm	22.79	21.19	21.96	20.65	22.24	23.47	1.88	0.40	0.31	0.70	0.75
Estimated Lean[4], %	52.51	53.19	52.45	53.08	52.47	52.02	0.66	0.50	0.27	0.95	0.40
Whole belly, kg	9.38	8.81	9.51	9.37	9.77	9.69	0.21	0.32	0.90	0.67	0.02
% of HCW	19.06	18.84	18.69	19.04	19.49	19.19	0.26	0.11	0.23	0.33	0.70
Natural fall belly, kg	7.75	7.24	7.78	7.74	8.06	7.94	0.19	0.33	0.84	0.93	0.05
% of HCW	15.74	15.47	15.28	15.72	16.08	15.74	0.24	0.10	0.10	0.16	0.55
Spare ribs, kg	1.63	1.57	1.73	1.63	1.71	1.74	0.04	0.50	0.09	0.05	<0.01
% of HCW	3.31	3.36	3.41	3.32	3.41	3.45	0.07	0.47	0.33	0.29	0.62
Length, cm	73.16	73.08	73.08	74.08	75.10	74.49	0.64	0.07	0.21	0.93	0.99
Width, cm	27.84	28.16	29.96	28.55	28.05	28.11	0.39	<0.01	0.06	<0.01	<0.01
Thickness, cm	4.15	3.82	3.85	3.93	4.18	4.04	0.09	0.03	0.18	0.01	0.83
Flop distance, cm	30.56	20.66	21.41	24.53	29.70	25.37	2.20	0.04	0.05	<0.01	0.77
Fat firmness[5]	68.00	68.13	63.76	64.54	69.99	66.86	2.35	0.16	0.40	0.20	0.18

[1]Whole belly, natural fall, and spare ribs wt. were multiply by 2 to calculate yield as percentage of HCW

[2]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI). The first at 9 wk and the second at 20, 18, 16, or 14 wk of age according to IC treatment group

[3]Linear (L) and quadratic (Q) effects of time after second Improvest dose

[4]Estimated Lean = [(25.568 + 0.503 × (HCW, lb) - 21.348 × (last rib backfat depth, in)) ÷ HCW, lb] × 100%

[5]Collected with a digital durometer at the anterior end of the belly (fat side facing up), at aproximatelly 7 cm from the anterior edge and midway from the dorsal to ventral edges

[*]Physically castrated barrows and gilts slaughtered at 24 wk of age

Table 4.4. Effect of time after secon Improvest dose on belly adipose tissue fatty acid profile of finishing pigs slaughtered at 24 wk of age (as % of total lipid)

			Time after second Improvest[1] dose, wk					*Single DF contrasts*			
Item	PC24[*]	G24[*]	IC24-4	IC24-6	IC24-8	IC24-10	SEM	L[2]	Q[2]	IC24-4 vs. PC24	IC24-4 vs. G24
Myristic acid (C14:0), %	1.36	1.34	1.32	1.32	1.37	1.32	0.03	0.75	0.27	0.02	0.53
Palmitic acid (C16:0), %	22.83	22.13	22.60	23.30	23.37	23.02	0.42	0.46	0.18	0.67	0.41
Palmitoleic acid (C16:1), %	3.19	3.07	3.34	3.13	3.28	2.97	0.09	0.01	0.56	0.20	0.03
Margaric acid (C17:0), %	0.35	0.34	0.34	0.32	0.30	0.32	0.02	0.30	0.40	0.64	0.69
Stearic acid (C18:0), %	9.96	9.90	10.06	10.75	10.11	10.87	0.32	0.17	0.91	0.80	0.70
Oleic acid (C18:1n-9), %	48.15	47.86	47.40	47.28	47.97	47.50	0.66	0.68	0.75	0.32	0.55
Linoleic acid (C18:2n-6), %	10.77	11.76	11.51	10.58	10.23	10.67	0.31	0.01	<0.01	0.03	0.48
α-linolenic acid (18:3n-3), %	0.47	0.50	0.48	0.45	0.43	0.45	0.02	<0.01	0.02	0.12	0.64
Arachidic acid (C20:0), %	0.18	0.19	0.17	0.18	0.18	0.18	0.005	0.17	0.35	0.34	0.01
Gadoleic acid (C20:1n-9), %	1.01	1.00	0.97	0.96	1.03	1.02	0.04	0.07	0.85	0.31	0.44
Eicosadienoic acid (C20:2n-6), %	0.52	0.58	0.54	0.50	0.50	0.52	0.01	0.22	0.03	0.19	0.03
Arachidonic acid (C20:4n-6), %	0.21	0.24	0.21	0.22	0.21	0.21	0.01	0.32	0.51	0.95	0.05
Other fatty acids, %	1.00	1.07	1.04	0.97	0.98	0.89	0.05	0.18	0.52	0.50	0.60
Total SFA[4], %	34.76	34.03	34.57	36.00	35.43	35.79	0.70	0.30	0.42	0.83	0.56
Total MUFA[4], %	52.86	52.44	52.20	51.83	52.74	51.94	0.72	0.96	0.72	0.43	0.77
Total PUFA[5], %	12.38	13.54	13.21	12.18	11.79	12.26	0.35	0.01	<0.01	0.03	0.41
UFA:SFA ratio[6]	1.89	1.98	1.92	1.79	1.84	1.81	0.06	0.28	0.38	0.72	0.50
PUFA:SFA ratio[7]	0.36	0.41	0.39	0.34	0.34	0.35	0.01	0.04	0.04	0.14	0.28
Iodine value[8], g/100g	65.21	66.65	66.04	64.01	64.14	64.22	0.72	0.08	0.12	0.38	0.52

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI). The first at 9 wk and the second at 20, 18, 16, or 14 wk of age according to IC treatment group

[2]Linear (L) and quadratic (Q) effects of time after second Improvest dose

[3]Total SFA = ([C14:0] + [C15:0] + [C16:0] [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration

[4]Total MUFA = ([C14:1] + [C16:1] + [C17:1] + [C18:1n-9] + [C20:1n-9] + [C22:1n-9]); brackets indicate concentration

[5]Total PUFA = ([C18:2n-6] + [C18:3n-6] + [C18:3n-3] + [C20:2n-6] + [C20:3n-6] + [C20:4:1n-6] + [20:3n-3] + [20:5n-3] + [22:2n-6] + [22:5n-3] + [22:6n-3])

[6]UFA:SFA ratio= (total MUFA + total PUFA) ÷ total SFA

[7]PUFA:SFA ratio= total MUFA ÷ total SFA

[8]Calculated as IV 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) (AOCS, 1998)

[*]Physically castrated barrows and gilts slaughtered at 24 wk of age

Table 4.5. Effect of time after second Improvest dose on cured belly characteristics of finishing pigs slaughtered at 24 wk of age

Item	PC24*	G24*	IC24-4	IC24-6	IC24-8	IC24-10	SEM	L[2]	Q[2]	IC24-4 vs. PC24	IC24-4 vs. G24
			Time after second Improvest[1] dose, wk					*Single DF contrasts*			
Thawed wt, kg	7.53	7.00	7.53	7.50	7.82	7.79	0.19	0.19	0.99	0.98	0.04
Purge loss[3], %	2.86	3.42	3.20	3.09	3.00	2.72	0.32	0.26	0.78	0.40	0.60
Green wt, kg	6.42	5.80	6.23	6.25	6.58	6.45	0.17	0.19	0.65	0.42	0.07
Pump wt, kg	7.17	6.54	7.07	7.04	7.38	7.26	0.20	0.20	0.70	0.55	0.08
Pump uptake, %	11.66	12.45	12.54	12.54	12.13	12.56	0.31	0.79	0.46	0.03	0.82
Cooked wt, kg	6.62	5.95	6.42	6.47	6.81	6.68	0.19	0.18	0.63	0.42	0.07
Cooked yield, %	103.17	102.64	102.97	103.35	103.43	103.53	0.29	0.20	0.64	0.63	0.43
Bacon ends wt, kg	0.69	0.69	0.51	0.81	0.82	0.79	0.05	<0.01	0.01	<0.01	<0.01
Trimmed cooked wt, kg	5.94	5.27	5.91	5.66	5.99	5.91	0.18	0.67	0.62	0.92	<0.01
Bacon pieces wt, kg	0.53	0.46	0.63	0.50	0.53	0.47	0.05	0.04	0.50	0.15	0.01
Sliced wt, kg	5.40	4.82	5.29	5.16	5.47	5.50	0.17	0.20	0.62	0.62	0.04
Slicing yield (green wt)**, %	83.76	82.98	84.73	82.46	83.00	84.01	0.94	0.27	0.05	0.40	0.14
Slicing yield (cooked wt)**, %	81.16	80.83	82.27	79.76	80.21	81.18	0.83	0.12	0.02	0.28	0.17
Slicing yield (trimmed cooked wt)**, %	90.84	91.23	89.45	91.11	91.19	92.18	0.73	0.01	0.62	0.13	0.06

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI). The first at 9 wk and the second at 20, 18, 16, or 14 wk of age according to IC treatment group

[2]Linear (L) and quadratic (Q) effects of time after second Improvest dose

[3]Purge loss = [(natural fall wt – thawed wt) ÷ natural belly wt] × 100

*Physically castrated barrows and gilts slaughtered at 24 wk of age

**Slicing yields were calculated by dividing the weight of number 1 slices (sliced weight) by green, cooked, and trimmed cooked wt

Table 4.6. Effect of time after secon Improvest dose on bacon characteristics of finishing pigs slaughtered at 24 wk of age

Item	PC24*	G24*	Time after second Improvest[1] dose, wk: IC24-4	IC24-6	IC24-8	IC24-10	SEM	*Single DF contrasts*: L[2]	Q[2]	IC24-4 vs. PC24	IC24-4 vs. G24
Number of slices, #	155.04	145.77	161.64	150.07	152.48	158.78	3.19	0.65	<0.01	0.12	<0.01
Blade											
Moisture, %	48.48	53.53	54.20	52.06	48.73	49.93	0.98	<0.01	0.08	<0.01	0.61
Lipid, %	34.77	27.05	27.12	29.98	34.57	32.78	1.29	<0.01	0.07	<0.01	0.97
Slice area, cm^2	105.29	95.77	99.52	102.55	106.80	106.45	2.43	0.02	0.49	0.08	0.27
Lean area, cm^2	58.71	62.25	60.03	60.02	58.83	60.82	1.70	0.87	0.55	0.57	0.35
Proportion of slice area	0.56	0.65	0.61	0.59	0.55	0.57	0.15	0.03	0.17	0.02	0.05
Secondary lean area, cm^2	4.33	3.85	4.95	5.91	4.58	5.46	0.84	0.94	0.92	0.47	0.23
Proportion of slice area	0.04	0.04	0.05	0.05	0.04	0.05	0.008	0.53	0.82	0.62	0.58
Middle											
Moisture, %	42.45	47.68	48.18	46.37	43.46	44.65	1.21	0.02	0.10	<0.01	0.77
Lipid, %	42.43	35.18	34.86	37.19	41.12	39.74	1.69	0.02	0.13	<0.01	0.89
Slice area, cm^2	101.52	93.18	94.14	96.89	101.15	100.08	1.97	0.01	0.33	<0.01	0.73
Lean area, cm^2	49.77	48.99	50.72	52.00	47.67	49.71	2.25	0.44	0.80	0.54	0.75
Proportion of slice area	0.49	0.53	0.54	0.54	0.47	0.49	0.02	0.04	0.29	0.06	0.80
Secondary lean area, cm^2	17.41	17.45	16.12	15.82	14.43	17.26	0.74	0.54	0.04	0.21	0.20
Proportion of slice area	0.17	0.19	0.17	0.16	0.14	0.17	0.01	0.92	0.02	0.69	0.07
Flank											
Moisture, %	46.60	51.33	53.53	52.06	48.80	49.60	1.24	<0.01	0.13	<0.01	0.17
Lipid, %	31.05	27.24	24.76	24.95	28.97	28.03	1.63	0.05	0.62	<0.01	0.27
Slice area, cm^2	107.86	106.96	105.58	106.94	110.80	107.35	2.35	0.38	0.31	0.48	0.67
Lean area, cm^2	61.08	63.46	66.17	66.76	65.89	67.51	3.03	0.80	0.80	0.22	0.54
Proportion of slice area	0.57	0.60	0.62	0.61	0.57	0.60	0.02	0.31	0.26	0.04	0.43
Secondary lean area, cm^2	16.31	17.33	17.20	18.18	15.78	17.54	1.56	0.88	0.70	0.70	0.96
Proportion of slice area	0.15	0.16	0.16	0.17	0.14	0.16	0.01	0.79	0.66	0.65	0.74
Average											
Moisture, %	46.60	51.33	53.53	52.06	48.80	49.60	1.24	<0.01	0.13	<0.01	0.17
Lipid, %	37.28	30.37	28.00	30.14	34.47	33.48	1.66	<0.01	0.13	<0.01	0.28
Slice area, cm^2	104.89	98.64	101.39	102.13	106.25	104.63	2.06	0.13	0.56	0.22	0.33
Lean area, cm^2	55.95	58.11	60.34	59.87	58.24	60.38	2.57	0.87	0.35	0.14	0.49
Proportion of slice area	0.54	0.60	0.59	0.58	0.53	0.56	0.02	0.27	0.11	0.15	0.85
Secondary lean area, cm^2	12.32	12.42	13.23	14.16	12.51	14.36	0.94	0.57	0.35	0.35	0.43
Proportion of slice area	0.12	0.13	0.13	0.13	0.11	0.13	0.004	0.46	0.14	0.70	0.38

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI) at 9 and either 20, 18, 16, or 14 wk of age according to IC group

[2]Linear (L) and quadratic (Q) effects of time after second Improvest dose

*Physically castrated barrows and gilts slaughtered at 24 wk of age

Table 4.7. Effect of increasing age at slaughter on carcass characteristics and belly yield[1] and quality of Immunologically[2] castrated (IC) barrows, physical castrates (PC) barrows, and gilts (G)

	Slaughter age, wk										*Single DF Constrast*						
	24			**26**			**28**				L[3]	L[4]	26 wk	26 wk	28 wk	28 wk	
Item	PC24	G24	IC24-4	PC26	G26	IC26-6	PC28	G28	IC28-8	SEM	IC	PC & G	IC vs. PC	IC vs. G	IC vs. PC	IC vs. G	PC vs. G[5]
Wt. at slaughter, kg	131.83	124.33	139.73	143.75	136.41	153.61	152.54	148.04	161.34	2.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
HCW, kg	98.23	92.84	101.58	108.13	102.13	113.52	116.55	110.90	120.18	1.80	<0.01	<0.01	0.03	<0.01	0.15	<0.01	<0.01
Dressing, %	74.51	74.61	72.59	75.17	74.93	73.88	76.37	74.90	74.40	0.63	0.03	0.26	0.10	0.22	0.05	0.55	0.23
Last rib backfat depth, mm	22.79	21.19	21.96	25.50	21.87	24.99	26.76	22.18	27.00	1.75	0.01	0.25	0.79	0.16	0.91	0.40	<0.01
Estimated Lean[6], %	52.51	53.19	52.45	51.19	52.66	51.33	50.73	52.28	50.68	0.62	0.02	0.10	0.84	0.10	0.96	0.06	<0.01
Whole belly, kg	9.38	8.81	9.51	10.24	9.60	10.84	11.33	10.70	12.13	0.22	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01
% of HCW	19.06	18.84	18.69	18.92	18.79	19.08	19.72	19.29	20.23	0.27	<0.01	0.04	0.67	0.46	0.19	0.01	0.23
Natural fall belly, kg	7.75	7.24	7.78	8.51	7.94	8.94	9.49	8.79	9.94	0.20	<0.01	<0.01	0.12	<0.01	0.11	<0.01	<0.01
% of HCW	15.74	15.47	15.28	15.73	15.51	15.75	16.52	15.85	16.54	0.25	<0.01	0.01	0.94	0.50	0.99	0.04	0.05
Spare ribs, kg	1.63	1.57	1.73	1.72	1.67	1.89	1.83	1.90	1.99	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	0.66
% of HCW	3.31	3.36	3.41	3.19	3.28	3.33	3.20	3.43	3.32	0.07	0.35	0.75	0.14	0.54	0.22	0.24	0.03
Length, cm	73.16	73.08	73.08	75.51	74.48	76.84	75.74	75.67	77.27	0.68	<0.01	<0.01	0.15	0.01	0.09	0.07	0.45
Width, cm	27.84	28.16	29.96	28.30	28.61	29.36	29.41	29.74	29.70	0.41	0.64	<0.01	0.06	0.19	0.6	0.94	0.31
Thickness, cm	4.15	3.82	3.85	4.27	4.09	4.17	4.66	4.10	4.71	0.10	<0.01	<0.01	0.42	0.54	0.66	<0.01	<0.01
Flop distance, cm	30.56	20.65	21.41	32.14	26.51	25.39	35.85	25.91	35.54	2.23	<0.01	<0.01	0.01	0.69	0.91	<0.01	<0.01
Fat firmness[7]	68.00	68.13	63.76	71.84	75.69	73.49	68.29	68.11	65.96	2.31	0.51	0.95	0.62	0.51	0.50	0.52	0.51

[1]Whole belly, natural fall, and spare ribs wt. were multiply by 2 to calculate yield as percentage of HCW

[2]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI)at 9 and 20 wk of age

[3]Linear effect of age (24, 26, and 28 wk) at slaughter in IC barrows

[4]Linear effect of age (24, 26, and 28 wk) at slaughter in gilts and PC barrows combined

[5]PC barrows vs. gilts avaraged over age at slaughter

[6]Estimated Lean = [(25.568 + 0.503 × (HCW, lb) - 21.348 × (last rib backfat depth, in)) ÷ HCW, lb] × 100%

[7]Collected with a digital durometer at the anterior end of the belly (fat side facing up), at aproximatelly 7 cm from the anterior edge and midway from the dorsal to ventral edges of the belly

Table 4.8. Effect of increasing age at slaughter on belly adipose tissue fatty acid profile of Immunologically[1] castrated (IC) barrows, physical castrates (PC) barrows, and gilts (G) (expressed as % of total lipid)

	Slaughter age, wk																
	24			**26**			**28**				*Single DF Constrast*						
Item	PC24	G24	IC24-4	PC26	G26	IC26-6	PC28	G28	IC28-8	SEM	L[2] IC	L[3] PC & G	26 wk IC vs. PC	26 wk IC vs. G	28 wk IC vs. PC	28 wk IC vs. G	PC vs. G[4]
Myristic acid (C14:0), %	1.36	1.34	1.32	1.35	1.34	1.30	1.36	1.31	1.36	0.03	0.20	0.55	0.13	0.31	0.95	0.11	0.10
Palmitic acid (C16:0), %	22.83	22.13	22.60	22.52	21.55	22.74	22.77	20.98	23.47	0.41	0.12	0.13	0.70	0.04	0.22	<0.01	<0.01
Palmitoleic acid (C16:1), %	3.19	3.07	3.34	3.22	3.15	3.11	3.07	3.08	2.97	0.09	<0.01	0.55	0.40	0.75	0.40	0.34	0.44
Margaric acid (C17:0), %	0.35	0.34	0.34	0.32	0.33	0.32	0.35	0.34	0.31	0.02	0.24	0.83	0.79	0.67	0.10	0.22	0.86
Stearic acid (C18:0), %	9.96	9.90	10.06	9.99	9.72	10.57	10.15	9.60	11.21	0.31	<0.01	0.85	0.17	0.05	0.01	<0.01	0.22
Oleic acid (C18:1n-9), %	48.15	47.86	47.40	48.45	48.46	47.77	48.45	48.73	47.13	0.65	0.73	0.29	0.39	0.39	0.09	0.04	0.99
Linoleic acid (C18:2n-6), %	10.77	11.76	11.51	10.79	11.86	10.85	10.48	12.26	10.29	0.31	<0.01	0.69	0.87	<0.01	0.60	<0.01	<0.01
α-linolenic acid (18:3n-3), %	0.47	0.50	0.48	0.45	0.50	0.45	0.44	0.51	0.42	0.02	<0.01	0.31	0.99	<0.01	0.40	<0.01	<0.01
Arachidic acid (C20:0), %	0.18	0.19	0.17	0.19	0.18	0.18	0.18	0.17	0.19	0.006	0.03	0.14	0.37	0.79	0.64	0.01	0.30
Gadoleic acid (C20:1n-9), %	1.01	1.00	0.97	1.00	1.01	1.03	1.02	1.02	1.07	0.04	0.01	0.48	0.57	0.66	0.23	0.24	0.95
Eicosadienoic acid (C20:2n-6),	0.52	0.58	0.54	0.51	0.57	0.53	0.51	0.59	0.52	0.01	0.25	0.98	0.38	0.06	0.50	<0.01	<0.01
Arachidonic acid (C20:4n-6), %	0.21	0.24	0.21	0.21	0.25	0.23	0.22	0.26	0.18	0.01	0.02	0.22	0.07	0.04	0.01	<0.01	<0.01
Other Fatty acids, %	1.00	1.07	1.04	0.98	1.07	0.94	1.00	1.16	0.89	0.05	0.01	0.28	0.42	0.03	0.07	<0.01	<0.01
Total SFA[5], %	34.76	34.03	34.57	34.47	33.23	35.19	34.89	32.52	36.63	0.68	0.03	0.29	0.45	0.04	0.07	<0.01	<0.01
Total MUFA[6], %	52.86	52.44	52.20	53.19	53.12	52.37	53.06	53.37	51.58	0.71	0.47	0.34	0.34	0.39	0.08	0.04	0.91
Total PUFA[7], %	12.38	13.54	13.21	12.34	13.64	12.46	12.03	14.12	11.81	0.34	<0.01	0.70	0.76	<0.01	0.59	<0.01	<0.01
UFA:SFA ratio[8]	1.89	1.98	1.92	1.93	2.03	1.87	1.88	2.10	1.75	0.06	0.04	0.33	0.46	0.06	0.11	<0.01	<0.01
PUFA:SFA ratio[9]	0.36	0.41	0.39	0.36	0.42	0.36	0.35	0.44	0.33	0.01	<0.01	0.51	0.79	<0.01	0.31	<0.01	<0.01
Iodine value[10], g/100g	65.21	66.65	66.04	65.49	67.44	64.92	64.76	68.30	63.21	0.70	<0.01	0.37	0.56	0.01	0.11	<0.01	<0.01

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI)at 9 and 20 wk of age

[2]Linear effect of age (24, 26, and 28 wk) at slaughter in IC barrows

[3]Linear effect of age (24, 26, and 28 wk) at slaughter in gilts and PC barrows combined

[4]PC barrows vs. gilts avaraged over age at slaughter

[5]Total SFA = ([C14:0] + [C15:0] + [C16:0] [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration

[6]Total MUFA = ([C14:1] + [C16:1] + [C17:1] + [C18:1n-9] + [C20:1n-9] + [C22:1n-9]); brackets indicate concentration

[7]Total PUFA = ([C18:2n-6] + [C18:3n-6] + [C18:3n-3] + [C20:2n-6] + [C20:3n-6] + [C20:4:1n-6] + [20:3n-3] + [20:5n-3] + [22:2n-6] + [22:5n-3] + [22:6n-3]); brackets indicate concentration

[8]UFA:SFA ratio= (total MUFA + total PUFA) ÷ total SFA

[9]PUFA:SFA ratio= total MUFA ÷ total SFA

[10]Calculated as IV 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) (AOCS, 1998)

Table 4.9. Effect of increasing age at slaughter on cured belly characteristics of Immunologically[1] castrated (IC) barrows, physical castrates (PC) barrows, and gilts (G)

	Slaughter age, wk																
	24			26			28				*Single DF Constrast*						
Item	PC24	G24	IC24-4	PC26	G26	IC26-6	PC28	G28	IC28-8	SEM	L[2] IC	L[3] PC & G	26 wk IC vs. PC	26 wk IC vs. G	28 wk IC vs. PC	28 wk IC vs. G	PC vs. G[4]
Thawed wt, kg	7.53	7.00	7.53	8.34	7.87	8.67	9.31	8.60	9.73	0.19	<0.01	<0.01	0.22	<0.01	0.11	<0.01	<0.01
Purge loss[5], %	2.86	3.42	3.20	2.11	2.68	2.94	1.50	2.16	2.23	0.32	0.03	0.01	0.06	0.56	0.10	0.87	0.02
Green wt, kg	6.42	5.80	6.23	7.15	6.65	7.23	8.00	7.31	8.46	0.18	<0.01	<0.01	0.73	0.02	0.06	<0.01	<0.01
Pump wt, kg	7.17	6.54	7.07	7.98	7.51	8.11	8.94	8.23	9.44	0.19	<0.01	<0.01	0.65	0.04	0.06	<0.01	<0.01
Pump uptake, %	11.66	12.45	12.54	11.77	11.90	12.21	11.81	12.57	11.75	0.34	0.06	0.65	0.29	0.48	0.88	0.05	0.02
Cooked wt, kg	6.62	5.95	6.42	7.41	6.86	7.51	8.34	7.58	8.80	0.19	<0.01	<0.01	0.71	0.02	0.08	<0.01	<0.01
Cooked yield, %	103.17	102.64	102.97	103.71	103.43	103.86	104.26	103.60	104.03	0.32	0.01	<0.01	0.72	0.34	0.59	0.30	0.05
Bacon ends wt, kg	0.69	0.69	0.51	0.69	0.74	0.59	0.82	0.85	0.46	0.05	0.40	<0.01	<0.01	<0.01	<0.01	<0.01	0.13
Trimmed cooked wt, kg	5.94	5.27	5.91	6.60	6.13	6.92	7.41	6.73	8.31	0.19	<0.01	<0.01	0.18	<0.01	<0.01	<0.01	<0.01
Bacon pieces wt, kg	0.53	0.46	0.63	1.35	1.27	1.25	1.49	1.43	1.35	0.68	0.01	<0.01	0.27	0.88	0.13	0.40	0.13
Sliced wt, kg	5.40	4.82	5.29	6.06	5.60	6.26	6.85	6.15	7.51	0.18	<0.01	<0.01	0.40	<0.01	<0.01	<0.01	<0.01
Slicing yield (green wt)*, %	83.76	82.98	84.73	84.89	84.10	86.46	85.68	84.16	88.77	0.92	<0.01	0.06	0.19	0.06	0.01	<0.01	0.14
Slicing yield (cooked wt)*, %	81.16	80.83	82.27	81.85	81.38	83.26	82.18	81.24	85.33	0.87	<0.01	0.33	0.19	0.09	<0.01	<0.01	0.34
Slicing yield (trimmed cooked wt)*, %	90.84	91.23	89.45	91.97	91.36	90.47	92.34	91.51	90.36	0.77	0.32	0.12	0.11	0.35	0.02	0.23	0.42

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI)at 9 and 20 wk of age

[2]Linear effect of age (24, 26, and 28 wk) at slaughter in IC barrows

[3]Linear effect of age (24, 26, and 28 wk) at slaughter in gilts and PC barrows combined

[4]PC barrows vs. gilts avaraged over age at slaughter

[5]Purge loss = [(natural fall wt – thawed wt) ÷ natural belly wt] × 100

**Slicing yields were calculated by dividing the weight of number 1 slices (sliced wt) by green, cooked, and trimmed cooked wt

Table 4.10. Effect of increasing age at slaughter on bacon slice characteristics of Immunologically[1] castrated (IC) barrows, physical castrates (PC) barrows, and gilts (G)

	Slaughter age, wk																
	24			**26**			**28**				*Single DF Constrast*						
											L[2]	L[3]	26 wk	26 wk	28 wk	28 wk	
Item	PC24	G24	IC24-4	PC26	G26	IC26-6	PC28	G28	IC28-8	SEM	IC	PC & G	IC vs. PC	IC vs. G	IC vs. PC	IC vs. G	PC vs. G[4]
Number of slices, #	155.04	145.77	161.64	165.55	158.22	180.33	174.34	162.75	193.28	3.19	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Blade																	
Moisture, %	48.48	53.53	54.20	47.02	50.13	51.42	44.90	50.63	49.22	0.96	<0.01	<0.01	<0.01	0.35	<0.01	0.28	<0.01
Lipid, %	34.77	27.05	27.12	36.95	32.20	30.87	39.40	31.72	34.03	1.36	<0.01	<0.01	<0.01	0.48	<0.01	0.20	<0.01
Slice area, cm^2	105.29	95.77	99.52	113.01	106.59	108.57	121.14	110.87	125.35	2.55	<0.01	<0.01	0.20	0.58	0.23	<0.01	<0.01
Lean area, cm^2	58.71	62.25	60.03	63.74	65.17	67.18	64.06	68.28	71.17	1.71	<0.01	<0.01	0.16	0.42	<0.01	0.23	0.03
Proportion of slice area	0.56	0.65	0.61	0.56	0.61	0.62	0.53	0.62	0.57	0.02	0.07	0.04	0.01	0.77	0.06	0.02	<0.01
Secondary lean area, cm^2	4.33	3.85	4.95	4.20	4.93	5.79	3.77	5.01	5.12	0.82	0.83	0.72	0.05	0.36	0.14	0.91	0.18
Proportion of slice area	0.04	0.04	0.05	0.04	0.05	0.05	0.03	0.05	0.04	0.007	0.44	0.66	0.08	0.79	0.27	0.55	0.02
Middle																	
Moisture, %	42.45	47.68	48.18	40.83	45.78	47.00	39.57	45.88	43.40	1.25	<0.01	0.19	<0.01	0.45	0.04	0.17	<0.01
Lipid, %	42.43	35.18	34.86	44.95	38.33	36.40	46.80	37.98	41.54	1.71	<0.01	0.17	<0.01	0.39	0.04	0.15	<0.01
Slice area, cm^2	101.52	93.18	91.14	105.16	102.45	101.31	112.43	107.34	114.52	2.01	<0.01	<0.01	0.17	0.69	0.46	<0.01	<0.01
Lean area, cm^2	48.99	49.77	50.74	47.32	52.77	54.51	51.32	57.51	56.70	2.28	0.02	0.14	0.01	0.55	0.10	0.79	<0.01
Proportion of slice area	0.49	0.53	0.54	0.45	0.52	0.54	0.46	0.54	0.50	0.02	0.08	0.67	<0.01	0.48	0.23	0.22	<0.01
Secondary lean area, cm^2	17.41	17.45	16.12	15.04	19.76	17.58	18.00	19.16	19.98	0.74	<0.01	0.11	0.02	0.05	0.06	0.44	<0.01
Proportion of slice area	0.17	0.19	0.17	0.14	0.20	0.17	0.16	0.18	0.18	0.007	0.54	0.19	<0.01	0.06	0.20	0.70	<0.01
Flank																	
Moisture, %	51.50	54.26	56.05	51.49	52.11	53.46	48.82	50.83	48.84	1.29	<0.01	0.07	0.17	0.42	0.99	0.24	0.01
Lipid, %	31.05	27.24	24.76	31.27	29.94	28.68	34.61	31.66	34.62	1.68	<0.01	0.07	0.18	0.56	0.99	0.20	<0.01
Slice area, cm^2	107.86	106.96	105.58	115.59	115.58	116.21	125.83	121.94	130.44	2.35	<0.01	<0.01	0.86	0.86	0.17	0.01	0.40
Lean area, cm^2	61.08	63.46	66.17	63.93	65.89	68.84	64.72	66.06	71.34	3.69	0.17	0.45	0.19	0.51	0.14	0.23	0.29
Proportion of slice area	0.57	0.60	0.62	0.56	0.59	0.58	0.54	0.57	0.55	0.02	<0.01	0.10	0.57	0.50	0.85	0.31	0.03
Secondary lean area, cm^2	16.31	17.33	17.20	17.95	18.56	16.29	18.33	17.93	18.26	1.56	0.58	0.65	0.35	0.27	0.98	0.90	0.67
Proportion of slice area	0.15	0.16	0.16	0.16	0.16	0.14	0.15	0.15	0.14	0.009	0.16	0.20	0.23	0.12	0.69	0.59	0.43
Average																	
Moisture, %	46.60	51.33	53.53	46.69	49.18	51.05	44.19	49.11	46.89	0.92	<0.01	0.13	<0.01	0.24	0.09	0.16	<0.01
Lipid, %	37.28	30.37	28.00	37.40	33.63	31.47	40.60	33.77	37.01	1.66	<0.01	0.11	<0.01	0.31	0.10	0.14	<0.01
Slice area, cm^2	104.89	98.64	101.39	111.25	108.21	108.70	119.80	113.28	123.44	2.10	<0.01	<0.01	0.38	0.87	0.22	<0.01	<0.01
Lean area, cm^2	55.95	58.11	60.34	58.16	60.85	63.99	59.56	63.48	66.18	2.55	0.03	0.15	0.03	0.33	0.04	0.40	0.02
Proportion of slice area	0.54	0.60	0.59	0.53	0.58	0.58	0.51	0.58	0.54	0.20	0.05	0.55	0.03	0.90	0.39	0.28	<0.01
Secondary lean area, cm^2	12.32	12.42	13.23	12.46	13.93	13.74	12.85	13.57	14.22	0.92	0.27	0.37	0.15	0.87	0.19	0.53	0.08
Proportion of slice area	0.12	0.13	0.13	0.11	0.14	0.12	0.12	0.13	0.12	0.005	0.34	0.18	0.35	0.02	0.51	0.23	<0.01

[1]IC barrows were immunologically castrated by giving 2 doses of Improvest (GnRF analog; Zoetis, Kalamazoo, MI)at 9 and 20 wk of age

[2]Linear effect of age (24, 26, and 28 wk) at slaughter in IC barrows

[3]Linear effect of age (24, 26, and 28 wk) at slaughter in gilts and PC barrows combined

[4]PC barrows vs. gilts avaraged over age at slaughter