The Effect of a Low Sodium Curing Solution on Further Processed Hams and Bellies from Purebred Berkshire Pigs Fed a Step-up Ractopamine Feeding Program

Thesis

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Abstract
The objective of the first study was to summarize previous literature, using a meta-analysis approach, on the effects of ractopamine hydrochloride (RAC) when fed at doses of 5 to 10 mg/kg for up to 35 days prior to harvest on carcass cutability and belly quality of finishing pigs. The objective of the second study was to determine the effect of a lower sodium curing solution on processing characteristics of hams and bellies from purebred Berkshire pigs fed a step-up RAC feeding program or a negative control diet. The first study reported that RAC pigs when compared to control pigs had a carcass cutting yield advantage of 1.01 percentage units (74.70% vs. 73.69%, respectively; P= 0.02; SED = 0.33) and a bone in lean cutting yield advantage of 1.10 percentage units (61.43% vs. 60.33%, respectively; P = 0.03; SED = 0.40). When further evaluated, RAC pigs had a boneless shoulder (Boston butt + picnic) yield advantage of 0.32 percentage units (P < 0.01; SED = 0.11), a boneless loin (Canadian back + tenderloin + sirloin) yield advantage of 0.43 percentage units (P = 0.01; SED = 0.13), and a boneless ham (inside + outside + knuckle) yield advantage of 0.51 percentage units (P < 0.001; SED = 0.11). A boneless yield was calculated using a summation of the percentage of side weight from the boneless shoulder, boneless loin, and boneless ham, which resulted in a 1.08 percentage unit (36.28% vs. 35.20%, respectively; P = 0.002; SED = 0.25) advantage of RAC pigs when compared to control pigs. For fresh belly characteristics, RAC pigs (15.27 cm; 73.42) had narrower flop distances (P=0.02; SED=0.62) and greater iodine
values (P=0.01; SED=0.33) respectively, when compared to control pigs (17.08 cm; 71.48). The second study compared hams and bellies derived from purebred Berkshire pigs fed RAC cured with a standard curing solution (1.98% NaCl; REG) or with a low sodium, potassium chloride substitute curing solution (0.67% NaCl and 1.29% KCl; LOW). Sixty pairs (n = 120) of hams and bellies were selected from 200 purebred Berkshire pigs. Pigs fed RAC had a 0.10 kg/d greater ADG (P < 0.01) and a 0.03 greater G:F (P < 0.01) over the 28 day finishing period and ended with 3.29 kg greater BW (P < 0.01). There were no differences (P > 0.05) in fresh loin quality or processing characteristics of hams and bellies between RAC and control pigs. Break strength (an indication of protein interaction) of LOW hams (5.97 kg) required less (P = 0.05) force to break than REG hams (6.99 kg). LOW hams had greater (P < 0.05) lightness (L*) and yellowness (b*), and had lesser (P < 0.05) redness (a*) values than REG hams. Pump uptake and cook yield was less (P < 0.01) in LOW bellies when compared to REG bellies. No differences (P < 0.05) between LOW and REG hams and bellies were detected by a trained sensory panelist for saltiness, flavor, or acceptability.
Dedication

Dedicated to my grandfather Richard Truman, the wisest man I know.
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I would like to thank many people for their support and guidance throughout my experience as an undergraduate and graduate student. First, I would like to thank my mother Lisa and father Steve who have showed me unconditional love and support throughout my life. They have provided me everything I have ever asked of them. My mother has always gone out of her way to make sure I was well taken care of. My father taught me how to act in tough situations and more importantly passed on his competitive nature and desire for success on to me. My two sisters Victoria and Jennifer have always been there and some of my dearest memories are spending the summers with them working with our livestock projects in our barn and backyard.

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Chapter 1: Review of Literature

Introduction

The swine industry has experienced great changes over the past half century and has shifted towards a vertically integrated business that has taken advantage of specialization (Reimer, 2006). Despite vertical integration, large operations specializing in particular segments of swine production, such as the finishing phase, have replaced the farrow-to-finish operations of the past (Key and McBride, 2007). The goals of swine finishers are to be profitable, efficient, and produce a consumer demanded product. Meat packers and processors demand pork that is high cutability, appeals to the consumer, and is still functional from a fabrication and processing standpoint.

It is important for producers to be aware of making a profit, but to also produce a product that consumers demand and processors can utilize. This is the major reason why swine producers have turned to technologies like growth promoters to assist and improve performance in the finishing stage of pork production. Paylean is Elanco Animal Health’s (Greenfield, IN) registered trademark brand of ractopamine hydrochloride (RAC), and is a feed additive labeled to be mixed into a complete ration and fed to pigs weighing more than 68 kg (Freedom of Information Summary, FDA, 1999). Ractopamine hydrochloride is an example of a β-adrenergic agonist (β-AA) and its mode
of action is a direct mediator receptor response where binding occurs to a β-adrenergic receptor (β-AA) found in the muscle cell membrane. A series of events then take place that lead to an increase in protein synthesis, a decrease in protein degradation, or a combination of the two. The resulting accretion of protein leads to an increase in muscle fiber size.

Sodium is a key nutrient in the diet and is needed in the body in relatively small quantities, but the average dietary intake of sodium (approximately 3,400 mg/day) far exceeds what is needed and recommended (2,300 mg/day; Dietary Guidelines for Americans, 2010). High sodium intake has been linked to high blood pressure, an increase in heart diseases and/or complications, among various other health issues (CDC, 2012). The most common source of sodium in the diet is sodium chloride, generally referred to as table salt. Sodium chloride has a variety of applications in processed meat products including its effect on moisture retention, flavor, and shelf life.

**β-adrenergic Agonist: Ractopamine Hydrochloride**

β-adrenergic receptors are present in nearly every type of cell in a pig’s body. The β-AR are located on the cell’s surface and have been most notably categorized into three different subtypes, β1-AR, β2-AR, and β3-AR. The three different kinds of β-ARs vary in their distribution between tissues within a given species and are also dependent of age and diet of that particular animal (Mersmann, 1998). Adrenergic receptors in a pig’s body have been estimated to be predominately β1-AR (McNeel and Mersmann, 1999; Liang and Mills, 2002). When quantitatively measuring the mRNA for porcine β-AR subtypes, it has been estimated that porcine adipocytes contain approximately 73% β1-AR, 20% β2AR, and 7% β3AR (McNeel and Mersmann, 1999). Liang and Mills (2002)
reported porcine adipose tissue contained 81% β1-AR and 19% β2AR, skeletal muscle tissue contained 59% β1-AR and 41% β2AR, heart tissue contained 72% β1-AR and 28% β2AR, lung tissue contained 58% β1-AR and 42% β2AR, and liver tissue contained 50% β1-AR and 50% β2AR (β3-AR was not reported as it is expressed poorly in most tissues). The adrenergic receptors produce a response when bound to norepinephrine and epinephrine and are part of a greater class of receptors known as the Gs protein-coupled receptors (GPCR) (Mersmann, 1998). Phenethanolamines are frequently discussed as repartitioning agents for their ability to transmit dietary nutrients towards muscle and away from adipose tissue (Moody et al., 2000). The GPCRs will go through a series of events and eventually become active individual receptors functioning in cascade to produce secondary receptors (cAMP and IP₃) (McCudden et al., 2005).

Phenethanolamines can be classified as groups of compounds that will bind to either α-adrenergic receptors, β-adrenergic receptors, or in some cases both (Mills et al., 2002). Ractopamine hydrochloride is an example of a phenethanolamine with β-adrenergic agonist properties; more specifically RAC is classified as a β-1 selective adrenergic agonist whose action occurs primarily with β1-AR.

*Ractopamine hydrochloride: mode of action*

Receptors are triggered by phenethanolamines, like RAC, causing an activation of Gs proteins and a stimulation of adenylyl cyclase will result in a flow of reactions that will ultimately achieve the phosphorylation of many enzymes and regulatory factors essential in metabolic regulation (Moody, et al., 2000). Adenosine triphosphate (ATP) is converted to cyclic adenosine monophosphate (cAMP), which acts as an intracellular
signaling molecule and eventually activates enzymes and regulatory factors through the protein kinase A (PKA) pathway (Mersmann, 1998).

Chemically, the β-agonist’s activity at its receptor has the ability to impact its absorption, distribution, metabolism, and elimination (Smith, 1998). Ultimately, these functions support RAC’s ability to change the direction of nutrients from fat deposits to muscle accretion (Watkins, et al. 1990). To further explain, Beerman et al. (2002) reported that β-adrenergic agonists produce a rapid increase in fractional rate of protein synthesis of skeletal muscle, and while some also reduce fractional protein degradation, RAC has little to no impact on protein degradation. Peterla and Scanes (1990) reported that β-adrenergic agonists decrease lipogenesis and typically increase lipolysis in porcine adipose tissue.

In 1999, RAC received approval from the Food and Drug Administration and it is still the only phenethanolamine β-adrenergic agonist approved as a dietary supplement in finishing swine diets. Ractopamine hydrochloride is an orally administered feed additive that is distributed to muscle tissues through the blood stream, where it binds to β-receptors in the muscle cell membranes. The result is an increase in protein synthesis which causes an increase in the proportion of white muscle fibers by increasing intermediate (Type IIA) and white (Type IIB) myofiber diameter (Aalhus et al., 1992).

There are three ways muscle hypertrophy can be influenced by a β-agonist: an increase in muscle protein synthesis, a decrease in protein degradation, or a combination of the two (Mersmann, 1998). It has been shown RAC influences protein synthesis and has little to no effect on protein degradation. Tenderness scores of fresh pork may best explain the lack of protein degradation that is observed when feeding RAC. Apple et al.
(2007a) reported via meta-analysis that three out of five studies, which compared pork from pigs fed 10 mg/kg RAC to pigs not fed RAC, concluded no differences (P > 0.05) in subjective tenderness scores from a trained sensory panelist. In contrast, Xiong et al. (2006) reported pigs fed 20 mg/kg RAC during the last 28 to 30 days before slaughter (a dosage level that currently exceeds allowable inclusion levels) had increased toughness (WBSF values) on pork due to a decrease in early-postmortem proteolytic activity. However, the investigators concluded there was only a decrease in initial tenderness as postmortem storage of RAC pork diminished associated toughness. Bergen et al. (1989) showed an increase in protein synthesis was caused by an increase of RNA synthesis. The study went on to prove an increase in RAC response was also reflected in the increased RNA/DNA ratio, which is a sign of muscle cell growth.

*Ractopamine hydrochloride: application*

Pigs fed RAC have increased weight gain, improved feed efficiency, and greater carcass leanness than pigs not fed RAC (Apple et al., 2007a). Apple et al. (2007a) used a meta-analysis evaluate differences in growth and carcass characteristics between RAC and non-RAC fed pigs. A meta-analysis is a modern statistical approach used to summarize previous collected data, create an understanding of the relationship of past studies, and allow overall conclusions to be made (Sauvant et al., 2008). Apple et al. (2007a) concluded that pigs fed 10 mg/kg of RAC had improved ADG of 0.09 kg/d and an increase in G:F of 0.04 when compared to pigs not fed RAC (0.94 vs. 0.85 kg/d, 0.34 vs. 0.30, respectively; P < 0.001). Whereas, pigs fed 5 mg/kg of RAC had improved ADG of 0.10 kg/d and an increase in G:F of 0.03 when compared to pigs not fed RAC (0.95 vs. 0.85 kg/d, 0.33 vs. 0.30, respectively, P < 0.001; Apple et al., 2007a). The
doses, durations, and dietary compositions of RAC greatly influence the overall impact RAC has on increasing weight gain, improving feed efficiency, and generating leaner carcasses (Armstrong et al., 2004; Apple et al., 2007a; Edmonds and Baker, 2010; Kutzler et al., 2011; Hinson et al., 2012b). Current label claims of RAC require supplementation of 5 to 10 mg/kg of RAC for the last 20.4 to 40.8 kg of gain prior to slaughter to pigs weighing over 68 kg and being fed a complete ration containing at least 16% crude protein. Ractopamine is typically fed at doses of 5, 7.4, or 10 mg/kg for the last 21 to 35 days prior to slaughter in the commercial setting. However, pigs can be fed for less than 21 days in certain feeding strategies that implement multiple pull marketing (Gerlemann et al., 2013). In multiple pull marketing schemes, pigs fed RAC can be pulled as early as 7 days after RAC inclusion; however the pen average must remain on RAC for the last 20.4 kg of weight gain prior to slaughter.

Apple et al. (2007a) summarized multiple studies at continuous 5, 10, and 20 mg/kg RAC doses levels and found that ADG and G:F were more favorable in RAC diets when compared to non-RAC diets, however no differences (P > 0.05) were reported between 5 and 10 mg/kg RAC doses (0.95 vs. 0.94 kg/d; 0.33 vs. 0.34; respectively). Apple et al. (2007a) reported similar findings for differences observed in RAC dose level as HCW increased, tenth rib fat depth decreased, tenth rib loin muscle area increased, and estimated fat free lean yield increased when feeding RAC but no differences (P > 0.05) among 5 mg/kg RAC doses when compared to 10 mg/kg RAC doses. Armstrong et al. (2004) reported similar findings between 5 and 10 mg/kg RAC doses for ADG, G:F, HCW, and tenth rib loin muscle area with linear increases at a greater rate with RAC when compared with pigs not fed RAC. Furthermore, Kutzler et al. (2011) conducted a
dose difference study of 5 mg/kg RAC vs. 7.4 mg/kg RAC, but eventually pooled the data due to a lack of differences in the carcass and meat quality variables observed between the two RAC dosage levels.

Although label claims indicate RAC can only be fed to pigs weighing over 68 kg for the last 20.4 to 40.8 kg of gain prior to slaughter, the lack of an established duration length that RAC is fed creates flexibility to the commercial producer. Ractopamine, like all β-adrenergic agonists, has a direct mediator receptor effect and thus is usually only effective for a limited amount of time because of desensitization or down-regulation of β-adrenergic receptors (Moody et al. 2000). Armstrong et al. (2004) reported advantages (P < 0.05) in ADG and G:F at only 6 d of RAC supplementation and in live weight and HCW at 13 d of RAC supplementation, regardless of 5 or 10 mg/kg RAC doses. However, the magnitude of the differences Armstrong et al. (2004) reported for ADG were the greatest at 6 d when feeding both 5 and 10 mg/kg RAC doses. Furthermore, it took 27 d of feeding 10 mg/kg RAC before an increase (P < 0.05) in tenth rib loin muscle area was observed (Armstrong et al., 2004).

At a time when feeding pigs 20 mg/kg RAC still complied with label requirements, Armstrong et al. (2004) fed pigs 20 mg/kg RAC and concluded feeding various doses of RAC for a longer duration had greater impact on carcass traits, such as: HCW, tenth rib loin muscle area, and predicted fat-free carcass lean, whereas increases in weight gain and feed efficiency were established at much shorter durations. Additionally, Kutzler et al. (2011) reported linear changes (P < 0.001) in lean cutting yield [2 x (inside ham + outside ham + knuckle + light butt + Canadian back + tenderloin + sirloin + boneless Boston butt + boneless picnic)/(HCW)] and carcass cut yield [2 x (inside ham +
outside ham + knuckle + light butt + Canadian back + tenderloin + sirloin + boneless Boston butt + boneless picnic + trimmed belly) /(HCW)] when feeding RAC for 7, 14, 21, 28, and 35 d prior to slaughter. Recently constant doses fed for duration periods of 21 d (Hinson et al. 2011) or 28 days (Mimbs et al., 2003; Carr et al., 2005; Kutzler et al., 2010; Boler et al. 2011) have been used, however in the commercial setting a wide array of durations may be appropriate, so further investigation of alternative feeding strategies is certainly warranted.

Dietary composition can vary greatly depending on price of feedstuffs, availability of feed sources, and production goals. A limited number of factors go into formulating a successful finisher pig diet, but two of the most important dietary specifications, when formulating a RAC diet, are dietary protein percentage and the percentage of lysine, which is the first limiting amino acid in a pig’s diet (Bundy et al. 2011). Finisher diets used commercially often supplement essential amino acids into the diet, thus making diets less expensive while lowering dietary protein percentage (3% reduction) without adversely effecting growth, feed efficiency, or carcass traits (Kerr et al., 2003). Studies have shown that RAC increased growth rate and improved feed efficiency in pigs fed 17.0 to 18.0% dietary protein, but not in pigs fed 13.0% dietary protein (Xiao et al., 1999; Adeola et al., 1990) when compared to pigs fed similar diets, but without RAC. Kutzler et al. (2011) compared pigs fed a 13.1% dietary protein, 0.73% total lysine or 0.64 % true ideal digestible (TID) lysine, and 0 mg/kg RAC diet (NEG), pigs fed a 17.8% dietary protein, 1.05% total lysine or 0.94% TID lysine, and 0 mg/kg RAC diet (POS), and pigs fed a 17.8% dietary protein, 1.05% lysine or 0.94% TID lysine, and 5 or 7.4 mg/kg RAC diet (RAC), and concluded that HCW, dressing
percentage, fat depth, loin depth, and cutting yields were not different (P > 0.05) between
the NEG and POS diets. Yet, RAC pigs had greater (P < 0.05) HCW, dressing
percentage, loin depth, and cutting yields expressed as percentage of side weight when
compared to NEG pigs. Furthermore, RAC pigs only had greater (P < 0.05) HCW than
POS pigs, yet trends were observed for loin depth (P = 0.06), lean cutting yield expressed
as a percentage of side weight (P = 0.08), and carcass cutting yield expressed as a
percentage of side weight (P = 0.09; Kutzler et al., 2011).

Webster et al. (2007) and Apple et al. (2004) reported that growth rate increased
in RAC pigs as dietary lysine increased. Webster et al. (2007) concluded that optimal
lysine levels in finishing diets were 0.6% total lysine or 1.81 g/mcal in non-RAC diets,
1.0% total lysine or 3.02 g/mcal in 5 mg/kg RAC diets, and 1.2% total lysine or 3.62
g/mcal in 10 mg/kg RAC diets. Furthermore, Apple et al. (2004) reported only
lysine:energy ratios (Lys/ME) and concluded from a study that fed pigs 10 mg/kg RAC
on three different levels of Lys/ME (1.7, 2.4, and 3.1 g/mcal), the lysine:energy ratio for
peak performance and carcass yields needs to be greater (3.0 g/mcal and above).
Furthermore, Hinson et al. (2011) fed 7.4 mg/kg RAC diets that contained similar
Lys:ME (2.65 g/kcal) and three different ME levels (3,314 kcal/kg; 3,366 kcal/kg; and
3,536 kcal/kg) and concluded feeding reduced dietary energy levels decreased the
magnitude of the difference of advantages between RAC and non-RAC diets for growth
performance traits, but 10th-rib fat depth was decreased. But ultimately, growth rates
were still improved when feeding RAC with lowered energy diets (Hinson et al., 2011).
Overall, formulating diets with optimal lysine levels when feeding RAC appears to be
more important than increasing energy in diets from a growth and carcass standpoint.
Ractopamine hydrochloride: Effect on live performance

Ractopamine consistently increases ADG and feed efficiency. Apple et al. (2007a) provided a review of 15 studies dating from 1990-2005. For the sake of this review only studies complying with current label requirements are discussed. Studies evaluating RAC fed at 20 mg/kg were omitted. When compared to control pigs, pigs fed 5 and 10 mg/kg RAC had an increase (P < 0.001) in ADG of 0.09 to 0.10 kg/d, respectively, and an increase (P < 0.001) in G:F of 0.03 and 0.04, respectively. Average daily feed intake (ADFI) was not different (P > 0.05) between pigs fed RAC and pigs not fed RAC. Overall, of all the comparisons made between RAC fed pigs (5 and 10 mg/kg RAC) and pigs not fed RAC in the 15 studies used, 19 out of 26 comparisons reported RAC pigs had an increased (P < 0.05) ADG, 21 out of 25 comparisons reported RAC pigs had a no change (P > 0.05) in ADFI, and 22 out of 26 comparisons reported RAC pigs had an increased (P < 0.05) G:F (Apple et al., 2007a).

Recent publications are consistent with the review Apple et al. (2007a) conducted using historical experiments; however the magnitude of the differences was exceeded in recent studies. Boler et al. (2011) reported RAC pigs (7.4 mg/kg) had an increase in ADG (1.01 vs. 0.86 kg/d; P < 0.001), a trending decrease in ADFI (2.68 vs. 2.81 kg; P = 0.09), and an increase in G:F (0.38 vs. 0.31; P < 0.001) in comparison to pigs not fed RAC. Kutzler et al. (2010) reported RAC pigs (10 mg/kg) had an increase in ADG (1.21 vs. 1.09 kg/d; P < 0.01), a numerical decrease in ADFI (3.42 vs. 3.54 kg; P = 0.16), and an increase in G:F (0.35 vs. 0.31; P < 0.001) when compared with pigs not fed RAC. Hinson et al. (2011) reported RAC pigs (7.4 mg/kg) had an increase in ADG (1.21 vs. 1.01 kg/d; P < 0.001), a trending decrease in ADFI (3.07 vs. 3.29 kg; P = 0.07), and an
increase in G:F (0.40 vs. 0.31; P < 0.001) when compared with pigs not fed RAC.  Hinson et al. (2012a) reported RAC pigs (5.0 mg/kg RAC and 5.0 to 7.4 mg/kg step-up RAC) had an increase in ADG (1.02 vs. 0.84 kg/d; P < 0.01), surprisingly an increase in ADFI (2.93 vs. 2.85 kg; P = 0.04), and an increase in G:F (0.35 vs. 0.29; P < 0.01) in comparison to pigs not fed RAC.  Rickard et al. (2012) reported RAC pigs (7.4 mg/kg) had an increase in ADG (1.35 vs. 1.19 kg/d; P < 0.001), a numerical decrease in ADFI (3.43 vs. 3.49 kg; P = 0.42), and an increase in G:F (0.18 vs. 0.15; P < 0.001) in comparison to pigs not fed RAC.  Pompeu et al. (2013) reported RAC pigs (7.4 mg/kg) had an increase in ADG (1.01 vs. 0.86 kg/d; P < 0.001), a decrease in ADFI (2.64 vs. 2.76 kg; P < 0.01), and an increase in G:F (0.38 vs. 0.31; P < 0.001) when compared with pigs not fed RAC.  Gerlemann et al. (2013) reported RAC pigs (7.4 mg/kg RAC and 5 to 10 mg/kg step-up RAC) had an increase in ADG (1.19/1.20 vs. 1.04 kg/d; P < 0.0001), no difference in ADFI (3.10/3.12 vs. 3.10 kg; P = 0.60), and an increase in G:F (0.39 vs. 0.34; P < 0.001) when compared with pigs not fed RAC.  Overall, recently published literature indicates RAC will increase ADG by a magnitude of 0.12 to 0.20 kg/d and increase G:F by 0.03 to 0.09 units in comparison to non-RAC pigs.

Ractopamine hydrochloride: Effect on carcass characteristics

Apple et al. (2007a) reported a consensus of studies (n = 14) ranging from 1990-2005 and concluded pigs fed 5 mg/kg RAC (79.6 kg) and 10 mg/kg RAC (80.2 kg) had 1.8 kg and 2.4 kg greater (P = 0.024) HCW, respectively, than pigs not fed RAC (77.8 kg).  Data suggests that pigs continue to grow faster and the weight of pigs at slaughter has increased, thus creating a greater RAC effect on HCW as pigs reach heavier weights at endpoint (Hinson et al., 2012a; Pompeu et al., 2013).  Apple et al. (2007a) reported 25
of 27 comparisons in which pigs had HCW less than 86 kg; whereas, Hinson et al.
(2012a) reported pigs fed 5 mg/kg RAC (91.50 kg) and a 5 to 7.4 mg/kg (91.24) step-up
RAC feeding program had a 3.06 and 2.80 kg greater (P < 0.01) HCW, respectively, than
pigs not fed RAC (88.44 kg) and Pompeu et al. (2013) reported RAC pigs (95.47 kg) fed
7.4 mg/kg had a 4.30 kg advantage (P < 0.001) in HCW when compared to pigs not fed
RAC (91.17 kg). It may be concluded that RAC is just as effective today on heavier
HCW as it was when pigs had lighter HCW.

Apple et al. (2007a) reported no differences (P > 0.05) in dressing percentage of
RAC pigs (5 and 10 mg/kg RAC) when compared to pigs not fed RAC, yet 10 of the 20
comparisons reported an increase (P < 0.05) in dressing percentage for RAC pigs versus
pigs not fed RAC. Likewise, Hinson et al. (2011), Kutzler et al. (2011), Hinson et al.
(2012b) reported no differences (P > 0.05) in dressing percentage. On the other hand,
Kutzler et al. (2010) reported pigs (76.13%) fed 10 mg/kg RAC had an increase (P =
0.02) in dressing percentage when compared to pigs not fed RAC (75.34%). Hinson et
al. (2012a) reported pigs fed a 5 mg/kg RAC (72.22%) and 5 to 7.4 mg/kg step-up RAC
(72.00%) had a greater (P < 0.01) dressing percentage than pigs not fed RAC (71.09%) when all pigs were slaughtered at live weights of 126 kg. Pompeu et al. (2013) reported
pigs fed 7.4 mg/kg RAC (74.71%) had an increase (P < 0.001) in dressing percentage when compared to pigs not fed RAC (73.70%). Although literature conflicts, it is
suggested that RAC does have an effect on dressing percentage in most circumstances.

Apple et al. (2007a) reported no differences (P > 0.05) in 10th rib fat depth
between pigs fed a 5 mg/kg RAC (2.30 cm) and pigs not fed RAC (2.34 cm), but
concluded pigs fed 10 mg/kg RAC (2.20 cm) had less (P < 0.001) 10th rib fat depth than
pigs not fed RAC. Of the 17 studies evaluated, only four reported a decrease \( (P < 0.05) \) in 10th rib fat depth for pigs fed 10 mg/kg RAC when compared with pigs not fed RAC. Recent literature (Fernández-Dueñas et al., 2008; Carr et al. 2009; Boler et al., 2011; Kutzler et al., 2010, 2011; Hinson et al., 2011, 2012a, 2012b; Tavárez et al., 2012) coincide with this data and report no differences \( (P > 0.05) \) in 10th rib fat depth between RAC and pigs not fed RAC. Yet, Rickard et al. (2012) and Pompeu et al. (2013) reported a decrease \( (P < 0.05) \) in 10th rib fat depth of RAC pigs when compared to pigs not fed RAC \((2.34 \text{ vs. } 2.66 \text{ cm} ; 1.95 \text{ vs. } 2.05, \text{ respectively})\). Furthermore, Gerlemann et al. (2013) reported pigs fed a continuous dose of 7.4 mg/kg RAC \((2.15 \text{ cm})\) had decreased \( (P < 0.05) \) 10th rib fat depth in comparison to pigs not fed RAC \((2.27 \text{ cm})\), but pigs fed a 5 to 10 mg/kg step-up RAC feeding program \((2.35 \text{ cm})\) did not differ \( (P > 0.05) \) from pigs not fed RAC.

Apple et al. (2007a) reported a greater \( (P < 0.001) \) loin muscle area \((\text{LMA})\) for RAC pigs fed a 5 \((37.9 \text{ cm}^2)\) and 10 mg/kg RAC \((39.1 \text{ cm}^2)\) when compared to pigs not fed RAC \((35.6 \text{ cm}^2)\). Of the nine studies evaluated, 12 reported RAC fed pigs had greater \( (P < 0.05) \) LMA when compared to pigs not fed RAC. Similarly, Carr et al. (2009) reported pigs fed 10 mg/kg RAC \((51.19 \text{ cm}^2)\) had greater \( (P < 0.05) \) LMA than pigs not fed RAC \((47.81 \text{ cm}^2)\), yet pigs fed 5 mg/kg RAC did not differ \( (P > 0.05) \) from pigs not fed RAC. Kutzler et al. (2010) reported pigs fed 10 mg/kg RAC \((55.42 \text{ cm}^2)\) had greater \( (P < 0.01) \) LMA than pigs not fed RAC \((52.23 \text{ cm}^2)\). Furthermore, both Hinson et al. (2011) and Rickard et al. (2012) reported pigs fed 7.4 mg/kg RAC \((51.21 \text{ cm}^2 \text{ and } 52.64 \text{ cm}^2; \text{ respectively})\) had greater \( (P < 0.01) \) LMA than pigs not fed RAC \((44.19 \text{ cm}^2 \text{ and } 47.52 \text{ cm}^2; \text{ respectively})\). Commercially, a common way to measure muscling on
carcasses has been to measure loin depth with a Fat-O-Meater. Fernández-Dueñas et al. (2008), Kutzler et al. (2011), and Hinson et al. (2012a) reported no differences (P > 0.05) in loin depth between RAC and non-RAC pigs. Boler et al. (2011), Tavárez et al. (2012), Gerlemann et al. (2013), and Pompeu et al. (2013) reported greater (P < 0.05) loin depth in RAC fed pigs when compared to pigs not fed RAC, with magnitude of differences ranging from 2.00 to 3.39 mm.

Apple et al. (2007a) reported estimated carcass lean was greater (P < 0.001) in pigs fed 10 mg/kg RAC when compared to pigs not fed RAC (52.7 vs. 51.4%; respectively), yet no differences (P > 0.025) were reported between pigs fed 5 mg/kg RAC when compared to pigs not fed RAC (52.3 vs. 51.4%; respectively). Furthermore, Pompeu et al. (2013) reported pigs fed 7.4 mg/kg RAC had greater (P < 0.001) estimated carcass lean when compared to pigs not fed RAC (52.96 vs. 52.24%, respectively). Likewise, Gerlemann et al. (2013) reported pigs fed continuous 7.4 mg/kg RAC had greater (P < 0.05) estimated carcass lean than pigs fed 5 to 10 mg/kg RAC and pigs not fed RAC (51.89 vs. 51.34%; respectively). On the other hand, Rincker et al. (2009), Kutzler et al. (2010), Kutzler et al. (2011) and Hinson et al. (2012a) reported no differences (P > 0.05) in estimated carcass lean between RAC and non-RAC pigs.

*Ractopamine hydrochloride: Effect on fresh meat quality*

Parameters when evaluating fresh pork quality include, but are not limited, loin pH, water holding capacity, color (both subjectively and objectively), firmness, marbling/intramuscular fat content, and tenderness. While parameters used to assess loin quality are an adequate way to measure lean pork quality, other parameters, most notably
iodine value, are used to assess fat quality. As RAC increases lean growth in pigs, it is important to ensure pork fat (bellies) from RAC pigs maintains usability and value.

Apple et al. (2007a) reported a summary of multiple studies ranging from 1990 to 2005 and concluded the effect RAC had on loin pH, percent moisture, and drip loss was not different (P > 0.05) when compared to pigs not fed RAC. Likewise, Fernández-Dueñas et al. (2008) fed pigs 0, 5, or 7.4 mg/kg RAC for 21 to 28 d and reported no differences (P > 0.05) in loin pH when compared to pigs not fed RAC. Furthermore, Kutzler et al. (2011) pooled RAC dose (5.0 and 7.4 mg/kg) and durations (7 to 35 d) and reported no differences (P > 0.05) between the pH of loins or hams from RAC and non-RAC pigs. On the other hand Rincker et al. (2009) reported loins from pigs fed 5 mg/kg RAC had greater (P < 0.01) 24-h pH values than pigs not fed RAC (5.80 vs. 5.74) and maintained this advantage (P < 0.01) at 7 d (5.70 vs. 5.62). Furthermore, Kutzler et al. (2010) and Rickard et al. (2012) reported greater (P < 0.01) pH values for RAC loins when compared to non-RAC loins (5.56 vs. 5.48 and 5.64 vs. 5.57). Rincker et al. (2009) and Kutzler et al. (2010, 2011) reported no differences (P > 0.05) in moisture percentage of loins from RAC and non-RAC pigs. Kutzler et al. (2010) reported less (P < 0.01) drip loss from loins from RAC pigs when compared to pigs not fed RAC (4.31 vs. 5.59%). Yet, Hinson et al. (2011) reported no difference (P > 0.05) in drip loss of loins from RAC or non-RAC pigs (5.11 vs. 6.21).

Pork color can be measured subjectively (NPPC color standards, 1999) and objectively [Minolta L*, a*, and b* color values; CIE (Commission internationale de l'eclairage), 1978]. Apple et al. (2007a) reported 3 of 15 studies published between 1990 and 2005 reported greater (P < 0.05) subjective color scores (darker lean tissue) for loins
from RAC pigs when compared to loins from pigs not fed RAC, whereas the remaining 12 of 15 studies reported no differences (P > 0.05). Furthermore, Rincker et al. (2009), Kutzler et al. (2010, 2011), and Rickard et al. (2012) reported no differences (P > 0.05) in subjective color between loins from RAC and non-RAC pigs. On the other hand Hinson et al. (2011) reported lower (P = 0.04) subjective color scores (lighter lean tissue) for loins from RAC pigs than pigs not fed RAC (2.54 vs. 2.89; respectively). Apple et al. (2007a) summarized studies published between 1990 and 2005 and reported 7 of 8 studies showed loins from RAC pigs and pigs not fed RAC had no differences (P > 0.05) in L* values, 5 of 6 studies showed loins from RAC pigs had lesser (P < 0.05) a* values than pigs not fed RAC, and 5 of 7 studies showed loins from RAC pigs had lesser (P < 0.05) b* values than pigs not fed RAC. Furthermore, Rincker et al. (2009), Kutzler et al. (2010, 2011), Hinson et al. (2011), and Rickard et al. (2012) reported no differences (P > 0.05) in L* values between loins from RAC pigs and pigs not fed RAC. Additionally, Rincker et al. (2009), Kutzler et al. (2010), Hinson et al. (2011), and Rickard et al. (2012) reported lesser (P < 0.05) a* values in loins from RAC pigs than pigs not fed RAC with magnitude of differences ranging from 0.49 (Rickard et al., 2012) to 1.69 (Kutzler et al., 2010), while Kutzler et al. (2011) reported no differences (P > 0.05) between loins from RAC pigs and pigs not fed RAC. Rincker et al. (2009) and Kutzler et al. (2010) reported lesser (P < 0.01) b* values for loins from RAC pigs when compared to pigs not fed RAC (3.46 vs. 3.87 and 4.29 vs. 5.65; respectively); whereas, Kutzler et al. (2011), Hinson et al. (2011), and Rickard et al. (2012) reported no differences (P > 0.05) in b* values between loins from RAC and non-RAC pigs.
Watkins et al (1990) was the only study prior to 2005 to report a difference in subjective firmness scores. In that study pigs fed 10 or 20 mg/kg RAC had greater (P < 0.05) firmness scores than pigs not fed RAC, however pigs fed 5 mg/kg RAC did not differ (P > 0.05) from pigs not fed RAC in their firmness scores. Furthermore, Kutzler et al. (2010) and Rickard et al. (2012) reported loins from RAC pigs were firmer (P < 0.05) than loins from non-RAC pigs (2.50 vs. 1.96 and 2.30 vs. 1.96; respectively). Whereas, Rincker et al. (2009) and Kutzler et al. (2011) reported no differences (P > 0.05) in firmness between loins from RAC pigs and pigs not fed RAC.

Apple et al. (2007a) reported Warner Bratzler Shear Force values (WBSF), a method for measuring cooked meat tenderness, in a consensus of seven studies dating from 1990 to 2005, pigs fed 10 mg/kg RAC had greater peak force (P < 0.011) than pigs not fed RAC (4.27 vs. 3.85 kg; respectively). Additionally, Fernández-Dueñas et al. (2008) reported pigs fed 5 mg/kg RAC had greater (P < 0.05) WBSF values than pigs not fed RAC, however pigs fed 7.4 mg/kg RAC were not different (P > 0.05) than pigs not fed RAC. On the other hand, Rincker et al. (2009), Kutzler et al. (2010, 2011), and Rickard et al. (2012) reported no differences (P > 0.05) for WBSF values between RAC and non-RAC pigs.

Apple et al. (2007a) reported a consensus from eleven studies dating from 1990 to 2005 (when RAC dose of greater than 10 mg/kg were allowed) for loin marbling scores (NPPC, 1991) and reported no differences (P = 0.99) between RAC and non-RAC pigs. Of the eleven studies used, 2 reported greater (P < 0.05) marbling in RAC pigs than non-RAC pigs, 1 reported less (P < 0.05) marbling in RAC pigs versus pigs not fed RAC, and 8 reported no differences (P > 0.05). Additionally, Apple et al. (2007a) reported 1 of 5
studies detected less (P < 0.05) percentage of extractible lipid in RAC loins compared to non-RAC loins, while the other 4 studies reported no differences (P > 0.05) between RAC and non-RAC loins. Additionally, Fernández-Dueñas et al. (2008), Rincker et al. (2009), Kutzler et al. (2010), Hinson et al. (2011), and Rickard et al. (2012) reported no differences (P > 0.05) in marbling scores and/or percentage of extractible lipid.

Scramlin et al. (2008) reported pigs fed 5.0 and 7.4 mg/kg RAC for 21 or 28 d prior to slaughter were not different (P > 0.05) in untrimmed or trimmed belly yield as a percentage of HCW. Furthermore, RAC had no effect (P > 0.05) on belly length, flop, thickness, pump uptake, and cook yield (Scramlin et al., 2008). Iodine value (IV) has been commonly used to estimate the unsaturation level of pork fat and ultimately serves as an indicator of fat quality (Madsen et al. 1992). Greater IV has been associated with a greater degree of unsaturated fatty acids, decreased firmness, and reduced fat quality. Pompeu et al. (2013) reported bellies from RAC pigs had greater (P < 0.01) IV than pigs not fed RAC (69.39 vs. 67.48). On the other hand, Apple et al. (2007b) reported bellies from RAC pigs tended to have greater IV than bellies from non-RAC pigs (69.45 vs. 68.51; P = 0.09).

**Ractopamine hydrochloride: Effect on carcass lean and cutting yields**

Estimated percent carcass lean equations can be calculated with several different procedures listed below (Burson & Berg, 2001):

**For ribbed carcasses:** lb. FFL = 8.588 + (0.465 x hot carcass wt., lb.) - (21.896 x 10th rib fat depth, in.) + (3.005 x 10\(^{th}\) rib loin muscle area, sq. in.)

**For unribbed carcasses measured with a ruler:** lb. SFFL = 23.568 + 0.503 x (hot carcass wt., lb.) - 21.348 x (last rib backfat thickness, in.)
For carcasses measured with the Fat-O-Meater: lb. SFFL = 15.31 + 0.51 x (warm carcass wt., lb.) - 31.277 x (last rib backfat thickness, in.) + 3.813 x (loin muscle depth, in.)

For carcasses measured with animal ultrasound system (AUS): lb. SFFL = 6.783 + 0.47 x (warm carcass wt., lb.) + 4.007 x (average loin muscle depth, in.) - 15.745 x (average backfat thickness, in.)

For live hogs measured with ultrasound using live weight: lb. lean = -0.534 + (0.291 x live wt., lbs.) - (16.498 x 10th rib fat depth, in.) + (5.425 x 10th rib loin muscle area, sq. in.) + (0.833 x sex of pig) (barrow=1, gilt=2)

For live hogs measured with ultrasound and using carcass weight: lb. lean = 5.7769 + (0.401 x warm carcass wt., lbs) - (18.838 x 10th rib fat depth, in.) + (4.357 x 10th rib loin muscle area, sq. in.) + (1.006 x sex of pig) (barrow=1, gilt=2)

The packers who utilize these estimates value pork carcasses on several different parameters that typically factor in weight, muscle, and trimness. Ractopamine appears to affect the cutability of the entire carcass and the above equations may not account for all of the carcass advantages of feeding RAC. To evaluate the effects RAC has on carcass cutting yields when primal pieces are separated and weighed, meat scientists can apply the following two equations:

Lean cutting yield

\[
\text{Lean cutting yield} = \left( \frac{\text{trimmed ham} + \text{trimmed loin} + \text{Boston butt} + \text{picnic}}{\text{chilled side weight}} \right) \times 100
\]

Carcass cutting yield

\[
\text{Carcass cutting yield} = \left( \frac{\text{lean cutting yield components} + \text{trimmed belly}}{\text{chilled side weight}} \right) \times 100
\]
These equations offer a more objective assessment of cutability using the four lean primals of pork carcass (lean cutting yield) and the total carcass (carcass cutting yields). Kutzler et al. (2011) used a variation of these two equations that actually took it a step further and broke down the lean cutting yield components into subprimals (inside ham + outside ham + knuckle + light butt + Canadian back + tenderloin + sirloin + boneless Boston butt + boneless picnic) and reported RAC pigs had a 1.22 percentage unit advantage in boneless lean cutting yield and a 1.21 percentage unit advantage in boneless carcass cutting yield when compared to pigs not fed RAC. Furthermore, Kutzler et al. (2011) reported a linear increase (P < 0.01) in lean cut yield % and carcass cut yield % as RAC duration increased over 7, 14, 21, 28 and 35 d durations.

Boler et al. (2011) reported whole hams from pigs fed 7.4 mg/kg RAC for 27 d prior to slaughter (12.56% of HCW) were 0.18 percentage units greater (P < 0.01) than whole hams of pigs not fed RAC (12.38% of HCW). Trimmed ham (11.28% vs. 11.06%; P < 0.01), inside ham (1.64% vs. 1.54%; P < 0.0001), outside ham (2.30% vs. 2.14%; P < 0.0001), the knuckle of ham (1.31% vs. 1.23%; P < 0.0001), and shank meat (1.19% vs. 1.17%; P = 0.05) were all greater when expressed as a percentage of HCW in RAC pigs in comparison to pigs not fed RAC (Boler et al., 2011).

Tavárez et al. (2012) reported whole shoulder pairs from pigs fed 7.4 mg/kg RAC for 28 d prior to slaughter were not different (P > 0.05) than whole shoulder pairs of pigs not fed RAC when expressed as a percentage of HCW. Yet, trimmed shoulder pairs from RAC pigs (18.31%) were greater (P < 0.01) than pigs not fed RAC (17.88%) when expressed as a percentage of HCW. Furthermore, paired boneless Boston butt shoulder from RAC pigs (8.03% of HCW) were 0.38 percentage units greater (P < 0.01) when
compared to pigs not fed RAC (7.65% of HCW; Tavárez et al., 2012). However, paired boneless picnic shoulders were not different (P > 0.05) in RAC pigs and pigs not fed RAC when expressed as a percentage of HCW.

Scramlin et al. (2008) reported paired untrimmed bellies, trimmed bellies, and spare ribs did not differ (P > 0.05) as a percentage of HCW in pigs fed 5.0 mg/kg or 7.4 mg/kg RAC for 21 or 28 d prior to slaughter when compared to pigs not fed RAC.

Carr et al. (2005) reported paired skin on loins from pigs fed 10 mg/kg RAC for 25-41 days prior to slaughter did not differ (P > 0.05) as a percentage of HCW when compared to pigs not fed RAC. However, paired Canadian back boneless loins (7.46% vs. 7.21%) and sirloins (2.05% vs. 1.86%) were greater (P < 0.05) as a percentage of HCW in RAC pigs when compared to pigs not fed RAC (Carr et al., 2005).

Based on the multiple studies currently available with primal and subprimal yields, a summary of cutability trials is needed.

**Ractopamine hydrochloride: Effect on further processed product quality**

Boler et al. (2011) reported cured hams from pigs fed 7.4 mg/kg RAC did not differ in cook yield (P > 0.05) and compositionally contained less fat (2.69 vs. 3.19% fat; P < 0.01) and greater protein (19.82 vs. 19.46% protein; P = 0.04). Yet, cured hams from RAC pigs had greater L* (lightness) values (66.04 vs. 64.48; P < 0.01) and lower a* (redness) values (12.11 vs. 12.61; P = 0.03) in comparison to pigs not fed RAC (Boler et al., 2011). Furthermore, cured hams from RAC and non-RAC pigs did not differ (P = 0.88) in break strength (an indication of protein binding).

Tavárez et al. (2012) reported iodine values of fresh pork shoulder from pigs fed 7.4 mg/kg RAC were greater (P < 0.01) than fresh shoulders from pigs not fed RAC.
(67.00 vs. 64.95%). However no differences (P > 0.05) between shoulders from RAC and non-RAC pigs in cure uptake, cook yield, or objective color was reported for cottage bacon or coppa (Tavárez et al., 2012).

Scramlin et al. (2008) reported bellies from RAC pigs did not differ (P > 0.05) in their pump yield or cook yield when compared to bellies from pigs not fed RAC, however pigs fed 5.0 mg/kg RAC (99.09%) had greater (P < 0.05) cook yield than pigs fed 7.4 mg/kg RAC (98.58%). Furthermore, bacon slices from RAC pigs were not different (P > 0.05) in moisture or fat percentage when compared to bacon slices from pigs not fed RAC (Scramlin et al., 2008). Based on these three studies, RAC has a no negative or positive effects on cook yield or cured color in further processed hams, shoulders, or bellies.

*Step-up RAC feeding strategies*

β-receptors can become desensitized or down-regulated with prolonged exposure to a β-agonist; this process consists of phosphorylation through the secondary receptors (Ferguson, 2001). When attempting to maximize return on investment with growth performance, feed efficiency, and carcass leanness. Step-up RAC feeding strategies provide another option in finishing programs and provide the producer options for implementing RAC. Step-up RAC feeding strategies start pigs at an initial RAC dose for a given amount of time and then increase to a greater RAC dose. This enables a greater average dose for longer durations at an overall reduced cost when feeding RAC. Step-up RAC feeding strategies can easily be accomplished while staying within label requirements of RAC.
Spurlock et al. (1994) explained that with prolonged exposure to a β-agonist, the receptor will become degraded, which will lead to a net loss of available membrane receptors. See et al. (2004) reported advantages (P < 0.05) in growth and some carcass traits (tenth rib fat depth and percent fat-free lean) when feeding a step-up RAC feeding strategy (5 mg/kg RAC for 14 d, 10 mg/kg RAC for 14 d, and 20 mg/kg RAC for 14 d), a step-down RAC feeding strategy (20 mg/kg RAC for 14 d, 10 mg/kg RAC for 14 d, and 5 mg/kg RAC for 14 d), or a constant RAC feeding strategy (11.7 mg/kg RAC) when compared to a non-RAC diet, however no differences (P > 0.05) between the three RAC feeding strategies were detected for growth traits over the entire period. Dressing percentage was greater (P < 0.05) in pigs fed step-up RAC and constant RAC doses in comparison to a step-down RAC feeding strategy; therefore it appeared inefficient to feed a step-down RAC feeding strategy (See et al., 2004). Armstrong et al. (2005) used two different step-up RAC feeding strategies, (5 mg/kg RAC for 14 d followed by 10 mg/kg RAC for 21 d and 5 mg/kg RAC for 21 d followed by 10 mg/kg RAC for 14 d) and compared these treatment diets to a constant dose of 5 mg/kg of RAC for 35 d and non-RAC diet and concluded live performance and carcass measurements were improved in all pigs fed RAC and pigs fed either the two RAC step-up feeding strategies had improved (P < 0.05) ADG, feed efficiency, loin depth, and lean weight in comparison to pigs fed 5 mg/kg RAC for 35 days. This study reported live and carcass advantages when feeding RAC step-up feeding strategies in comparison to constant RAC diets when pen integrity was maintained throughout the duration of the study (Armstrong et al., 2005). Furthermore, Hinson et al. (2012a) compared pigs fed a step-up RAC feeding strategy (5 mg/kg RAC for 21 d, followed by 7.4 mg/kg RAC for 14 d) and constant 5
mg/kg RAC and concluded that although all growth and carcass traits were similar (P > 0.05) within RAC diets for the 35 d period, the step-up feeding strategy pigs had greater (P < 0.05) feed efficiency (G:F and F:G) for the last 14 d of the finishing period. Yet this was expected as pigs in this study (Hinson et al., 2012a) were removed upon reaching 124.4 kg of BW, thus producing lower stocking density for slower growing pigs. Similarly, Gerlemann et al. (2013) reported no differences (P > 0.05) in growth performance between pigs fed a step-up feeding strategy (5 mg/kg RAC for 14 days, followed by 10 mg/kg RAC for 14 days) and constant 7.4 mg/kg RAC. However, the study reported that in multiple marketing strategies selling partial pens to be slaughtered soon after the onset of RAC, may lead to economic incentives that would allow RAC to be fed at a low dose (5 mg/kg) for shorter duration to fast growing pigs and fed for longer durations to help improve growth rates and carcass traits of the slower growing pigs. Step-up RAC feeding strategies provide the producer options and may be used as marketing strategies as technologies evolve in the future.

An example of a new technology that will be used with RAC in the future is immunological castration of male pigs. Briefly, when male pigs are immunologically castrated (IC), they are able to grow as an intact male for much of their life until a second anti-gonadotrophin-releasing factor (GnRF) injection is given at approximately 4 weeks after a primer immune injection. After the second anti-GnRF injection is given, a marketing window of 3 to 10 weeks is established. Overall, IC barrows have faster growth rates, improved feed efficiency, and increased carcass leanness over the grower-finisher period when compared to physically castrated (PC) barrows (Dunshea et al., 2001). Once the second anti-GnRF injection is given, the IC barrows will synthesize
nutrients like a PC leading to an increase in fat gain via de novo fatty acid synthesis (Cronin et al., 2003). Average daily feed intake of IC barrows increases to a level above PC barrows after the second injection (Puls et al., 2012) and changes in endogenous fat synthesis are also likely to occur. Thus feeding RAC with a step-up strategy may be advantageous to reduce fat gain and shift the increased energy intake to lean tissue gain (Rikard-Bell et al., 2009). However, when compared by Moore et al. (2009) no differences (P > 0.05) were detected for growth performance or carcass traits between using a step-up RAC feeding strategy (5 mg/kg for 14 days, followed by 10 mg/kg for 12 days) or constant 5 mg/kg RAC, yet the two technologies were successfully used together and had major impacts on growth performance. Overall, with diets pooled IC barrows fed RAC (1.29 kg/d, 75.2 kg) had 0.20 kg/d greater (P < 0.05) ADG and 4.5 kg greater (P < 0.05) HCW when compared to PC barrows not fed RAC (1.09 kg/d, 71.2 kg). Furthermore, IC barrows fed pooled RAC doses had 0.09 kg/d greater ADG (1.29 vs. 1.20 kg/d), 0.21 kg/d less daily feed intake (3.68 vs. 3.89 kg/d), and 0.37 less feed to gain conversion (2.89 vs. 3.26). At the same time, PC barrows fed pooled RAC doses had 0.12 kg/d greater ADG (1.21 vs. 1.09 kg/d), 0.09 kg/d greater average daily feed intake (3.43 vs. 3.34 kg/d), and 0.15 less feed to gain conversion (2.92 vs. 3.07).

**Niche Marketing**

Niche market products specialize in a particular aspect of that market that sets itself apart from other products within that sector of the market. McMullen (2006) explained a niche market provides customers with specific needs of a distinct product and typically will receive greater than average prices. Niche marketing has been increasingly prevalent in the meat industry as consumers have more distinct demands today and
producers are more dedicated to starting these markets than ever before (Carr et al., 2008). While niche marketing in pork has been nowhere near as widespread as in other food commodities; unique opportunities in pork niche marketing are still present (Honeyman et al., 2006). Honeyman et al. (2006) discussed how pork niche markets are centered on product differentiation in two general ways, superior or unique product quality, and social or credence attributes.

**Berkshire Pork**

An example of niche marketing focused on providing customers with improved pork quality has been used with purebred Berkshire pork. The Berkshire breed was originally imported to the United States from England in the early 1800s and Berkshire breeders have continued to center breeding strategies of producing pigs with above average meat quality centering on a high ultimate pH score, improved loin firmness/drip loss, enhanced meat color, and higher cooked loin quality (McMullen, 2006). Demand for purebred Berkshire pork has been exceeding supply in many areas in the world, and particularly Japan (McMullen, 2006). The American Berkshire Association (ABA) markets Berkshire pork on quality and focus of re-emphasizing to breeders this competitive advantage as industry remains to produce pigs with an emphasis on carcass leanness.

Ryu et al. (2008) reported purebred Berkshire pork had a greater proportion of type I muscle fibers, and correspondingly had a greater pH, were less pale (lower lightness scores), and had greater WHC (lower drip loss percentage) when compared to Landrace, Yorkshire, and Yorkshire x Landrace x Duroc pigs. Likewise, Lee et al. (2012) reported a greater proportion of type I muscle fibers leading to improved meat
color and also reported cooked loins from Berkshire pigs were softer, more tender, and had a more desirable aroma (P < 0.05) than loins from Duroc, Yorkshire, and Landrace pigs. Suzuki et al. (2002) reported Berkshire pigs had greater (P < 0.05) water holding capacity when compared to Durocs, Berkshire x Landrace-Duroc cross, and Duroc x Landrace-Duroc cross pigs and used a combination of drip loss and cooking loss tests. Stoller et al. (2003) reported Berkshire pork loin chops were more (P < 0.05) tender when compared to loin chops from purebred Duroc and “high-lean” crossbred counterparts, and this was the case with both a sensory panel using a 10 pt. scale where 1 = tough and 10 = tender (Berkshire = 7.10, Duroc = 5.27, high-lean = 6.10) and Instron mechanical assessment (greater values indicate reduced tenderness) using WBSF (Berkshire = 4.97 kg, Duroc = 6.10 kg, high-lean = 5.95 kg). The advantage in these quality traits has led Japanese pork markets to setting a 50% premium for Berkshire pork when compared to a typical Japanese three-way cross (Suzuki et al., 2002).

Even with the advantages of purebred Berkshire pork from a meat quality standpoint, they are rarely used in the commercial industry, because they are often viewed as inefficient in growth and reproductive performance (McMullen, 2006). A typical purebred Berkshire sow will market 10 to 14 pigs per year and those pigs will have 10 to 15 percent poorer feed efficiency than the average commercial pig (McMullen, 2006). Performance shortcomings along with the way pork is marketed (carcass weight, fat depth, and muscle) may explain why Berkshires have not been used as a source of commodity pork.
Reduced Sodium Meat Products

Consumption of meat, and particularly processed meat products, has been suspect of causing an increased risk of chronic diseases such as obesity, cancer and stroke (Jimenez-Colmenero et al., 2001). On the other hand, meat consumption has many dietary benefits because of increased protein and a balanced amino acid profile, along with the availability of essential vitamins and minerals. Yet some viewpoints hold the meat industry liable for reducing health (McAfee et al., 2010). Particularly in the U.S., incidences of obesity, cardiovascular disease, hypertension and continue to become more prevalent (CDC, 2005). Processed foods, such as processed meat products, are a primary source of sodium in the diet (Ruusunen and Puolanne, 2005). Sodium is essential in the diet and plays vital roles in regulation of blood pressure, water transport into and out of cells, tissue osmolality, and transmission of nerve cell impulses (Guinee, 2004).

However, excessive intake of sodium has been linked to hypertension and an increase in chronic diseases and U.S. consumer’s sodium intake exceeds nutritional recommendations (Ruusunen and Puolanne, 2005). The U.S. Dietary Guidelines reports the average American consumes approximately 3,300 mg of sodium per day, yet it is recommended adults consume less than 2,300 mg of sodium per day (CDC, 2012). The U.S. Department of Health and Human Services (2010) established 2,300 mg of sodium a day as an upper limit and 1,500 mg of sodium a day as an adequate limit. Engstrom et al. (1997) reported meat and meat products contribute for 21% of the average American’s sodium intake. Fresh meat only contains 100 mg of sodium per 100 g of product; however sodium is typically added during processing of meat such as cured and smoked ham and bacon products (Ruusunen and Puolanne, 2005).
Non-meat ingredients play a crucial role in meat processing, and ingredients range in purpose and aid in helping meat processors effectively present consumers with desired products. One of the most common non-meat ingredients used in curing solutions is sodium chloride (NaCl), or more commonly known as table salt. For many years, NaCl has been used as a preservative due to its ability to lower water activity by binding and trapping water through charge-charge interactions (Weiss, 2010). Sodium chloride contains 39.3% sodium and is not regulated in many processed meat products, however too much salt will lead to a “salty” flavor, which is undesirable to the consumer, so it is regarded as self-regulated (Desmond, 2006). Consumers have become accustomed to the taste of sodium chloride and often prefer this taste in their food and notice when it is missing (Desmond, 2006). The effect NaCl has on flavor can be best described as the Na⁺ cation with Cl⁻ anion modifying the perception of taste and it is widely speculated that NaCl acts as an enhancer and improves the flavor characteristics of meat products (Ruusunen and Puolanne, 2005). Sodium chloride plays an integral role in meat processing and when reduced will have negative impacts on water holding capacity, protein binding, and fat binding functions and requires other ionic compounds to replace these functions (Doyle and Glass, 2010). Aliño et al. (2010) reported a reduction of brine influenced swelling pressure of pork meat. The increase of binding properties improves texture and corresponds to a decrease in cooking loss and therefore increases juiciness and supplementing mouth feel (Desmond, 2006). Another concern when reducing NaCl levels without any other preservative measure is a reduction in product shelf life and it is important to examine microbial shelf life and product safety in products with reduced NaCl (Desmond, 2006). Ruusunen and Puolanne (2005) reported the most detrimental
effect from a consumer-perspective when lowering NaCl content in processed meat products has been the weaker characteristic flavor. Desmond (2006) reported the most detrimental effect, from a meat processor’s standpoint, of lowering sodium and replacing it with an alternative is the cost. Sodium chloride substitutes can increase the cost of the cure solution.

Because of the potential health concerns and consumer demand of high sodium products, there is a need to conduct research to find alternative ingredients for processed meat products that would lower sodium intake. As an industry, consumers, marketers, and food processors alike have realized the need to lower sodium in meat products and have made attempts to do so (Ruusunen and Puolanne, 2005). However, sacrificing the obvious advantages of sodium chloride can be challenging when producing a product consumers will still find acceptable.

Salt cannot be completely eliminated due to its binding capabilities and ability to improve texture of processed products, however it can be reduced and salt reductions are being made in many instances (Desmond, 2006). Meat processors have many different options for lowering the sodium content in meat products, which include using salt substitutes, flavor enhancers and masking agents, and utilizing different processing techniques (Desmond, 2006). Potassium chloride substitution or a combination of KCl and sodium chloride has been an alternative commonly used in low sodium or reduced sodium products. Desmond, 2006 reports that in sodium and potassium salt mixtures typical inclusion rates for KCl is 25 to 40%. Pérez-Juan, Flores, and Toldrá (2006) analyzed the effect of different salts (NaCl, KCl, MgCl₂, and CaCl₂) on the binding ability of porcine soluble protein extracts and reported KCl produced a similar salting out
effect as NaCl, while MgCl₂ and CaCl₂ did not produce a salting out effect on the volatile compounds studied. Although, KCl is a capable substitute in its binding capabilities, it is only added at limited levels because it tends to leave products with a very strong and undesirable after taste, and for this reason is added with limiting inclusion rates in processed meat products (Ruusunen & Puolanne, 2005). To compensate, when KCl has been added, masking agents such as flavor enhancers can also be used to improve the saltiness of the product (Desmond, 2006).

Consumers continue to demand meat products that are healthy and inexpensive, while still tasting, looking, and smelling like traditionally formulated products that the general public has become accustomed to (Weiss, 2010). Therefore, the strategy mentioned to reduce NaCl content in meat products is something that will affect both the producer and consumer in the near future. If consumers continue to demand products with lower sodium, it only makes sense to find ways to make products that will provide variety, acceptable taste, a desirable texture, and nutritional value to consumers while lowering the concentration of NaCl in processed products.

**Research Objectives**

The pork industry emphasizes the production of fast growing pigs that are efficient to produce with an acceptable amount of carcass leanness and greater carcass cutability. With that being said, both producers and packers strive to use available feed additive resources to help produce faster growing pigs with acceptable leanness. A summary of the effect RAC has on carcass cutability and fresh belly quality is needed. Potential feed additives designed to scientifically improve finishing performance also need to hold up in post-mortem quality testing from both a fresh meat and processed meat.
standpoint, while improving live performance on a wide variety of genetic lines. The overall goals were to use the benefits of RAC to produce purebred Berkshires that grow more efficiently and to stay leaner until slaughter, while maintaining above average pork quality, which makes them an acceptable raw material source for low sodium ham and bacon products.

**Live Research**

The primary objective of the live portion of the research was to analyze the effects of a step-up RAC feeding program on Berkshire pigs. There have only been a few published reports on the effects of RAC Berkshire pigs and none examining the possibilities of a step-up feeding program. So the objectives were to evaluate the effects of feeding purebred Berkshire pigs a 28 day RAC step-up feeding program on growth rate, intake, feed efficiency, lean muscle growth, and fat deposition. Real-time ultrasonic images were used to measure fat thickness and loin muscle area during the finishing trial.

**Post-Mortem Research**

Feeding RAC has been reported to increase (P < 0.01) ultimate pH in pork (Rincker et al., 2009) and numerous other studies show similar magnitude of differences in pH between RAC and non- RAC pigs (Apple et al., 2004; Kutzler et al., 2010; Hinson et al., 2011; Rickard et al., 2012). Additionally, Berkshire pork has a greater proportion of type I muscle fibers and a greater pH when compared to Landrace, Yorkshire, and Yorkshire x Landrace x Duroc pigs (Ryu et al., 2008). Pork quality attributes, specifically attributes determining water holding capacity (subjective firmness, subjective color, 21-d purge loss, and cook loss) are improved when ultimate pH is greater (Boler et al., 2010). On the other hand, salt impacts a number of functional properties in meat
products and lowering sodium in curing solutions may lower water holding capacity 
(Terrell, 1983). Thus, the push for processors to produce products low in sodium content 
without sacrificing flavor, appearance, and most importantly texture makes Berkshire 
pork from RAC pigs a candidate to test if a product with increased pH will overcome the 
reduction in sodium.

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Chapter 2: Review: Meta-analysis of the effects of ractopamine hydrochloride on carcass cutability and primal yields of finishing pigs

ABSTRACT: The objective was to summarize previous literature, using a meta-analysis approach, on the effects of ractopamine hydrochloride (RAC) when fed at doses of 5 to 10 mg/kg for up to 35 days prior to harvest on carcass cutability and belly quality of finishing pigs. The meta-analysis provided an opportunity to determine the consensus of previously published literature. Ten studies were evaluated to determine cutting yields and eight studies were used to determine belly quality in this review. Pooled dietary RAC concentrations (5 mg/kg, 7.4 mg/kg, 10 mg/kg, and step-up feeding programs) and pooled feeding durations (up to 35 d prior to harvest) were compared to pigs not fed RAC (controls) and were analyzed as a meta-analysis using the mixed procedure of SAS.

Ractopamine inclusion was the fixed effect in the model and the individual study was considered a random variable. The only difference between RAC and control pigs for whole primals as a percentage of side weight was the whole ham (P <0.01). No other differences were detected for whole primals as a percentage of side weight. Yet, differences were detected in the standardized trimmed primal yields. A difference (P < 0.05) in percentages of the side weight was detected for the Boston butt, trimmed loin, and trimmed ham. This translated into RAC pigs having a carcass cutting yield (74.70% vs. 73.69%, respectively; P= 0.02; SED = 0.33) advantage of 1.01 percentage units and a bone in lean cutting yield (61.43% vs. 60.33%, respectively; P = 0.03; SED = 0.40)
advantage of 1.10 percentage units when compared to control pigs. The advantage in bone-in cutability was a result of increased boneless sub primal yields in each of the lean cuts (shoulder, loin, and ham). When further evaluated, RAC pigs had a boneless shoulder (Boston butt + picnic) yield advantage of 0.32 percentage units (P < 0.01; SED = 0.11), a 0.43 percentage unit (P = 0.01; SED = 0.13) yield advantage in the boneless loin (Canadian back + tenderloin + sirloin), and a 0.51 percentage unit (P < 0.001; SED = 0.11) advantage in the boneless ham (inside + outside + knuckle). A boneless yield was calculated using a summation of the percentage of side weight from the boneless shoulder, boneless loin, and boneless ham, which resulted in a 1.08 percentage unit (36.28% vs. 35.20%, respectively; P = 0.002; SED = 0.25) advantage of RAC pigs when compared to control pigs. There were no subprimal yield differences (P = 0.93) in the trimmed belly between RAC pigs (12.18%) and control pigs (12.18%). However, RAC pigs (15.27 cm; 73.42) had narrower flop distances (P=0.02; SED=0.62) and greater iodine values (P=0.01; SED=0.33) respectively, when compared to control pigs (17.08 cm; 71.48).

**INTRODUCTION**

Ractopamine hydrochloride (RAC) has been marketed under the trade name Paylean (Elanco Animal Health; Greenfield, IN). Even though RAC received approval from the Food and Drug Administration over 10 years ago (December 1999), it is still the only phenethanolamine β-adrenergic agonist approved as a dietary supplement in finishing swine diets. Currently, RAC label claims state it can be used to increase rate of
weight gain, improve feed efficiency, and increase carcass leanness when used in pigs weighing at least 68 kg and are fed a complete ration, with at least 16% crude protein, for the last 20.4 to 40.8 kg of weight gain prior to harvest. Apple et al. (2007a) confirmed each of these claims in a meta-analysis of data from the time of approval through 2005. This review was very comprehensive, yet it did not focus on the effects of RAC on carcass cutability and specific primal yields in relation to side weight. Presumably, for RAC to be effective, allometric growth, which can be defined as the growth rate of parts (primals) of the animal in relationship to the growth rate of the entire animal, must be influenced. It is well accepted that dietary RAC increases loin muscle area between 2.3 and 3.5 cm² and at the same time slightly reduces 10th rib back fat thickness (Apple et al., 2007a), but this does not explain the increase in the amount of closely-trimmed primals yielded as a percentage of side weight relative to pigs not fed RAC (controls). Additionally, there has been no consensus in the literature for the effects of RAC on belly yield and quality. Ham and loin weights of finishing pigs steadily increased over the years, but belly weights stayed relatively unchanged (Stetzer and McKeith, 2003). This led to thinner bellies that reduced processing yields (Person et al., 2005). Therefore, it was important to understand which primal pieces are most directly influenced by the use of RAC, specifically, the two most valuable primal pieces, the belly and loin. The objective of this meta-analysis was to determine the effects of RAC on carcass cutability in terms of primal and subprimal yield and belly quality of finishing pigs. To make the paper relevant with RAC’s current label dosage and duration, the review centered on data with a dose of 5 to 10 mg/kg for up to 35 days prior to harvest.
MATERIALS AND METHODS

A meta-analysis was conducted using data from studies where pigs were fed using current label instructions. A meta-analysis is a modern statistical approach used to summarize previous literature, create an understanding of the relationship of past studies, and allow overall conclusions to be made (Sauvant et al., 2008). Step up RAC programs meeting label criteria were also included. A total of nine references, though some references included more than one study, were used to determine the effects of RAC on primal and subprimal yields of finishing pigs. These references were used to determine total carcass cutability and included Crome et al. (1996), Mimbs (2003); Carr et al. (2005a, 2009), Fernández-Dueñas et al. (2008), Kutzler et al. (2010, 2011), Boler et al. (2011), and Tavárez et al. (2012). Eight studies, meeting the same criteria as for cutability, were used to determine the effects of RAC on belly thickness, belly flop, and iodine value (Mimbs, 2003; Carr et al., 2005b; Shook, 2006; Apple et al., 2007b; Scramlin et al., 2008; Amaral et al., 2009; Leick et al., 2010; Rickard et al., 2012;).

Pooled one way ANOVA was utilized to test between pooled dietary RAC concentrations (5 mg/kg, 7.4 mg/kg, 10 mg/kg, and step-up feeding programs) and feeding durations (up to 35 d prior to harvest) in relation to controls and then analyzed as a meta-analysis using the mixed procedure of SAS (SAS Inst., Cary, NC). Ractopamine inclusion was the fixed effect in the model and individual study was considered a random variable. Average dose across all studies was calculated to be 7.4 mg/kg for studies used for carcass cutability determination and 7.6 mg/kg for belly quality determination.
RESULTS AND DISCUSSION

Whole Primal Yield

Subtle differences in fabrication specifications were reported in each study therefore importance should be placed on the magnitude of differences between RAC and controls rather than absolute values. There were no differences among whole primal weights (skin-on, untrimmed) when expressed as a percentage of side weight, except for whole ham (Table 1).

Whole Ham In all the studies used, hams from RAC pigs (23.17%) made up a greater percentage (P < 0.01; SED = 0.08) of side weight than hams from control pigs (22.79%; Table 1). Kutzler et al. (2011) reported the least (0.11 percentage units) magnitude of difference between treatments and Carr et al. (2009) reported the greatest magnitude of difference between treatments (0.81 percentage units). Boler et al. (2011) reported single ham primal and subprimal data as a percentage of hot carcass weight as opposed to a two ham percentage of hot carcass weight or a single ham percentage of side weight, so the total percentage may be slightly lesser than expected, but the overall magnitude of the differences are representative of published literature.

The average magnitude of the response difference in each of the other 3 whole primals was a 0.17 percentage unit advantage for control pigs in the whole shoulder, a 0.02 percentage unit advantage for control pigs in the whole loin, and a 0.04 percentage unit advantage for RAC pigs in the whole belly (Table 1). Overall, the meta-analysis was representative of the individual studies as the two had similar magnitude of differences.
Whole Shoulder

Five studies were used to evaluate the effects of RAC on whole shoulders. Two of 5 studies showed advantages in whole shoulder as a percentage of side weight in RAC pigs. The minimum difference in whole shoulder percentage of side weight was -0.46 percentage units (Kutzler et al., 2010) and the maximum difference was 0.15 percentage units (Fernández-Dueñas et al., 2008). The average magnitude of difference (P = 0.09; SED = 0.09) for the whole shoulder as a percentage of side weight between RAC (23.89%) and control pigs (24.06%) was -0.17 percentage units (Table 1).

Whole Loin

Four studies were used to calculate the least squares means in the whole loin. Crome et al. (1996) and Carr et al. (2005a) reported loins from RAC pigs comprising a greater percentage of side weight relative to control pigs. Fernández-Dueñas et al. (2008) and Kutzler et al. (2010) reported loins from RAC pigs made up a smaller percentage of side weight relative to percentages of whole loins from control pigs. The average magnitude of difference (P = 0.93; SED = 0.16) for the whole untrimmed loin as a percentage of side weight between RAC pigs (25.15%) and control pigs (25.17%) was -0.02 percentage units (Table 1).

Whole Belly

Only three studies were available to calculate the difference in whole belly percentage between RAC and control pigs. In 2 of the 3 reports (Kutzler et al., 2010; Carr et al., 2005a) whole bellies of control pigs comprised a greater percentage of side weight relative to whole bellies from RAC pigs. Only Kutzler et al. (2011) reported RAC bellies made up a greater proportion of side weight relative to control pigs. In each case, the magnitude of the absolute difference between the two treatments was ≤ 0.22 percentage units. Overall, the average magnitude of difference (P = 0.74; SED = 0.11)
for the whole untrimmed belly as a percentage of side weight between RAC (17.45%) and control (17.41%) pigs was 0.04 percentage units (Table 1).

**Trimmed Primal Yield**

Several differences were detected in the standardized trimmed primals. When expressed as a percentage of side weight, Boston butt, trimmed loin, and trimmed ham percentages were greater (P < 0.05) in RAC pigs compared to control pigs (Table 1). It was not surprising that percentage differences were detected in these cuts, as these were standardized by trimming to a specific fat thickness. RAC pigs had a greater estimated carcass lean when fed at all inclusion levels and less back fat thickness when fed high RAC levels (10 mg/kg) in comparison to control pigs (Apple et al., 2007a; Kutzler et al., 2011).

The difference in lean weight after trimming fat away was further validated by the clear plate of RAC pigs being 0.08 kg lighter (P = 0.01; SED = 0.02) and making up 0.31 fewer % units (P < 0.01; SED = 0.05) of side weight in comparison to control pigs (Table 2). Thus, the trimmed Boston butt of RAC pigs (8.35) was 0.15 % units greater (P = 0.01; SED = 0.05) than control pigs (8.19) as a percentage of side weight (Table 1).

Eight studies were used to conduct the meta-analysis of data on the bone-in Boston butt. Seven of eight studies reported the trimmed bone-in Boston butts from RAC pigs (8.35%) comprised a greater percentage (P = 0.01; SED = 0.05) of the side weight relative to the trimmed bone-in Boston butt percentages from control pigs (8.19%; Table 1). The differences in magnitude of response ranged from a high of 0.40 percentage units (Carr et al., 2009; Tavárez et al., 2012) to a low of -0.02 percentage units (Mimbs, 2003).
There were no differences (P=0.45; SED=0.05) in bone-in trimmed picnic as a percentage of side weight between RAC and control pigs (Table 1).

Like the Boston butt, differences in the loin became apparent after trimming (Table 1). Again this was likely related to RAC pigs being leaner in some cases relative to control pigs. Five of six studies showed an increase in trimmed loin as a percentage of side weight in RAC pigs with a maximum of 0.62 percentage units (Carr et al., 2005a). Kutzler et al. (2010) was the lone study to report a 0.06 decrease in trimmed loin as a percentage of side weight in RAC pigs. Trimmed loins from RAC pigs (21.04%) made up 0.38 percentage units more (P = 0.04; SED = 0.16) of the side weight than trimmed loins from control pigs (20.66%; Table 1).

Differences observed in whole hams as a percentage of side weight persisted when trimmed. Trimmed hams from RAC pigs (20.20%) comprised 0.43 percentage units more (P < 0.01; SED = 0.12) of the side weight than control pigs (19.77%). All six studies used in the meta-analysis reported trimmed ham as a percentage of side weight in RAC pigs to be greater than trimmed ham as a percentage of side weight in control pigs. The magnitude of difference as a percentage of side weight ranged from a high of 1.13 percentage units (Crome et al., 1996) to a low of 0.22 percentage units (Boler et al., 2011).

Trimmed bellies as percentage of side weight did not differ (P = 0.93; SED = 0.06) between RAC and control pigs. In six total studies evaluated, four studies reported bellies from control pigs made up a greater percentage of side weight (Crome et al., 1996;
Mimbs, 2003; Carr et al., 2005a; Kutzler et al., 2010), whereas the others reported the opposite effect (Carr et al., 2009; Kutzler et al., 2011).

Subprimal Yield

**Boneless Boston Butt** All eight studies noted a greater percentage of side weight was evident in boneless Boston butt shoulders from RAC pigs when compared to control pigs (Table 2). Boneless Boston butt shoulders of RAC pigs (7.52%) made up 0.20 more percentage units (P < 0.0001; SED = 0.03) of side weight when compared to control pigs (7.32%). The magnitude of these differences as a percentage of side weight ranged from 0.10 percentage units (Kutzler et al., 2011) to 0.35 percentage units (Carr et al., 2005a). The magnitude of RAC response in boneless Boston butts was similar to the response for bone-in Boston butts. Cutability advantages of boneless Boston butts were expected. The scapula is the only bone present in the Boston butt and the absolute weight of the bone was not different between the two treatments. Therefore, by removing the additional weight of the clear plate on control pigs; the cutability difference must be attributed to muscle.

**Boneless Picnic** The results of removing the bones in the picnic shoulder were not consistent with the results observed after removing the scapula from the Boston butt. Bone-in picnic percentages did not differ (P = 0.45; SED = 0.05) between RAC and control pigs (Table 1), but boneless picnic shoulders of RAC pigs comprised a greater percentage (P = 0.01, SED = 0.04) of side weight relative to control pigs (Table 2). Boneless picnic shoulders of RAC pigs (8.18%) made up 0.12 percentage units more of the side weight when compared to control pigs (8.06%). Seven of eight studies show an
increase in boneless picnic shoulder as a percentage of side weight, only Carr et al. (2009) reported that control pigs cut a greater percentage of boneless picnic shoulder (0.04 percentage units). Crome et al. (1996) reported the greatest difference, with RAC pigs having 0.43 percentage units more boneless picnic shoulder than control pigs. Greater cut-out values in RAC pigs were observed in the boneless picnic shoulder; whereas no differences were observed in the bone-in picnic shoulder. This may be due to the percentage of bone in the picnic shoulder relative to the amount of muscle tissue. Bone weight and percentage of side weight were calculated by subtracting the boneless weights from the bone-in weights. Absolute picnic shoulder bone weights were the same (RAC=1.22 kg vs. Con=1.24 kg, P=0.09; SED=0.01) for RAC and control pigs (Table 2). However, since absolute bone-in picnic shoulder weights were 0.14 kg heavier in RAC pigs relative to control pigs (Table 1), control pigs had a 0.16 percentage unit greater (P < 0.01; SED=0.04) proportion of picnic bones as a percentage of side weight (2.82%) when compared to RAC pigs (2.66%; Table 2). Therefore, lack of differences (P = 0.45; SED = 0.05) between RAC and control pigs in bone-in picnic percentages must be attributed to a general increase in picnic muscle of RAC fed pigs when compared with controls. Additionally, the advantage in cutability in boneless picnic shoulders demonstrated an efficacy of RAC in shoulder muscle tissue. Overall, the effect of RAC on the boneless shoulders (boneless Boston butt + boneless picnic shoulder) from RAC pigs (15.70%) was 0.32 percentage units greater than boneless shoulder yields of control pigs (15.38%; P < 0.01; SED = 0.11; Table 2).
**Loin** Both the Canadian back and sirloin portion of the loin primal made up a greater portion of the side weight of RAC pigs relative to control pigs (Table 3). The proportion of the tenderloin tended ($P = 0.08; \text{SED} = 0.02$) to be greater in RAC pigs when compared to control pigs. The Canadian back of RAC pigs (7.33%) made up 0.26 percentage units more ($P = 0.02; \text{SED} = 0.09$) of side weight when compared to control pigs (7.07%). Of the five studies used in the meta-analysis, four reported that Canadian back loins from RAC pigs made up a greater percentage of side weight compared to control pigs. Only Kutzler et al. (2010) reported Canadian back loins from control pigs were 0.02 percentage units greater than Canadian back loins from RAC pigs. In the current analysis, the magnitude of the difference in proportions of Canadian back ranged from a minimum of 0.06 percentage units (Carr et al., 2009) to a maximum of 0.50 percentage units (Kutzler et al., 2011). The sirloin portion of the loin from RAC pigs (2.15%) made up 0.10 percentage units more ($P = 0.01; \text{SED} = 0.03$) side weight when compared to those from control pigs (2.05%). All six studies used reported sirloins from RAC pigs comprised a greater proportion of side weight compared to control pigs (Table 3). The magnitude of the difference in proportions of side weights in sirloins ranged from a minimum of 0.02 percentage units (Kutzler et al., 2010) to a maximum of 0.19 percentage units (Carr et al., 2005a; Mimbs, 2003).

Even though the meta-analysis revealed only a trend ($P=0.08; \text{SED}=0.02$) in the proportion of the tenderloin in RAC pigs when compared to control pigs, six of seven studies reported greater proportions of the tenderloin in RAC pigs. Only Mimbs (2003) reported that tenderloins from control pigs made up a greater percentage of side weight.
compared to RAC pigs. Additionally, the magnitude of the difference between RAC and control pigs reported by Mimbs (-0.13%) was greater than the study with the greatest RAC advantage (0.11%; Crome et al., 1996) used in the meta-analysis. Overall, the effect of RAC on the boneless loin (Canadian back + tenderloin + sirloin) of RAC pigs (10.30%) was 0.43 percentage units greater than boneless loin yields of control pigs (9.87%; P = 0.01; SED = 0.13; Table 3).

**Ham** The ham from RAC pigs was greater as a percentage of the side weight in both the whole ham (P<0.001; SED=0.08) and the trimmed ham (P=0.01; SED=0.12) when compared to control pigs (Table 1). It was to no surprise that the subprimals within the ham of RAC pigs were also proportionally greater than control pigs. A meta-analysis of data was conducted on the inside (n = 6), outside (n = 7) and the knuckle (n = 7). An advantage in cutability of RAC pigs in comparison to control pigs was reported in all studies. The inside from RAC pigs (3.44%) was 0.16 percentage units greater (P = 0.01; SED = 0.05) as a percentage of side weight than control pigs (3.28%). The magnitude of this range was from 0.09 percentage units (Carr et al., 2009; Kutzler et al., 2011) to 0.46 percentage units (Crome et al., 1996). The outside from RAC pigs (4.48%) was 0.22 percentage units greater (P < 0.01; SED = 0.05) as a percentage of side weight in comparison to control pigs (4.26%). The magnitude of this range was from 0.10 percentage units (Carr et al., 2009; Kutzler et al., 2011) to 0.39 percentage units (Crome et al., 1996). The knuckle from RAC pigs (2.48%) was 0.12 percentage units greater (P < 0.01, SED = 0.03) as a percentage of side weight when compared to control pigs (2.36%). The magnitude of this range was from 0.02 percentage units (Carr et al. 2009; Kutzler et
al., 2011) to 0.46 percentage units (Crome et al. 1996). When the three main components of the boneless ham (inside, outside, and knuckle) were summed, RAC pigs (10.28%) yielded a 0.51 percentage unit advantage in total boneless ham cutability as a percentage of side weight relative to control pigs (9.78%; P < 0.001; SED = 0.11; Table 4).

**Belly** Modifications to allometric growth rates led to cutability advantages of RAC pigs in the shoulder, loin, and ham, coupled with a reported increase in estimated carcass lean indicates bellies may be thinner and comprise a lesser percentage of side weight in RAC pigs when compared to control pigs. However, trimmed belly yields were not different (P = 0.93; SED = 0.06) in RAC pigs (12.18%) as a percentage of side weight when compared to control pigs (12.18%; Table 1). The magnitude of the difference across the seven studies expressed as a percentage of side weight was a -0.23 percentage unit (Crome et al., 1996) to a 0.22 percentage unit advantage in RAC pigs (Carr et al., 2009). The same lack of difference (P = 0.99; SED = 0.03) was apparent when evaluating the spareribs as a percentage of side weight between RAC pigs (3.53%) and control pigs (3.53%; Table 1). The magnitude of this difference was a 0.03 percentage unit advantage for control pigs (Kutzler et al., 2010) to a 0.09 percentage unit advantage for RAC pigs (Carr et al., 2009) across 5 studies. RAC pigs had greater hot carcass weights (94.55 kg., 91.65 kg., respectively; P < 0.01; SED = 0.54) and this coupled with the lack of differences in belly percentage of side weight between treatments translates to absolute trimmed bellies from RAC pigs (5.92 kg) being heavier (P < 0.01; SED = 0.03) than control pigs (5.73 kg; Table 1). The magnitude of the difference of trimmed belly weights ranged from 0.09 kg (Carr et al., 2009) to 0.25 kg
Similarly, the spareribs were heavier (P < 0.01; SED = 0.01) in RAC pigs (1.72 kg) relative to control pigs (1.66 kg; Table 1). The magnitude of the difference in weight of spareribs ranged from 0.02 kg (Carr et al., 2009) to 0.11 kg (Carr et al., 2005a).

**Cutability** Overall carcass cutability differences were reported in Table 5. The carcass cutting yield was calculated using the following equation: percentage of bone-in trimmed Boston butt shoulder + percentage of bone-in trimmed picnic shoulder + percentage of bone-in trimmed loin + percentage bone-in trimmed ham + percentage of trimmed belly. Lean cutting yield was calculated with the following equation: percentage of bone-in trimmed Boston butt shoulder + percentage of bone-in trimmed picnic shoulder + percentage of bone-in trimmed loin + percentage bone-in trimmed ham. Boneless yield was calculated with the following equation: boneless shoulder + boneless loin + boneless ham. Carcass cutting yield revealed a 1.01 percentage unit advantage in RAC pigs (74.70%) when compared to control pigs (73.69%; P = 0.02; SED = 0.33). Similarly, lean cutting yield equation had a 1.10 percentage unit advantage in RAC pigs (61.43) when compared to control pigs (60.33; P = 0.03; SED = 0.40). Additionally, boneless yield showed a 1.08 percentage unit advantage in RAC pigs (36.28%) when compared to control pigs (35.20%; P = 0.002; SED = 0.25).

**Belly Quality**

There was no loss in belly yield when expressed as a percentage of side weight in RAC pigs when compared to control pigs. Today, the belly is one of the more valuable primals in a pork carcass and it is important to ensure there are limited negative belly...
quality issues when comparing RAC pigs to control pigs. Eight studies (Amaral et al., 2009; Apple et al., 2007b; Carr et al. 2005b; Leick et al., 2010; Mimbs, 2003; Rickard et al., 2012; Scramlin et al., 2008; Shook, 2006) were used to conduct a meta-analysis of belly quality factors that may be of influence. The loss from an economic standpoint associated with thin bellies can be accredited to a reduction in processing yield and the number of top grade bacon slices. Thin bellies tended to contain fewer grade 1 slices, increased smokehouse loss, and greater unusable end pieces (Person et al., 2005). Belly thickness was evaluated using six studies (Table 6). There were no differences (P = 0.89; SED = 0.26) in thickness of RAC pigs (30.13 mm) compared to control pigs (30.09 mm). The magnitude of the differences ranged from 0.74 mm (Amaral et al., 2009) advantage in control pigs to 0.75 mm (Scramlin et al., 2008) advantage in RAC pigs.

Belly fat quality, in terms of firmness, was estimated with a belly flop test, which has been related to the fatty acid composition, particularly the concentration of unsaturated fatty acids. More unsaturated fatty acids make bellies softer and contributed to a reduced (narrower) belly flop distance value. Belly flop tests show RAC bellies (15.27 cm) had narrower flop distances (P = 0.02; SED = 0.62) when compared to control pigs (17.08 cm) (Table 6). The magnitude of the differences in the seven studies that conducted a belly flop test ranged from a distance of 0.365 cm (Scramlin et al., 2008) to 5.5 cm (Carr et al., 2005b) greater width in control pigs relative to RAC pigs.

Iodine value (IV) has been commonly used to estimate the unsaturation level of pork fat and ultimately serves as an indicator of fat quality (Madsen et al. 1992). Greater IV has been associated with a high degree of unsaturated fatty acids, decreased firmness,
and reduced fat quality. Iodine value from six studies showed RAC pigs (73.4) had a
greater value (P < 0.01; SED = 0.40) in comparison to control pigs (71.5) (Table 6). The
magnitude of the differences ranged from a 0.94 (Apple et al., 2007b) to 2.9 (Leick et al.,
2010) increase in IV for RAC pigs. Leick et al. (2010) fed diets that ranged in distillers
dried grains with solubles from 0% inclusion up to 60% inclusion. This resulted in
greater average calculated iodine values for both pigs fed RAC (92.0) and pigs not fed
RAC (89.1) than normally observed in pork fat tissue. However the magnitude of the
difference was similar to other studies that reported an IV on belly fat. This shows that
RAC would increase the calculated IV by approximately 2 IV units of pork belly fat
when pigs were fed a variety of diets (Table 6). The consensus of the literature indicated
RAC bellies were softer (according to both belly flop tests and IV). Bellies from pigs fed
RAC were likely softer than bellies from pigs not fed RAC because fat tissue from RAC
fed pigs had a greater concentration of PUFA relative to fat tissue from pigs not fed RAC
(Rickard et al., 2012). Scramlin et al. (2008) reported that despite RAC pigs having
softer bellies, very limited effects on bacon processing characteristics were observable.
RAC appeared to have limited effects on belly processing, but this may depend on the
processing procedures used and threshold levels set by processors. Furthermore, bellies
from RAC pigs were not thinner and were not different in terms of primal yield as a
proportion of side weight when compared to bellies from control pigs.

**IMPLICATIONS**

Bone-in carcass cutability of RAC pigs was improved by over one percentage unit
when compared to control pigs. When the bones were removed and cutability was
recalculated, boneless cutability was improved as well. The improvement in cutability has been explained by increases in subprimal components from each of the major primals of the pork carcass. Pigs fed RAC (74.60%) had an overall carcass cutability advantage of 1.01 percentage units when compared to control pigs (73.69%; P = 0.02; SED = 0.33). Furthermore, RAC pigs (61.43%) had an overall bone-in lean advantage of 1.10 percentage units when compared to control pigs (60.33%; P = 0.03; SED = 0.40). The advantage in bone-in cutability was a result of increased subprimal yields in each of the lean cuts (shoulder, loin, and ham). When further evaluated, RAC pigs had a boneless shoulder (Boston butt + picnic) yield advantage of 0.32 percentage units (P < 0.01; SED = 0.11), a 0.43 percentage unit (P = 0.01; SED = 0.13) yield advantage in the boneless loin (Canadian back + tenderloin + sirloin), and a 0.51 percentage unit (P < 0.001; SED = 0.11) advantage in the boneless ham (inside + outside + knuckle). The summation of these three boneless lean primals equated to a 1.08 percentage unit (P = 0.002; SED = 0.25) advantage in boneless cutability of RAC pigs compared to control pigs.

RAC pigs have been known to be leaner than control pigs, however; the meta-analysis did not indicate a reduction in belly yield as a percentage of side weight, but showed bellies from RAC pigs had narrower flop distances and a greater IV than pigs not fed RAC. This review illustrated the general effects of RAC on carcass cutability and belly fat quality. However, current swine production practices are more complex than implied in this review. Pigs are marketed over several weeks to minimize variation in body weight and carcass composition (Hinson et al. 2012). This leads to RAC duration differing among a single population of pigs. Some marketing strategies even employ a
three-phase marketing approach where RAC would not be added to the diet until 7 d prior to the initial marketing period. Pigs left in the barn after the initial marketing period would be fed RAC for longer durations, but may be slower growing and more inclined to fat deposition than pigs marketed during the early periods. These marketing strategies become even more complex when step-up dosage strategies are used. Finally this review did not separate the effects of RAC and other emerging technologies that may become a factor in swine production in the future. Additional data analysis will be warranted as data become available to determine the effects of RAC when used in more complex marketing strategies or along with other production technologies.

**LITERATURE CITED**


### Table 2.1. Average fixed effects of ractopamine hydrochloride (RAC - Con) on whole and trimmed primal cut-out values from a meta-analysis of data

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>min</th>
<th>max</th>
<th>95% CI</th>
<th>sed</th>
<th>P - value</th>
<th># studies</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Carcass Weight, kg</td>
<td>94.55</td>
<td>91.65</td>
<td>2.89</td>
<td>74.83</td>
<td>113.00</td>
<td>(1.71, 4.08)</td>
<td>0.54</td>
<td>&lt; 0.01</td>
<td>10</td>
<td>1324</td>
</tr>
<tr>
<td>Whole shoulder, kg</td>
<td>11.34</td>
<td>11.05</td>
<td>0.29</td>
<td>8.45</td>
<td>15.30</td>
<td>(0.11, 0.47)</td>
<td>0.08</td>
<td>0.01</td>
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<td>700</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>23.89</td>
<td>24.06</td>
<td>-0.17</td>
<td>21.87</td>
<td>27.53</td>
<td>(-0.37, 0.03)</td>
<td>0.09</td>
<td>0.09</td>
<td>5</td>
<td>748</td>
</tr>
<tr>
<td>Bone-in Boston, kg</td>
<td>3.98</td>
<td>3.79</td>
<td>0.19</td>
<td>2.90</td>
<td>4.42</td>
<td>(0.12, 0.26)</td>
<td>0.03</td>
<td>&lt; 0.01</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>8.35</td>
<td>8.19</td>
<td>0.15</td>
<td>7.47</td>
<td>9.46</td>
<td>(0.04, 0.27)</td>
<td>0.05</td>
<td>0.01</td>
<td>8</td>
<td>956</td>
</tr>
<tr>
<td>Bone-in picnic, kg</td>
<td>5.00</td>
<td>4.86</td>
<td>0.14</td>
<td>4.05</td>
<td>5.91</td>
<td>(0.07, 0.21)</td>
<td>0.03</td>
<td>&lt; 0.01</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>10.84</td>
<td>10.88</td>
<td>-0.04</td>
<td>9.54</td>
<td>15.20</td>
<td>(-0.15, 0.08)</td>
<td>0.05</td>
<td>0.45</td>
<td>8</td>
<td>956</td>
</tr>
<tr>
<td>Whole loin, kg</td>
<td>11.86</td>
<td>11.32</td>
<td>0.54</td>
<td>9.51</td>
<td>14.46</td>
<td>(0.24, 0.84)</td>
<td>0.07</td>
<td>0.02</td>
<td>3</td>
<td>340</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>25.15</td>
<td>25.17</td>
<td>-0.02</td>
<td>24.37</td>
<td>25.70</td>
<td>(-0.47, 0.44)</td>
<td>0.16</td>
<td>0.93</td>
<td>4</td>
<td>508</td>
</tr>
<tr>
<td>Trimmed loin, kg</td>
<td>9.58</td>
<td>9.02</td>
<td>0.56</td>
<td>7.52</td>
<td>11.45</td>
<td>(0.20, 0.93)</td>
<td>0.15</td>
<td>0.01</td>
<td>4</td>
<td>580</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>21.04</td>
<td>20.66</td>
<td>0.38</td>
<td>18.13</td>
<td>23.90</td>
<td>(0.02, 0.73)</td>
<td>0.16</td>
<td>0.04</td>
<td>6</td>
<td>804</td>
</tr>
<tr>
<td>Whole ham, kg</td>
<td>11.74</td>
<td>11.15</td>
<td>0.59</td>
<td>9.20</td>
<td>13.78</td>
<td>(0.42, 0.75)</td>
<td>0.08</td>
<td>&lt; 0.01</td>
<td>7</td>
<td>980</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>23.17</td>
<td>22.79</td>
<td>0.38</td>
<td>12.38</td>
<td>27.54</td>
<td>(0.21, 0.55)</td>
<td>0.08</td>
<td>&lt; 0.01</td>
<td>9</td>
<td>1204</td>
</tr>
<tr>
<td>Trimmed ham, kg</td>
<td>10.35</td>
<td>9.72</td>
<td>0.63</td>
<td>8.54</td>
<td>11.55</td>
<td>(0.38, 0.88)</td>
<td>0.11</td>
<td>&lt; 0.01</td>
<td>5</td>
<td>780</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>20.20</td>
<td>19.77</td>
<td>0.43</td>
<td>11.06</td>
<td>24.36</td>
<td>(0.16, 0.70)</td>
<td>0.12</td>
<td>&lt; 0.01</td>
<td>6</td>
<td>948</td>
</tr>
<tr>
<td>Whole belly, kg</td>
<td>8.33</td>
<td>8.02</td>
<td>0.30</td>
<td>5.19</td>
<td>10.48</td>
<td>(0.16, 0.45)</td>
<td>0.06</td>
<td>&lt; 0.01</td>
<td>3</td>
<td>484</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>17.45</td>
<td>17.41</td>
<td>0.04</td>
<td>13.78</td>
<td>20.09</td>
<td>(-0.24, 0.32)</td>
<td>0.11</td>
<td>0.74</td>
<td>3</td>
<td>484</td>
</tr>
<tr>
<td>Trimmed belly, kg</td>
<td>5.92</td>
<td>5.73</td>
<td>0.19</td>
<td>3.72</td>
<td>7.91</td>
<td>(0.14, 0.25)</td>
<td>0.03</td>
<td>&lt; 0.01</td>
<td>6</td>
<td>780</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>12.18</td>
<td>12.18</td>
<td>0.01</td>
<td>9.88</td>
<td>17.86</td>
<td>(-0.13, 0.15)</td>
<td>0.06</td>
<td>0.93</td>
<td>7</td>
<td>836</td>
</tr>
<tr>
<td>Spareribs, kg</td>
<td>1.72</td>
<td>1.66</td>
<td>0.06</td>
<td>1.35</td>
<td>2.18</td>
<td>(0.02, 0.09)</td>
<td>0.01</td>
<td>&lt; 0.01</td>
<td>6</td>
<td>780</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>3.53</td>
<td>3.53</td>
<td>0.00</td>
<td>3.26</td>
<td>3.89</td>
<td>(-0.07, 0.07)</td>
<td>0.03</td>
<td>0.99</td>
<td>5</td>
<td>600</td>
</tr>
</tbody>
</table>

1 Analyses only include data from studies where animals were fed RAC between 5.0 and 10.0 mg/kg for no more than 35 days

2 Sources include: Boler et al. (2011); Carr et al. (2005a, 2009); Crome et al. (1996); Fernandez-Duenas et al. (2008); Kutzler et al. (2010, 2011); Mimbs (2003); Tavarez et al. (2012). Some sources include more than one study.
Table 2.2. Average fixed effects of ractopamine hydrochloride (RAC - Con) on shoulder carcass cut-out values from a meta-analysis of data \(^1,2\)

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>min</th>
<th>max</th>
<th>95% CI</th>
<th>sed</th>
<th>P-value</th>
<th># studies</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boneless Boston, kg</td>
<td>3.68</td>
<td>3.47</td>
<td>0.21</td>
<td>2.66</td>
<td>4.08</td>
<td>(0.14, 0.27)</td>
<td>0.03</td>
<td>&lt; 0.0001</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>7.52</td>
<td>7.32</td>
<td>0.20</td>
<td>6.77</td>
<td>8.06</td>
<td>(0.12, 0.28)</td>
<td>0.03</td>
<td>&lt; 0.0001</td>
<td>8</td>
<td>956</td>
</tr>
<tr>
<td>Boneless picnic, kg</td>
<td>3.78</td>
<td>3.62</td>
<td>0.16</td>
<td>2.86</td>
<td>4.78</td>
<td>(0.08, 0.23)</td>
<td>0.03</td>
<td>0.001</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>8.18</td>
<td>8.06</td>
<td>0.12</td>
<td>7.15</td>
<td>11.20</td>
<td>(0.03, 0.20)</td>
<td>0.04</td>
<td>0.01</td>
<td>8</td>
<td>956</td>
</tr>
<tr>
<td>Picnic Bone, kg</td>
<td>1.22</td>
<td>1.24</td>
<td>-0.02</td>
<td>1.00</td>
<td>1.45</td>
<td>(-0.034, 0.002)</td>
<td>0.01</td>
<td>0.09</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>2.66</td>
<td>2.82</td>
<td>-1.60</td>
<td>1.90</td>
<td>4.10</td>
<td>(-0.25, -0.06)</td>
<td>0.04</td>
<td>0.004</td>
<td>8</td>
<td>956</td>
</tr>
<tr>
<td>Neckbones, kg</td>
<td>0.88</td>
<td>0.86</td>
<td>0.02</td>
<td>0.60</td>
<td>1.30</td>
<td>(-0.02, 0.06)</td>
<td>0.02</td>
<td>0.22</td>
<td>4</td>
<td>580</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>1.81</td>
<td>1.91</td>
<td>-0.11</td>
<td>1.33</td>
<td>2.20</td>
<td>(-0.18, -0.03)</td>
<td>0.03</td>
<td>0.02</td>
<td>3</td>
<td>400</td>
</tr>
<tr>
<td>Clear plate, kg</td>
<td>0.81</td>
<td>0.89</td>
<td>-0.08</td>
<td>0.77</td>
<td>0.98</td>
<td>(-0.13, -0.03)</td>
<td>0.02</td>
<td>0.01</td>
<td>3</td>
<td>516</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>1.86</td>
<td>2.17</td>
<td>-0.31</td>
<td>1.81</td>
<td>2.23</td>
<td>(-0.44, -0.17)</td>
<td>0.05</td>
<td>0.002</td>
<td>2</td>
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<tr>
<td>Cushion, kg</td>
<td>0.85</td>
<td>0.80</td>
<td>0.05</td>
<td>0.70</td>
<td>0.93</td>
<td>(0.02, 0.09)</td>
<td>0.01</td>
<td>0.01</td>
<td>4</td>
<td>500</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>1.74</td>
<td>1.72</td>
<td>0.03</td>
<td>1.47</td>
<td>1.89</td>
<td>(-0.01, 0.06)</td>
<td>0.01</td>
<td>0.11</td>
<td>4</td>
<td>500</td>
</tr>
<tr>
<td>Jowl, kg</td>
<td>1.59</td>
<td>1.52</td>
<td>0.07</td>
<td>1.27</td>
<td>2.06</td>
<td>(-0.07, 0.21)</td>
<td>0.03</td>
<td>0.18</td>
<td>3</td>
<td>340</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>3.41</td>
<td>3.34</td>
<td>0.08</td>
<td>2.98</td>
<td>3.69</td>
<td>(-1.25, 1.41)</td>
<td>0.11</td>
<td>0.61</td>
<td>2</td>
<td>160</td>
</tr>
<tr>
<td>Boneless Shoulder(^3), kg</td>
<td>7.46</td>
<td>7.10</td>
<td>0.36</td>
<td>5.52</td>
<td>8.67</td>
<td>(0.24, 0.48)</td>
<td>0.07</td>
<td>&lt;0.0001</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>15.70</td>
<td>15.38</td>
<td>0.32</td>
<td>14.33</td>
<td>18.46</td>
<td>(0.19, 0.45)</td>
<td>0.11</td>
<td>0.001</td>
<td>8</td>
<td>956</td>
</tr>
</tbody>
</table>

\(^1\)Analyses only include data from studies where animals were fed RAC between 5.0 and 10.0 mg/kg for no more than 35 days

\(^2\)Sources include: Carr et al. (2005a, 2009); Crome et al. (1996); Fernandez-Duenas et al. (2008)
Kutzler et al. (2010, 2011); Mimbs (2003); Tavarez et al. (2012). Some sources include more than one study.

\(^3\)Boneless shoulder = boneless Boston butt + boneless picnic
Table 2.3. Average fixed effects of ractopamine hydrochloride (RAC - Con) on loin carcass cut-out values from a meta-analysis of data\textsuperscript{1,2}

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>min</th>
<th>max</th>
<th>95% CI</th>
<th>sed</th>
<th>P - value</th>
<th># studies</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian back, kg</td>
<td>3.59</td>
<td>3.37</td>
<td>0.21</td>
<td>2.70</td>
<td>4.04</td>
<td>(0.09, 0.33)</td>
<td>0.05</td>
<td>0.003</td>
<td>5</td>
<td>684</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>7.33</td>
<td>7.07</td>
<td>0.26</td>
<td>6.89</td>
<td>7.79</td>
<td>(0.05, 0.47)</td>
<td>0.09</td>
<td>0.02</td>
<td>5</td>
<td>684</td>
</tr>
<tr>
<td>Tenderloin, kg</td>
<td>0.47</td>
<td>0.42</td>
<td>0.05</td>
<td>0.34</td>
<td>0.52</td>
<td>(0.03, 0.07)</td>
<td>0.01</td>
<td>0.0004</td>
<td>6</td>
<td>780</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>1.03</td>
<td>0.98</td>
<td>0.05</td>
<td>0.86</td>
<td>1.51</td>
<td>(-0.01, 0.10)</td>
<td>0.02</td>
<td>0.08</td>
<td>7</td>
<td>836</td>
</tr>
<tr>
<td>Sirloin, kg</td>
<td>0.98</td>
<td>0.91</td>
<td>0.06</td>
<td>0.70</td>
<td>1.09</td>
<td>(0.02, 0.11)</td>
<td>0.02</td>
<td>0.02</td>
<td>5</td>
<td>684</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>2.15</td>
<td>2.05</td>
<td>0.10</td>
<td>1.79</td>
<td>2.96</td>
<td>(0.02, 0.18)</td>
<td>0.03</td>
<td>0.01</td>
<td>6</td>
<td>740</td>
</tr>
<tr>
<td>Boneless loin\textsuperscript{3}, kg</td>
<td>5.03</td>
<td>4.71</td>
<td>0.32</td>
<td>3.74</td>
<td>5.61</td>
<td>(0.13, 0.50)</td>
<td>0.08</td>
<td>0.003</td>
<td>5</td>
<td>684</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>10.30</td>
<td>9.87</td>
<td>0.43</td>
<td>9.72</td>
<td>10.80</td>
<td>(0.15, 0.72)</td>
<td>0.13</td>
<td>0.01</td>
<td>5</td>
<td>684</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Analyses only include data from studies where animals were fed RAC between 5.0 and 10.0 mg/kg for no more than 35 days

\textsuperscript{2}Sources include: Carr et al. (2005a, 2009); Crome et al. (1996); Fernandez-Duenas et al. (2008); Kutzler et al. (2010, 2011); Mimbs (2003). Some sources include more than one study.

\textsuperscript{3}Boneless loin = Canadian back + tenderloin + sirloin.
Table 2.4. Average fixed effects of ractopamine hydrochloride (RAC - Con) on ham carcass cut-out values from a meta-analysis of data1,2

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>min</th>
<th>max</th>
<th>95 % CI</th>
<th>sed</th>
<th>P - value</th>
<th># studies</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside, kg</td>
<td>1.75</td>
<td>1.62</td>
<td>0.14</td>
<td>1.41</td>
<td>2.11</td>
<td>(0.08, 0.20)</td>
<td>0.03</td>
<td>0.0004</td>
<td>7</td>
<td>980</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>3.44</td>
<td>3.28</td>
<td>0.16</td>
<td>1.54</td>
<td>4.70</td>
<td>(0.06, 0.26)</td>
<td>0.05</td>
<td>0.01</td>
<td>6</td>
<td>800</td>
</tr>
<tr>
<td>Outside, kg</td>
<td>2.79</td>
<td>2.59</td>
<td>0.21</td>
<td>1.77</td>
<td>6.15</td>
<td>(0.13, 0.29)</td>
<td>0.04</td>
<td>0.0001</td>
<td>7</td>
<td>980</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>4.48</td>
<td>4.26</td>
<td>0.22</td>
<td>2.14</td>
<td>5.24</td>
<td>(0.10, 0.34)</td>
<td>0.05</td>
<td>0.002</td>
<td>7</td>
<td>1036</td>
</tr>
<tr>
<td>Knuckle, kg</td>
<td>1.23</td>
<td>1.13</td>
<td>0.10</td>
<td>0.62</td>
<td>1.53</td>
<td>(0.07, 0.13)</td>
<td>0.01</td>
<td>&lt; 0.0001</td>
<td>7</td>
<td>900</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>2.48</td>
<td>2.36</td>
<td>0.12</td>
<td>1.23</td>
<td>3.27</td>
<td>(0.06, 0.18)</td>
<td>0.03</td>
<td>0.002</td>
<td>7</td>
<td>856</td>
</tr>
<tr>
<td>Light butt, kg</td>
<td>0.32</td>
<td>0.30</td>
<td>0.02</td>
<td>0.20</td>
<td>0.38</td>
<td>(0.01, 0.05)</td>
<td>0.01</td>
<td>0.11</td>
<td>3</td>
<td>504</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>0.51</td>
<td>0.49</td>
<td>0.02</td>
<td>0.38</td>
<td>0.67</td>
<td>(0.03, 0.06)</td>
<td>0.02</td>
<td>0.47</td>
<td>4</td>
<td>560</td>
</tr>
<tr>
<td>Boneless Ham3, kg</td>
<td>5.30</td>
<td>4.88</td>
<td>0.42</td>
<td>4.15</td>
<td>6.44</td>
<td>(0.26, 0.58)</td>
<td>0.07</td>
<td>&lt; 0.0001</td>
<td>7</td>
<td>980</td>
</tr>
<tr>
<td>% chilled side wt</td>
<td>10.28</td>
<td>9.78</td>
<td>0.51</td>
<td>4.91</td>
<td>12.62</td>
<td>(0.25, 0.76)</td>
<td>0.11</td>
<td>&lt; 0.001</td>
<td>6</td>
<td>800</td>
</tr>
</tbody>
</table>

1Analyses only include data from studies where animals were fed RAC between 5.0 and 10.0 mg/kg for no more than 35 days
2Sources include: Boler et al. (2011); Carr et al. (2005a, 2009); Crome et al. (1996); Fernandez-Duenas et al. (2008)
   Kutzler et al. (2010, 2011); Mimbs (2003). Some sources include more than one study.
3Boneless ham = outside ham + inside ham + knuckle.
Table 2.5. Average fixed effects of ractopamine hydrochloride (RAC - Con) on carcass cutability from a meta-analysis of data\(^1\)

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>Min</th>
<th>Max</th>
<th>95 % CI</th>
<th>sed</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone-in carcass cutting yield,(^2) %</td>
<td>74.70</td>
<td>73.70</td>
<td>1.01</td>
<td>70.35</td>
<td>79.41</td>
<td>(0.22, 1.79)</td>
<td>0.33</td>
<td>0.02</td>
</tr>
<tr>
<td>Bone-in lean cutting yield,(^3) %</td>
<td>61.43</td>
<td>60.34</td>
<td>1.10</td>
<td>58.57</td>
<td>63.47</td>
<td>(0.16, 2.03)</td>
<td>0.40</td>
<td>0.03</td>
</tr>
<tr>
<td>Boneless yield,(^4) %</td>
<td>36.28</td>
<td>35.20</td>
<td>1.09</td>
<td>33.68</td>
<td>38.16</td>
<td>(0.52, 1.65)</td>
<td>0.25</td>
<td>0.002</td>
</tr>
</tbody>
</table>

\(^1\) Calculated from data included in subprimal analyses

\(^2\) Bone-in carcass cutting yield = trimmed ham + trimmed loin + Boston butt + picnic shoulder + trimmed belly

\(^3\) Bone-in lean cutting yield = trimmed ham + trimmed loin + Boston butt + picnic shoulder

\(^4\) Boneless yield = boneless ham + boneless loin + boneless shoulder
Table 2.6. Average fixed effects of ractopamine hydrochloride (RAC - Con) on belly quality values from a meta-analysis of data

<table>
<thead>
<tr>
<th>Item</th>
<th>RAC</th>
<th>Con</th>
<th>Effect</th>
<th>Min</th>
<th>Max</th>
<th>95% CI</th>
<th>sed</th>
<th>P-value</th>
<th># studies</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness, mm</td>
<td>30.13</td>
<td>30.09</td>
<td>0.04</td>
<td>24.37</td>
<td>37.80</td>
<td>(-0.58, 0.65)</td>
<td>0.26</td>
<td>0.89</td>
<td>6</td>
<td>746</td>
</tr>
<tr>
<td>Belly Flop, cm³</td>
<td>15.27</td>
<td>17.08</td>
<td>-1.81</td>
<td>8.10</td>
<td>22.52</td>
<td>(-3.24, -0.39)</td>
<td>0.62</td>
<td>0.02</td>
<td>7</td>
<td>746</td>
</tr>
<tr>
<td>Iodine Value</td>
<td>73.42</td>
<td>71.48</td>
<td>1.95</td>
<td>63.89</td>
<td>92.00</td>
<td>(1.11, 2.78)</td>
<td>0.33</td>
<td>0.01</td>
<td>6</td>
<td>590</td>
</tr>
</tbody>
</table>

1 Analyses only include data from studies where animals were fed RAC between 5.0 and 10.0 mg/kg for no more than 35 days.
2 Sources include: Amaral et al. (2009); Apple et al. (2007); Carr et al. (2005b); Leick et al. (2010); Mimbs (2003); Rickard et al. (2011); Scramlin et al. (2008); Shook (2006) Some sources include more than one study.
3 Belly Flop tests were analyzed as vertical side down with a 2.54 cm bar.
Chapter 3: The effect of a low sodium curing solution on further processed hams and bellies from purebred Berkshire pigs fed a step-up ractopamine feeding program

ABSTRACT: Objectives of the study were to test the effect of a lower sodium curing solution on processing characteristics of hams and bellies from purebred Berkshire pigs fed a step-up ractopamine (RAC) feeding program or a negative control diet. Hams and bellies were cured with a standard cure solution (1.98% NaCl; REG) or a low sodium with potassium chloride substitute (0.67% NaCl and 1.29% KCl; LOW) cure solution. Sixty pairs (n = 120) of hams and bellies were selected from two blocks of purebred Berkshire pigs (n = 200) fed either 7.4 mg of ractopamine/kg of diet for 14 days followed by 10.0 mg of ractopamine /kg of diet for the last 14 days prior to slaughter or a control diet. Pigs fed RAC were 3.29 kg heavier (P < 0.01) than control pigs at the end of the 28 day finishing period. Furthermore, RAC pigs had a 0.10 kg/d greater (P < 0.01) ADG and a 0.03 greater (P < 0.01) gain:feed ratio over the 28 day finishing period. There were no differences (P ≥ 0.07) for ham weights throughout processing, pump uptake, or cook yield [(cooked weight / green weight) x 100] detected for the effect of diet, cure solution, or the interaction between diet and cure solution. Break strength (an indication of protein interaction) of LOW hams (5.97 kg) required less (P = 0.05) force to break than REG hams (6.99 kg). Hams cured with the LOW sodium cure solution had greater (P < 0.05)
lightness (L*) and yellowness (b*) and lesser (P < 0.05) redness (a*) values than REG hams. Additionally, LOW hams had a lower (P < 0.01) protein fat-free (PFF) value than REG hams (24.58 vs. 25.98%; respectively). Pump uptake and cook yield was less (P < 0.01) in LOW sodium cure solution bellies than REG bellies. LOW treated bellies tended (P = 0.09) to yield fewer bacon slices (127 vs. 131) than REG treated bellies. No differences (P < 0.05) for the first block of hams and bellies (n = 60) were detected by a trained sensory panelist for saltiness, flavor, or overall acceptability of LOW treated ham or bacon in comparison to REG treated. Overall, using a potassium chloride substitute in comparison to a standard solution may have impacts on visual color of hams and processing characteristics of bellies, but may be a justifiable way to lower sodium content of processed meat products without affecting taste or eating satisfaction.

INTRODUCTION

The inclusion of sodium chloride, commonly referred to as table salt, in the curing solution of further processed meat products has many functional properties. Salt increases hydration and water holding capacity by activating proteins (Desmond, 2006). The increase in water holding capacity improves product texture and reduces cook loss, thus increasing tenderness and juiciness of the product (Desmond, 2006). Consumer’s sodium intake often exceeds the U.S Department of Health and Human Services (2010) nutritional recommendations of 2,300 mg/day. Excessive sodium intake has been linked to hypertension and an increase in chronic diseases (CDC, 2012). One approach to lowering sodium content in processed meat products is to use a sodium chloride substitute. Potassium chloride (KCl) is a viable substitute for sodium chloride from an antimicrobial (Bidlas and Lambert, 2008) and protein-bind standpoint (Desmond, 2006).
However, KCI may change consumer acceptability because it can lead to changes in flavor, juiciness, and tenderness of finished products (Ruusunen and Puolanne, 2005). Additionally, KCL may alter consumer perception of cured color in pork sausage type products (Tobin et al., 2013).

Purebred Berkshire pigs are rarely used in the commercial swine industry because of poorer growth and reproductive performance when compared with crossbred genetics used in large scale commercial pig production (McMullen, 2006). On the other hand, Berkshire pork tends to have more desirable meat quality characteristics. Ryu et al. (2008) reported purebred Berkshire pork had a greater (P < 0.05) proportion of type I muscle fibers, and correspondingly had a greater ultimate muscle pH, were less pale (lower lightness scores), and had greater water holding capacity (lower drip loss percentage) when compared to purebred Landrace, purebred Yorkshire, and Yorkshire x Landrace x Duroc composites. Additionally, Lee et al. (2012) reported purebred Berkshire pork had a greater (P < 0.05) ultimate pH, lower drip loss and cooking loss, and was more tender (via Warner-Bratzler shear force test) than pork from purebred Landrace and Yorkshire pigs. This may be explained by a greater (P < 0.05) proportion of a cross-sectional area being occupied type I muscle fibers as opposed to type II fibers being greater in Berkshire pork than in other breeds.

Ractopamine hydrochloride (RAC) increases live performance (Apple et al. 2007) and carcass cutability of finisher pigs (Bohrer et al. 2013), but does not negatively influence processing characteristics of further processed products (Scramlin et al., 2008; Boler et al., 2011; Tavárez et al. 2012). Step-up RAC feeding programs allow for a greater average RAC dose for a longer duration without negatively affecting efficiency.
(Hinson et al., 2012a; Gerlemann et al., 2013). Feeding RAC to purebred Berkshire pigs may compensate, at least to some degree, for poorer growth performance. At the same time, the inherent improvement in water holding capacity of purebred Berkshire pork relative to other pork may aid in brine retention of lower sodium processed products.

Therefore, the objective of the study was to determine the effect of a lower sodium curing solution on processing characteristics of hams and bellies from purebred Berkshire pigs fed a step-up ractopamine feeding program.

**MATERIAL AND METHODS**

The protocol for pig care during the live phase portion of the experiment was reviewed and approved by The Ohio State University Animal Care and Use Committee.

**Animals and Housing**

Two hundred purebred Berkshire pigs (118 barrows and 82 gilts), with an average initial body weight of 68.94 kg were stratified over two blocks and housed in mixed-sex pens. Pens from eight replicates contained six barrows and four gilts. The other two replicates contained five barrows and five gilts. Pigs were raised at the Ohio State University Western Agriculture Research Station. Overall pen size was 16.25 m$^2$ (including 3.9 m$^2$ of slatted floor area), so pigs were provided approximately 1.63 m$^2$ of floor space apiece. Each pen had a double nipple water drinker and a 4-hole single-sided box feeder that provided a total of 122 cm of linear feeder space (12.2 cm/pig). Pigs were housed in a curtain-sided, naturally ventilated barn and were provided ad libitum access to feed and water throughout the finishing trial. Pigs were allotted by bodyweight and provided a 14 d allocation period prior to the start of the treatment diets. Pigs were finished with two different feeding strategies: a step-up ractopamine diet (RAC; 17.1% crude protein,
1.04% total lysine; as fed basis) with 7.4 mg/kg RAC inclusion for 14 days followed by 10 mg/kg RAC inclusion for the last 14 days prior to slaughter or a non-RAC diet (Con; 13.1% crude protein, 0.76% lysine; as-fed basis; Table 1). Pigs were weighed and scanned for real-time ultrasonic images (Aloka 500V SSD, 3.5 MHz 12.5-cm long linear array transducer; Corometrics Medical Systems, Inc. Wallingford, CT) for 10th rib fat thickness and loin muscle area (LMA) on d 0, 7, 14, 21, and 28 of the finishing period. These measurements were used to calculate live predicted percent lean (Burson and Berg, 2001) with the following equation:

\[
Live \ Predicted \ Percent \ Lean, \% \\
= (-0.534 + (0.291 \times \text{liveweight, lbs}) \\
- (16.498 \times 10th \ rib \ fat \ depth, in) \\
+ (5.425 \times 10th \ rib \ loin \ muscle \ area, \text{sq. in}) \\
+ (0.833 \times \text{sex \ of \ pig; \ barrow = 1, gilt = 2})/(\text{liveweight} \times 0.74%) \]

Feeders were weighed on d 0, 7, 14, 21, and 28 to calculate feed disappearance for each pen. At the end of the feeding period (d 28), two barrows and one gilt were randomly selected from each pen (n = 60) and transported to The Ohio State University Meat Science Laboratory for humane slaughter using electrical immobilization and exsanguination. Pigs were kept in lairage overnight with free access to water, but no access to feed.

**Loin Quality Measurements**

Carcasses were allowed approximately 24 h to chill to 4°C. The left side of each carcass was separated at the 10th and 11th rib interface and measured for back fat thickness and loin muscle area. The right side loin primal was fabricated into a NAMP
Canadian back loin and set aside for later determination of subjective and objective fresh muscle quality parameters. Data for fresh loin pork quality was collected by trained Ohio State University personnel. Loins were cut at the area of the 10th rib location (posterior to the m. spinalis dorsi). Loins were allowed at least 15 min to bloom prior to evaluation. Visual color scores (1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red; NPPC, 1999), marbling (1 through 10 corresponding to intramuscular lipid content, NPPC, 1999) and firmness (1 = soft, cut surface distorts easily, 2 = firm, cut surface tends to hold shape, 3 = very firm, cut surface were very smooth with no distortion of shape; NPPC, 1999) were assessed and recorded in whole numbers. Objective CIE (L*, a*, and b*) color scores were attained using a Minolta CR-400 with D65 light source and a 0° observer with a 50mm aperture (Minolta Chroma Meter CR-400 colorimeter; Minolta Corp., Osaka, Japan). Ultimate pH was obtained by inserting a portable pH meter into the longissimus dorsi (accumet AP60 Series Portable pH Meter; Thermo Fisher Scientific Inc. Singapore). A 1.27 cm-thick loin chop was cut at approximately the 10th rib location for use in a water holding capacity-drip loss test. The chops were weighed, suspended in a plastic bag (Ziploc) by a fish hook and placed in a refrigerator unit at 4° C for 24 hours, and then reweighed to determine 24h drip loss percentage.

A 2.5 cm thick loin chop was cut at the area of the 10th rib location to determine fat and moisture percentage. The loin was trimmed of all subcutaneous fat and homogenized in a food processor. A 10 g sample was oven-dried at 100° C for at least 24 hours to determine moisture percentage. The dried sample was then washed multiple times in warm petroleum ether to remove fat.
Three 2.54 cm thick loin chops were cut and stored at 4° C in vacuum packages until 4, 8, or 12 d postmortem. Chops were frozen at -20° C after the appropriate storage time. Chops were later thawed and used for Warner-Bratzler Shear Force (WBSF) analysis to determine objective tenderness. Twenty-four hours before cooking, chops were thawed in a 4° C refrigerating unit. Individual chop weight was recorded before and after cooking to evaluate cook loss. A thermocoupler (Digi-sense, K-type probe, Omega Engineering, Inc, Stamford, CT) was placed in the center of each chop and chops were cooked using a clam-style cooker (George Forman Grill) preheated to 191° C. Chops were removed from the grill upon reaching an internal temperature of 71° C and cooled to room temperature. Four, 1.25 cm diameter cores were taken from each chop parallel to the longitudinal orientation of the muscle fibers. Peak shear force was measured using a Texture Analyzer Plus (Model TAXTplus) with an attached WBSF blade and a machine cross head speed of 3.3 mm/s. Maximum force was recorded for each core and the average of the 4 cores was reported.

**Fresh Belly Characteristics**

Bellies were laid flat and allowed to equilibrate to 4° C before firmness testing was conducted. Belly thickness and firmness was evaluated using the right side bellies after the spareribs were removed, but prior to squaring and trimming. Average belly thickness was obtained by taking an average thickness at eight different locations: four from the ventral side and four from the dorsal side approximately dividing the belly into quarter sections on each side. Belly firmness was evaluated using the belly-bar technique. Bellies were draped vertically skin side down over a smokehouse stick at the midpoint and the distance between the anterior and posterior ends were recorded.
Ham Processing

One ham (n = 60) from each pig was randomly assigned to the regular sodium (REG) cure solution treatment and the other ham (n = 60) was assigned to the reduced sodium (LOW) cure solution (REG hams contained 1.98% sodium chloride and LOW hams contained 1.29% potassium chloride and 0.67% sodium chloride). Three piece boneless hams (NAMP 402G) consisting of the outside (NAMP 402D), inside (NAMP 402F), and knuckle subprimals were placed in a net and weighed as a set for green weight determination. Hams were pumped with the desired cure to a target initial uptake of 130% of original green weight using a multi-needle injector. Pumped weights were recorded and hams were macerated, tumbled in a vacuum sealed tumbler, and allowed to equilibrate overnight. An equilibrium weight was collected and hams were stuffed into a curing net with the knuckle toward the factory clipped end and the inside portion of the ham placed on top of the outside portion of the ham to maintain anatomical orientation in the same manner as described by Boler et al. (2011). Stuffed and weighed hams were transported to a USDA FSIS inspected facility for processing. All hams within a block were smoked in a single batch to eliminate variation in processing yields due to smokehouse variation. Hams were allowed to cool for a period of at least 48 hours after being processed. Hams were sliced at a standardized location 3/4th the distance from the factory clipped end and evaluated for objective color (Minolta values; L*, a*, b*). Samples were collected for proximate composition (moisture, fat, protein, and sodium), break strength testing, and sensory testing. Break strength was performed with TAXTplus22 software using a platform set a standardized width of 4 cm. The bar was descended to break a 10 cm long, 2.54 cm thick ham slice perpendicular to the inside-
outside binding portion of the slice. Moisture and fat percentage was determined in the same manner as in fresh loin chops. Protein concentrations were measured by determining nitrogen content using the combustion method (AOAC, 2000; 990.03; model TruMac, LECO Corp., St. Joseph, MI) using EDTA as a standard. Protein fat free values were calculated with the following equation:

\[
\text{Protein Fat Free} = \left( \frac{\text{Percent of meat protein}}{100 - \text{percent of fat}} \right) \times 100
\]

**Belly Processing**

One trimmed and squared belly (n = 60) from each pig was randomly assigned to the regular sodium (REG) cure solution treatment and the other trimmed and squared belly (n = 60) was assigned to the reduced sodium (LOW) cure solution (REG bellies contained 1.98\% sodium chloride and LOW bellies contained 1.29\% potassium chloride and 0.67\% sodium chloride). Bellies were pumped to a target of 113\% of initial green weight. Bellies were weighed just after injection to determine pump uptake and pumped weight. Bellies were smoked in an Alkar smokehouse (Lodi, Wisconsin) in 3 loads with equal number of bellies and equal number of bellies per treatment in each load. Cured and smoked bellies were individually weighed to obtain a cooked weight. Cooked yield was calculated using the following equation: [(cooked weight/green weight) x 100]. Thermally processed bellies were allowed to cool for a period of at least 48 hours before slicing. Bellies were sliced starting at the anterior end and working toward to the posterior end for a desired thickness to achieve 20 slices per kg. Complete slices were counted, while ends and incomplete pieces were sorted off. Sliced bellies were oriented based on anatomical order from the blade end to the flank end. Bellies were then divided into five equal zones, with the appropriate number of slices in each zone based on the
total number of slices in each particular belly. Zones were designated as A (blade end), B, C, D, and E (flank end; Robles, 2004). The first two slices in a given zone were packaged and stored for proximate composition (moisture, fat, and protein. One complete slice was collected from the middle of each of the five aforementioned zones for sensory analysis. Slice proximate composition was conducted using the same manner as fresh loin chops and cured hams.

**Sensory Testing**

Sensory evaluations was conducted by a trained sensory panelist for the first block (n = 60) of hams and bellies. Parameters of evaluation included saltiness, overall flavor, and overall acceptability. Results of the second block of sensory testing has yet to be determined, therefore was not included in this analysis.

**Statistical Analysis**

The live and carcass portion of the data were analyzed with the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC) as a randomized complete block design with the fixed effect of diet and the random effect of replication nested within block. Pen served as the experimental unit. Ultrasonic carcass measurements were analyzed using the MIXED procedure in SAS as repeated measures over time with fixed effects of diet, day, and their interaction. The effect of replication nested within block served as the random variable. An unstructured covariance structure was used based on Akaike’s information criteria. Statistical differences were detected using the slice option. Processed ham and belly data were analyzed as a 2 x 2 factorial in a split design. The whole plot of diet was tested with the interaction of block and diet. The split plot was sodium curing solution (low or regular) and the three way interaction of block, diet, and
curing solution served as the error term. Normality of the residuals was tested in the UNIVARIATE procedure of SAS with normal probability plots. Statistical differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Growth Performance

Blocking criteria were met and there were no differences ($P = 0.91$) in BW at the time of allocation (14 days prior to initiation of treatment diets) or on day 0 ($P = 0.14$) of the trial between pigs fed and not fed RAC (Table 2). However, RAC pigs (87.85 kg) were 1.84 kg heavier ($P < 0.01$) than control pigs (86.01 kg) at d 7 and the magnitude of the difference can be attributed to RAC fed pigs being 22.6% more efficient ($P < 0.01$) during this period which resulted in a 0.18 kg/d advantage (1.04 vs. 0.86 kg/d; $P < 0.01$) for RAC pigs in ADG from d 0 to d 7 (Table 2). This was the only 7 d increment where RAC pigs had greater ($P < 0.05$) performance indicators than control pigs, but over the duration of the entire feeding period RAC fed pigs grew faster ($P < 0.01$) and were more feed efficient ($P < 0.01$) than pigs not fed RAC (Table 2). The magnitude of difference in BW between RAC and control pigs increased during the entire 28 d feeding period. Pigs fed RAC were 1.84 kg greater at d 7, 2.43 kg greater at d 14, 2.98 kg greater at d 21, and at the end of the finishing period (d 28), RAC pigs (106.80 kg) were 3.29 heavier ($P < 0.01$) than control pigs (103.51 kg; Table 2). Additionally, RAC pigs had a 0.10 kg/d advantage ($P < 0.01$) in ADG from d 0 to 28, and had a gain to feed ratio (G:F) of 0.03 units greater ($P < 0.01$) than control pigs (Table 2). Similarly, Apple et al. (2007) reported via meta-analysis pigs fed 10 mg/kg RAC had a 0.09 kg/d advantage ($P < 0.01$) in ADG and a G:F of 0.04 units greater ($P < 0.001$) than control pigs. No differences ($P$
> 0.05) were detected for average daily feed intake (ADFI) at any time during the
finishing period (Table 2).

**Real-time Ultrasonic Measurements**

There were no differences in real-time ultrasonic measurements for 10th-rib LMA
in RAC and control pigs at allocation (P = 0.49), d 0 (P = 0.14), or d 7 (P = 0.20; Figure
1). Pigs fed RAC had 1.65 cm² greater (P < 0.01) LMA than control pigs at d 14 and the
statistical significance (P ≤ 0.05) was sustained for the rest of the feeding trial (Figure 1).
Additionally, the magnitude of the difference in LMA increased from 1.65 cm² to 2.30
cm² on d 21 to 2.49 cm² on d 28 (Figure 1). There were no differences (P ≥ 0.15) in 10th
rib fat thickness at any point during the 28 d feeding trial (Figure 2). However, RAC fed
pigs had a magnitude of difference of 0.13 cm less (P = 0.15) 10th rib fat thickness than
control fed pigs at the end of the feed trial.

There were no differences (P > 0.05) for predicted percent lean between RAC and
control pigs at allocation (P = 0.99), d 0 (P =0.11), or d 7 (P = 0.28) of the feeding trial
(Figure 3). Pigs fed RAC had 0.90 percentage units greater (P = 0.02) predicted percent
lean at d 14. The difference in predicted percent lean increased to 1.2 percentage units (P
= 0.01) on d 21 and increased further to 1.31 percentage units (P = 0.01) on d 28 (Figure
3).

**Carcass Characteristics**

Pigs were randomly selected for harvest because the primary objective of the meat
quality phase of the experiment was to test the effect of the cure solution rather than
effects of RAC on carcass characteristics. So the lack of statistical differences observed
in some carcass parameters may not agree with previously published literature, but the
magnitudes of difference were similar to previous research. Furthermore, the magnitude of differences observed for true carcass characteristics of the subpopulation were very similar to the magnitudes of differences observed using real-time ultrasonic measurements on the entire population. Therefore the subpopulation of pigs used in the further processed portion of the experiment appears to be representative of the entire population of pigs used during the feeding portion of the experiment. Differences in true fat thicknesses of the carcasses were 0.12 cm and differences in fat thickness using real-time ultrasound on the entire population were 0.13 cm. Differences in true LMA of the carcasses were 2.44 cm² and differences in LMA using real-time ultrasound on the entire population were 2.49 cm². Overall, the magnitude of reduced fat thickness and increased LMA of RAC pigs in the current study agreed with previous studies that used similar feeding programs at the same durations in crossbred commodity pigs (Boler et al., 2011; Kutzler et al., 2011; Hinson et al., 2012b). Differences in estimated carcass lean of the selected carcasses were 1.01 percentage units and differences in predicted percent lean using real-time ultrasound on the entire population was 1.31 percentage units. The magnitude of difference between RAC and control pigs for both estimated carcass lean and predicted percent lean were similar to a separate lean equation analysis conducted by Bohrer et al. (2013) where advantages of RAC pigs vs. control pigs for bone-in carcass yield (1.01 percentage units), bone-in lean cutting yield (1.10 percentage units), and boneless cutting yield (1.08 percentage units). Hot carcass weights were not statistically different (P = 0.21) between carcass from RAC fed pigs (78.93 kg) and carcasses from pigs not fed RAC (77.09 kg), but RAC fed pig carcasses were still 1.84 kg heavier than control carcasses. The magnitude of difference reported for HCW was slightly less than
previously published literature where pigs were marketed in a similar manner; however this may be due to pigs in the current study being marketed at a lighter weight. Carcass yields were not statistically different (P = 0.14) between RAC fed pigs (78.36%) and pigs not fed RAC (77.93%), but RAC fed pig carcasses were still 1.84 kg heavier than control carcasses.

**Loin and Fresh Belly Quality**

No differences (P > 0.05) among RAC and control pigs were detected for loin or fresh belly quality (Table 3). The magnitude of the difference in loin pH (RAC = 5.65; control = 5.61) was similar to the difference reported by Rincker et al. (2009; RAC = 5.80, control = 5.74; P < 0.01) and to multiple other studies (Apple et al., 2004; Kutzler et al., 2010; Hinson et al., 2011; Rickard et al., 2012). Boler et al. (2010) reported pork quality attributes (subjective firmness, subjective color, 21-d purge loss, and cook loss) were improved when ultimate pH was greater. No differences (P > 0.05) were detected in Warner-Bratzler shear force tests between loins from RAC and control pigs when frozen at 4, 8, and 12 d, as thus the days were pooled. (Table 3). The lack of differences (P > 0.05) detected in belly flexibility and thickness between RAC and control pigs was similar to Scramlin et al. (2008).

**Cured Ham**

Hams from RAC pigs tended (P ≤ 0.08) to be heavier than hams from control pigs throughout processing. Green weights (inside + outside + knuckle) of hams from RAC pigs (4.63 kg) tended to be 0.23 kg heavier (P = 0.07) than hams from control pigs (4.40 kg). Bohrer et al., (2013) reported a magnitude of difference in boneless ham (inside, outside, and knuckle) from RAC and control pigs of 0.44 kg (RAC = 5.77 kg, control =
5.34 kg). No differences (P > 0.05) were detected between hams from RAC and control pigs for pump uptake, cook yield, objective color, or proximate composition. There were no differences (P ≥ 0.16) for ham processing characteristics between the cure solutions. This was expected, assuming bilateral symmetry, no differences should have been detected because ham treatments were randomly assigned to one ham from each pig.

Sodium chloride functions in curing solutions to increase hydration of proteins, thus enhancing the binding of proteins to other proteins and to fat (Doyle and Glass, 2010). Break strength is a way to assess the bind of meat proteins, a characteristic with known implications on product texture. Hams cured with LOW solution (5.97 kg) required less (P = 0.05) force to break than REG hams (6.99 kg).

There were no differences in cured color (P ≥ 0.17) between RAC and control hams, but low sodium hams were lighter (P = 0.03), less red (P < 0.01), and more yellow (P < 0.0001) than REG hams (Table 4). Similarly, Tobin et al., (2013) concluded a reduction in salt when producing sausage resulted in paler color. Traditionally, a reported disadvantage of salt inclusion in curing solutions is its effect on darkening meat color (Ockerman, 1996). The differences in objective color values may not be attributed to sodium content. But, rather the amount of chlorine, as KCl contains less chlorine than NaCl and the decrease of chlorine may be slowing the curing reaction, thus altering the cured color. Boler et al. (2011) reported lower (P < 0.05) a* values in every fresh ham muscle evaluated in the study except the semimembranosus of RAC fed pigs when compared with controls. Furthermore, Boler et al. (2011) reported cured ham color of RAC hams were lighter (P < 0.01) and less red (P = 0.03) than cured hams from control fed pigs. Therefore the interaction trends between cure solution and RAC treatment were
not unexpected. Trending interactions of cure solution and diet were observed for L* values \((P = 0.09)\) and a* values \((P = 0.06)\). Control hams cured with REG solution had lower \((P < 0.05)\) L* values \((62.87)\) and greater \((P < 0.05)\) a* values \((16.79)\) when compared to control hams cured with LOW solution \((64.84; 15.66)\), RAC hams cured with REG solution \((64.40; 16.14)\), and RAC hams cured with LOW solution \((64.69; 15.87)\).

No differences \((P \geq 0.25)\) were reported in composition of RAC and control hams. This was dissimilar to the findings of Boler et al. (2011) who reported cured hams from RAC pigs had less fat percentage \((P < 0.001)\) and greater protein percentage \((P = 0.04)\). Furthermore, there were no differences in moisture \((P = 0.89)\) or fat \((P = 0.56)\) percentages between the two cure solutions, but the REG hams had 0.79 percentage units greater \((P = 0.01)\) protein than LOW hams (Table 4). Despite the difference in protein content and calculated PFF, both LOW and REG hams meet the minimum PFF value \((20.5\%)\) to be labeled as cooked ham.

**Cured Belly**

Weights of bellies did not differ \((P > 0.05)\) regardless of diet or cure solution. However, the magnitude of the difference \((0.27 \text{ kg RAC advantage})\) in trimmed belly weight \((\text{green weight})\) in the current study was similar to the magnitude of difference reported in Bohrer et al. (2013; 0.19 kg RAC advantage). Pump uptake was less \((P < 0.001)\) in LOW bellies \((14.36\%)\) when compared to REG bellies \((16.84\%)\). Furthermore, cook yield of LOW bellies \((102.62\%)\) was less \((P < 0.01)\) in comparison to REG bellies \((104.31\%)\). Bellies cured with LOW solution tended \((P = 0.09)\) to yield fewer bacon
slices (127 vs. 131) than REG bellies. Bacon slice composition did not differ (P > 0.05) for diet, cure solution, or their interaction.

**Sensory Testing**

No differences (P > 0.05) were detected for saltiness, flavor, or acceptability between LOW and REG hams or bellies (Table 6). The data presented only includes the first block of hams and bellies (n = 60) as the second and final block has yet to be determined.

**CONCLUSION**

Pigs fed RAC had greater (P < 0.01) ADG and G:F than control pigs. There were no effects (P > 0.05) on processing characteristics of hams and bellies from RAC pigs when compared to control pigs. Hams cured with a lower sodium solution were not different (P > 0.05) in processing characteristics, yet the cured product was lighter (greater L*) , less red (lower a* value) and required less force to break the protein bound seam when compared with hams cured with regular sodium solution. Bellies cured with a lower sodium solution had reduced (P < 0.01) pump uptake and cook yield when compared to bellies cured with a regular sodium solution. No differences (P > 0.05) in block one hams and bellies were detected for saltiness, flavor, or acceptability between hams and bellies cured with either solution by a trained sensory panelist. Overall, addition of potassium chloride to curing solution as a replacement to sodium chloride appears to be a justifiable method of reducing sodium in hams and bellies; however alterations in cured color of hams may be present and processing yields of bellies may decrease.
LITERATURE CITED


Ockerman H.W. 1996. Chemistry of meat tissue. The Ohio State University, Columbus, OH.


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<sup>1</sup> Analyzed levels were within acceptable tolerances (75 - 125% of claim) for each diet

<sup>2</sup> Provided either 0.0, 7.4, or 10.0 mg of ractopamine hydrochloride (Paylean 9) per kg of diet. Paylean® is a registered trademark of Eli Lilly and Company (Elanco Animal Health), Greenfield, IN
Table 3.2. Effects of ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) on the growth performance of purebred Berkshire pigs during a 28 day feeding period

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<td>ADFI, kg</td>
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**Table 3.3.** Effects of ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) on carcass characteristics and fresh pork quality of purebred Berkshire pigs during a 28 day feeding period.

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<td></td>
<td>0.14</td>
</tr>
<tr>
<td>Estimated carcass lean¹, %</td>
<td>52.19</td>
<td>53.20</td>
<td>0.75</td>
<td></td>
<td>0.28</td>
</tr>
<tr>
<td><strong>Loin Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.61</td>
<td>5.65</td>
<td>0.03</td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>Marbling²</td>
<td>1.40</td>
<td>1.57</td>
<td>0.10</td>
<td></td>
<td>0.29</td>
</tr>
<tr>
<td>Firmness²</td>
<td>1.50</td>
<td>1.60</td>
<td>0.09</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Subjective color²</td>
<td>1.93</td>
<td>1.92</td>
<td>0.08</td>
<td></td>
<td>0.87</td>
</tr>
<tr>
<td>Objective color Scores³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>55.92</td>
<td>56.31</td>
<td>0.52</td>
<td></td>
<td>0.53</td>
</tr>
<tr>
<td>a*</td>
<td>17.66</td>
<td>17.26</td>
<td>0.22</td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td>b*</td>
<td>6.50</td>
<td>6.47</td>
<td>0.23</td>
<td></td>
<td>0.88</td>
</tr>
<tr>
<td>Driploss, %</td>
<td>1.32</td>
<td>1.44</td>
<td>0.13</td>
<td></td>
<td>0.52</td>
</tr>
<tr>
<td>Cookloss⁴, %</td>
<td>19.43</td>
<td>19.06</td>
<td>0.69</td>
<td></td>
<td>0.52</td>
</tr>
<tr>
<td>WBSF⁴, kg</td>
<td>2.29</td>
<td>2.27</td>
<td>0.08</td>
<td></td>
<td>0.76</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>73.90</td>
<td>73.63</td>
<td>0.13</td>
<td></td>
<td>0.14</td>
</tr>
<tr>
<td>Fat, %</td>
<td>2.41</td>
<td>2.58</td>
<td>0.15</td>
<td></td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Belly Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSD belly flex, cm</td>
<td>10.23</td>
<td>10.27</td>
<td>0.76</td>
<td></td>
<td>0.94</td>
</tr>
<tr>
<td>Length, cm</td>
<td>57.40</td>
<td>56.72</td>
<td>2.07</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Width, cm</td>
<td>23.83</td>
<td>24.50</td>
<td>1.21</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Thickness, cm</td>
<td>3.70</td>
<td>3.72</td>
<td>0.12</td>
<td></td>
<td>0.82</td>
</tr>
</tbody>
</table>

¹Estimated carcass lean = (-0.534 + (0.291 x liveweight, lb) – (16.498 x 10⁻⁶ rib fat depth, in) + (5.425 x 10⁻⁶ rib LMA, in²) + (0.833 x sex of pig; barrow=1, gilt = 2)) / (liveweight x 0.74%) (Burson and Berg, 2001)

²Values assessed using NPPC standards and recorded in whole numbers
³L* = lightness, a* = redness, b* = yellowness
⁴Due to lack of differences across time, cooked loss and WBSF dates (4, 8, and 12 d) were pooled.
## Table 3.4. Effects of a low sodium curing solution on cured ham characteristics of purebred Berkshire pigs fed ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) during a 28 day feeding period.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cure Treatment</th>
<th>Diet</th>
<th>P - values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reg</td>
<td>Low</td>
<td>SEM</td>
</tr>
<tr>
<td>Green weight, kg</td>
<td>4.57</td>
<td>4.46</td>
<td>0.14</td>
</tr>
<tr>
<td>Pumped weight, kg</td>
<td>6.05</td>
<td>5.94</td>
<td>0.18</td>
</tr>
<tr>
<td>Pump Uptake, %</td>
<td>32.59</td>
<td>33.44</td>
<td>1.36</td>
</tr>
<tr>
<td>Equilibrium weight, kg</td>
<td>5.60</td>
<td>5.49</td>
<td>0.16</td>
</tr>
<tr>
<td>Stuffed weight, kg</td>
<td>5.58</td>
<td>5.48</td>
<td>0.16</td>
</tr>
<tr>
<td>Cooked weight, kg</td>
<td>4.98</td>
<td>4.86</td>
<td>0.15</td>
</tr>
<tr>
<td>Cook Yield(^1), %</td>
<td>110.07</td>
<td>109.06</td>
<td>1.25</td>
</tr>
<tr>
<td>Break force Strength</td>
<td>6.99</td>
<td>5.97</td>
<td>0.74</td>
</tr>
<tr>
<td>Objective Color Scores(^2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L(^*)</td>
<td>63.64</td>
<td>64.76</td>
<td>0.53</td>
</tr>
<tr>
<td>a(^*)</td>
<td>16.47</td>
<td>15.77</td>
<td>0.15</td>
</tr>
<tr>
<td>b(^*)</td>
<td>6.01</td>
<td>6.59</td>
<td>0.22</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>71.01</td>
<td>71.05</td>
<td>0.57</td>
</tr>
<tr>
<td>Fat, %</td>
<td>6.43</td>
<td>6.19</td>
<td>0.36</td>
</tr>
<tr>
<td>Protein, %</td>
<td>24.03</td>
<td>23.22</td>
<td>0.47</td>
</tr>
<tr>
<td>PFF(^3)</td>
<td>25.98</td>
<td>24.58</td>
<td>0.59</td>
</tr>
</tbody>
</table>

\(^1\) Cooked yield = (cooked weight/green weight) x 100

\(^2\) L\(^*\) = lightness, a\(^*\) = redness, b\(^*\) = yellowness

\(^3\) PFF (protein fat-free) = [\% protein / (100 - \% fat)] x 100
Table 3.5. Effects of a low sodium curing solution on cured bacon characteristics of purebred Berkshire pigs fed ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) during a 28 day feeding period.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cure Treatment</th>
<th>Diet</th>
<th>P - values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reg</td>
<td>Low</td>
<td>SEM</td>
</tr>
<tr>
<td>Green weight, kg</td>
<td>6.04</td>
<td>6.31</td>
<td>0.47</td>
</tr>
<tr>
<td>Pumped weight, kg</td>
<td>7.01</td>
<td>7.30</td>
<td>0.56</td>
</tr>
<tr>
<td>Pump Uptake, %</td>
<td>15.74</td>
<td>15.46</td>
<td>0.64</td>
</tr>
<tr>
<td>Equilibrium weight, kg</td>
<td>6.91</td>
<td>7.21</td>
<td>0.55</td>
</tr>
<tr>
<td>Cooked weight, kg</td>
<td>6.26</td>
<td>6.54</td>
<td>0.49</td>
</tr>
<tr>
<td>Cook Yield¹, %</td>
<td>103.47</td>
<td>103.46</td>
<td>0.44</td>
</tr>
<tr>
<td>Slice Count</td>
<td>129</td>
<td>129</td>
<td>6.98</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>46.26</td>
<td>47.37</td>
<td>0.64</td>
</tr>
<tr>
<td>Fat, %</td>
<td>37.14</td>
<td>35.42</td>
<td>1.07</td>
</tr>
<tr>
<td>Protein, %</td>
<td>39.34</td>
<td>40.51</td>
<td>0.06</td>
</tr>
</tbody>
</table>

¹ Cooked yield = (cooked weight/green weight) x 100
Table 3.6. Effects of a low sodium curing solution on cured ham and bacon sensory characteristics of purebred Berkshire pigs\(^1\).

<table>
<thead>
<tr>
<th>Item</th>
<th>Cure Solution</th>
<th>Reg</th>
<th>Low</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ham</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saltiness</td>
<td></td>
<td>6.77</td>
<td>7.06</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>Overall flavor</td>
<td></td>
<td>7.32</td>
<td>7.28</td>
<td>0.16</td>
<td>0.84</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td></td>
<td>7.22</td>
<td>7.23</td>
<td>0.15</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Bacon</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saltiness</td>
<td></td>
<td>6.35</td>
<td>6.17</td>
<td>0.20</td>
<td>0.51</td>
</tr>
<tr>
<td>Overall flavor</td>
<td></td>
<td>6.57</td>
<td>6.11</td>
<td>0.22</td>
<td>0.15</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td></td>
<td>6.24</td>
<td>5.89</td>
<td>0.21</td>
<td>0.25</td>
</tr>
</tbody>
</table>

A trained sensory panel used a scoring system using whole numbers where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.

\(^1\)Excludes data from block 2 (yet to be determined)
Figure 3.1. Effects of ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) on real-time ultrasonic 10^{th}-rib loin muscle area (LMA) measurements of purebred Berkshire pigs fed ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) during a 28 day feeding period.
Figure 3.2. Effects of ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) on real-time ultrasonic 10th-rib fat thickness measurements of purebred Berkshire pigs fed ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) during a 28 day feeding period.
**Figure 3.3.** Effects of ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) on predicted percent lean of purebred Berkshire pigs fed ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) during a 28 day feeding period.
COMPLETE LITERATURE CITED

**Literature Cited: Chapter 1**


Pérez-Juan, M., M. Flores, and F. Toldrá. 2007. Effect of ionic strength of different salts on the binding of volatile compounds to porcine soluble protein extracts in model systems. Food research international 40.6: 687-693.


**Literature Cited: Chapter 2**


**Literature Cited: Chapter 3**


Ockerman H.W. 1996. Chemistry of meat tissue. The Ohio State University, Columbus, OH.


