The effect of feeding ractopamine on growth performance, carcass composition, muscle quality, and cortisol concentration in purebred Berkshire swine

THESIS

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ABSTRACT

The study evaluated the effects of a 28 d pre-harvest ractopamine (RAC) feeding program on average daily gain (ADG), feed conversion efficiency (FC), backfat (BF) and loin muscle area (LMA), pork loin quality, and cortisol concentration in purebred Berkshire pigs (n = 117) utilizing a randomized complete block design with three treatments (Control (C), 0 ppm; RAC5, 5.0 ppm; RAC10; 10 ppm) in four replicates. Litter-mate pigs were randomly assigned to each of the three treatments within a replicate. Ultrasonic BF and LMA, pig weight, and salivary cortisol concentrations were measured at days 0, 7, 14, 21, and 28 of the feeding period. Blood was collected during harvest at exsanguination for plasma cortisol measurements. Carcass composition and pork quality (NPPC, 2000; visual color, marbling, firmness, and wetness and instrumental measures of ultimate pH and Minolta L*, a*, and b* were assessed at 24h post-harvest. Mixed model procedures of SAS were used in analyses. Fixed effects were treatment, sex, and a treatment × sex interaction, with sex and interaction effects removed if not significant ($P > 0.10$). Random effects included replication and litter nested within replication. Individual ADG was greater ($P < 0.05$) for RAC10 when compared with C and RAC5 by d 14 and through d 28, while pigs fed RAC5 had greater ADG than the C from d 1 to 14 and d 1 to 21 ($P < 0.05$) only. However, when assessed on a pen basis, ADG was not different across the 28 d feeding period. Feeding RAC5 or RAC10

improved pen FC throughout the trial when compared with pens fed the C diet ($P < 0.05$); however, no differences were observed between RAC5 and RAC10. Serial ultrasonic measures of BF were significantly decreased in RAC10 pigs from 95 to 120 kg of BW when compared to C pigs and from 115 to 120 kg BW when compared to RAC5 pigs. Pigs fed RAC5 had decreased BF from 110 to 120 kg BW when compared to C. Ultrasonic measures of LMA were increased in RAC10 pigs from 105 to 120 kg BW when compared to C, however no differences were seen between RAC5 and RAC10 fed pigs throughout the trial. Carcass LMA of RAC10 was greater than C ($P < 0.05$) and BF was less than RAC5 and C ($P < 0.05$). Carcass fat-free lean percentage was greater for pigs fed RAC10 ($P < 0.05$) when compared with carcasses of pigs fed C and RAC5 diets. Neither RAC5 nor RAC10 diets influenced fresh loin quality, as there were no differences in visual color, marbling, firmness, wetness, or L*. However, ultimate pH was greater for the RAC10 treatment when compared with C. On d 0, baseline cortisol concentrations did not differ between treatment groups. No differences in salivary or plasma cortisol concentrations were observed between treatments regardless of day. Final results indicate feeding ractopamine improved feed conversion efficiency, maintained (RAC5), or improved (RAC10) carcass lean content and, therefore, value without negatively influencing pig cortisol concentrations or pork loin quality.

Dedicated in honor of David and Melinda Betts

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

Niche markets are defined as small distinct markets that may provide higher prices for products that meet specific customer needs (McMullen, 2006). In the past several decades, niche marketing has become a phenomenon in the meat industry due to changing U. S. consumer demands. Today, consumers are more aware of animal care and environmental footprint, and desire a higher quality, better tasting product (Honeyman et al., 2006). In a pork industry that is currently mostly producing a commodity product, the demand from a segment of the pork consuming population for high quality pork is not being met. The American Berkshire Association, the world's first swine registry, has taken advantage of this niche marketing opportunity.

The Berkshire breed is well known for producing high quality pork that is consistently tender, juicy, and palatable. The United States pork industry has sacrificed pork quality to meet the demands for leanness; however the Berkshire breed has maintained its excellent muscle quality for over 300 years (McMullen, 2006). Literature has shown the Berkshire breed produces pork products with the most desirable ultimate pH, color, firmness, and cooked loin quality worldwide, and may explain the demand for Berkshire pork by chefs, consumers, and Asian markets. Berkshire pork is consistently higher

quality than commodity pork, and with this recognition, a niche market has been formed for producers that allow premiums for a higher quality product.

Although the Berkshire breed is known for its high quality, tender, juicy pork, Berkshire pigs are also known to have undesirable maternal traits, poorer growth rates and feed efficiency, and produce lower percent lean carcasses (McMullen, 2006). On average, a Berkshire sow will wean 7 to 8 pigs per parity making her capable of producing 10 to 15 pigs per year (McMullen, 2006). Crossbred commercial sows produce 21 to 26 pigs per year making them much more efficient (McMullen, 2006). Additionally, Berkshires have five to 10 percent lower feed conversion efficiency (FC) when compared to commercial crossbred pigs. Berkshire pigs are also known to require approximately 20 to 35 more days to reach a market weight of 250 pounds when compared with commercial finishing pigs (McMullen, 2006). Moreover, the Berkshire breed produces carcasses with a lower percentage of fat-free lean. Poor reproductive efficiency, less desirable FC and growth, and lower percent lean carcasses has resulted in a greater break-even price for Berkshire producers as well as a greater environmental footprint due to more days on feed, which is a concern of today's consumer.

In the past ten years, the industry has utilized a feed additive, ractopamine hydrochloride (RAC), a beta-adrenergic agonist. Ractopamine acts as a repartitioning agent which has the capability to divert nutrients away from fat deposition which may allow for more nutrients to be transmitted towards muscle accretion (Moody, 2000). In over 30 years of intense research and development, RAC has been shown to improve average daily gain (ADG) (Watkins et al., 1990), FC (Armstrong et al., 2004), and percent carcass lean (See et al., 2004), as well as provide potential environmental benefits

such as reduced nitrogen and phosphorus excretion in urine and feces of finishing pigs (Sutton et al., 2001).

Ractopamine hydrochloride for use in finishing swine is marketed as Paylean® 9 by Elanco. Paylean® 9 is available as a Type A Medicated Article that contains RAC at 20 g/kg. Further dilutions are necessary to obtain a Type B medicated Feed and then to a Type C complete medicated feed. According to the label, Paylean® 9 is to be fed in a complete finishing swine ration containing at least 16 percent crude protein at a concentration of 5 to 10 ppm in finishing swine weighing not less than 68 kg and for the last 20 to 41 kg of gain prior to slaughter.

Although there have been many studies that have shown RAC improves growth efficiency and percent carcass lean, there has been little research done on animal behavior and well-being. The Paylean® 9 label states that ractopamine may increase the number of injured and/or fatigued pigs during marketing. According to Marchant-Forde et al. (2003) and Poletto et al. (2010) RAC could have a negative effect on animal behavior and well-being. RAC-fed pigs have exhibited negative behaviors towards handlers and other pigs and were overall more difficult to handle (Marchant-Forde et al., 2003). Moreover, higher levels of circulating concentrations of epinephrine were found in pigs fed RAC at 10 ppm (Poletto et al., 2010). Pigs that are fed RAC are more susceptible to the negative impacts of rough handling and increased stress during transport, which could result in negative impacts on fresh pork quality. Understanding the relationship between RAC and the possible benefits and pitfalls it has on Berkshire pork production provide producers with a better understanding of how to increase profit margins without compromising fresh pork quality and animal well-being.

The objectives of this experiment were to evaluate the effects of a 28 d pre-harvest RAC feeding program on average daily gain, feed conversion efficiency, carcass composition, and pork quality as well as salivary and plasma cortisol levels in purebred Berkshire swine. If it can be shown that RAC improves growth efficiency and carcass composition of the Berkshire pig without effecting quality or stress induced hormones, there could be expanded opportunities for the Berkshire breed to further capitalize on niche marketing opportunities.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Pork Industry

History

The United States Department of Agriculture has reported that since 1986, the number of hog operations has decreased from approximately 350,000 to 69,100 operations in 2010. The nation's swine industry has lost hundreds of thousands of small hog operations, however, it continues to increase the total volume of pork produced. This is mostly due to greater production efficiency combined with a greater understanding of the present technology available to the industry. Pork producers and pork processors have developed strong ties with each other to form a more vertically integrated industry. This structure has allowed the industry to utilize new technology to improve growth performance, reproductive efficiency, and a greater percentage of carcass lean. The average number of pigs born annually per sow increased to 22.8 in 2010, when compared to 20.0 in 2002 (Bounds, 2011). The industry is more efficient than ever before, allowing producers to sustain on fewer sows while increasing the pig crop.

During the 1950's, pigs were raised as predominately lard producing animals for cooking, and serving as an important part in producing nitroglycerine for explosives

during World War II. However, as the WWII came to an end and vegetable oils and shortenings became more popular, consumer demand decreased for lard (Cromwell, 1999). As consumers became more health conscious, the pork industry began to shift from lard-type pigs (Figure 2.1) to high-lean producing pigs (Figure 2.2). This shift in the industry happened very quickly as benefits of crossbreeding were recognized and breeding stock with extreme muscle became popular. The use of extremely heavy muscled pigs resulted in a high occurrence rate of pale, soft, and exudative (PSE) pork and porcine stress syndrome (PSS) problems. The industry has moved away from the extremes of lard type or extremely heavy muscled pigs, which has helped it become as reproductively and productively efficient as it is today, however, meat quality has still been sacrificed (Cromwell, 1999).

As stated earlier, the pork industry is predominantly vertically integrated. There is a strong relationship between the producer and packer in a vertically integrated industry. In fact, eight of the largest hog producers are owned by five of the major packers in the pork industry (Lawrence and Grimes, 2000). This allows producers and packers to market pigs with greater uniformity, providing the consumer with a more consistent product. There is less genetic variation and fewer differences in management practices compared to the industry 50 years ago. With the majority of the pork in the U. S. marketed through commodity channels, there is little variation in pork products.

Pork producers are paid, primarily, on the fat to lean ratio of the carcass, with no premium for meat quality. Therefore there is no incentive to produce a high quality product. National Pork Producers Council reported during the Lean Growth Symposium (1999) that the industry is losing market share to the alternative meat or protein sources

as a result of quality issues. Consumers have stated that pork must cost less than chicken and be of very high, proven quality to achieve a 50 percent probability of purchase over poultry products. Although the industry is producing a fairly consistent product, as pork becomes leaner, there is a greater incidence of poor quality, less juicy, tougher pork, turning consumers away. According to Salvage (2005), some consumers wanted more tender, juicy, flavorful pork and were willing to pay a premium for it.

Berkshire Pork

The Berkshire breed was a breed that was popular in the early 1900s but faded out of the industry after the 1950s when the industry shifted towards leaner pigs. The breed is well known for producing high quality pork that is consistently tender, juicy, and flavorful. While the United States pork industry has sacrificed pork quality to meet the demands for leanness, the Berkshire breed has maintained its excellent muscle quality for over 300 years (McMullen, 2006). Results from the 1991-2004 National Barrow Show Progeny Test illustrate the breeds' superior meat quality. The Berkshire breed produced pork products with the most desirable ultimate pH, color, firmness, as well as cooked loin quality. These claims are supported by the results presented in Table 2.1. The Japanese have long recognized the superior quality of Berkshire pork or "kurobota" as it is known to them. They are willing to pay up to a 50 percent premium for the product (Honeyman, 2006). Recently, there has also been a high demand for Berkshire pork from chefs and consumers desiring a higher quality product, making it one of the only pork products with a global demand.

Between the demand for Berkshire pork overseas and in the U. S. producers of Berkshire pigs cannot keep up. The American Berkshire Association (ABA) registers approximately 5,000 litters per year which is not enough to meet the demands. Few producers in the U.S. raise Berkshires due to their undesirable maternal traits, poorer growth rates and feed efficiency, and their ability to produce carcasses with a lower percentage of fat-free lean (Table 2.2). Due to the inadequate supply of Berkshire pork, producers are able to demand a higher price for their product, therefore creating a niche market.

History of the Berkshire Breed

The Berkshire breed was discovered 300 years ago in England and was well known throughout the country for producing hams and bacon of the highest quality. The breed became very popular with upper class English farmers, even the Royal Family raised Berkshire pigs. The black color pattern with the six points of white was not the Berkshires original color, Berkshires were crossed with Siamese and Chinese genetics to create this color pattern and make the breed more efficient. These two breeds are the only outside bloodlines known to have gone into the Berkshire breed since the time they have been recorded (McMullen, 2006).

Berkshire pigs were first imported into the U.S. in 1823 and became very popular in many hog operations. Due to the breeds' popularity, a group of purebred producers established the ABA in 1875 as a way to keep the Berkshire breed pure. The ABA's mission was to maintain the excellent quality that made them so popular in England by

keeping records on purebred Berkshire production. Today, the breed is still descendent from the animals that were imported from England 188 years ago (McMullen, 2006).

2.2 Beta-Adrenergic Agonists

History

Pharmaceutical companies have used beta agonists for many decades. They have been used to treat asthma, delay premature labor, and can be used as a cardiac stimulant to prevent cardiogenic shock, heart failure, and regulate blood pressure (Mersmann, 1998).

For over 30 years, researchers have recognized the potential of beta-agonists as a way to alter the pattern of growth in livestock and improve efficiency. Beta-agonists or phenethanolamines are considered repartitioning agents, meaning that they have the ability to redirect nutrients towards muscle production and away from producing adipose tissue (Figure 2.3) (Ricks, 1984). The four main effects repartitioning agents have on livestock are: 1) increase ADG, 2) improve FE, 3) increase leanness or muscle mass, and 4) increase dressing percent (Moody, 2000). There are many forms of phenethanolamines on the market today. The most common forms are ractopamine, clenbuterol, cimaterol, salbutamol, L644,969 and zilpaterol, however only ractopamine and zilpaterol are currently approved for use on livestock.

Ractopamine hydrochloride was first approved for the use in finishing swine in December of 1999. Ractopamine has been highly studied as a way to increase profit margins in the swine industry by ways of improving efficiency, carcass composition, and percentage fat-free lean. (Figure 2.4)

Chemical Structure

According to the Paylean® Technical Manual, RAC is DL-4-hydroxy-[[[(3-4-hydroxy-phenyl)-1-methyl-propyl]-amino]-methyl]benzene-methanol hydrochloride with an empirical formula of $C_{12}H_{23}NO_3HCl$ and molecular weight of 337.85. The structure can be seen in Figure 2.5.

Classification

Ractopamine hydrochloride is classified as a small organic molecule known as a β-adrenergic receptor (β-AR) agonist. β-adrenergic receptor agonists are considered phenethanolamines which are classified by a substituted aromatic ring attached to a ethanolamine side chain (Figure 2.2) (Mills 2002a). This distinctive structure is how phenethanolamines develop their biological activity. According to Mills (2002a), RAC can be compared to endogenous catecholamines epinephrine and norepinephrine as they are physiological β-AR agonists. Epinephrine and norepinephrine have been known to stimulate β-AR since the 1940's (Mersmann, 1998).

There are three subtypes of β-AR, β1, β2, and β3 that are classified as seven transmembrane-domain proteins (Figure 2.6) that form more than 400 amino acids in a continuous polypeptide chain (Mersmann, 1998). The amino acid sequence of the seven transmembrane domain structure is what makes these three subtypes differ (Figure 2.7), as they only share 30 to 50 percent of the same amino acid sequence (Mills 2002a). There is also variation seen between a given tissue between species, as well as variation in the amino acid sequences between species. This has made it difficult to obtain a greater understanding of the physiological functions controlled by β-AR as different

subtypes have different affinities for phenethanolamines (Mills 2002a). Ractopamine hydrochloride is considered a β1 selective adrenergic agonist, meaning the mode of action primarily occurs at β1-receptor sites (Mills 2002a). β1-receptor subtypes are the primary receptor in pig tissues, encompassing 80 percent of β-receptors in adipose, 72 percent in heart, 65 percent in lung, 60 percent in skeletal muscle, ad 50 percent in liver (Mills 2002a).

Mode of Action

Ractopamine hydrochloride is a synthetic β-1AR agonist that binds to a physiological beta-adrenergic receptor. This binding creates a physiological response by the body which causes growth modification (Mersmann, 1998). Mersmann (1998) reviewed the mechanisms of action associated with β-AR and β-AR agonists. As the agonist and receptor bind, G-stimulatory (Gs) protein is activated. The Gs protein α-subunit activates the enzyme adenylyl cyclase, which is responsible for producing cyclic adenosine monophosphate (cAMP). cAMP is an intracellular signaling molecule that will bind to protein kinase A (PKA) and allow the subsequent phosphorylation of a number of intracellular proteins (Figure 2.8) (Mersmann, 1998, Mills and Mersmann, 1995).

When PKA is activated hormone sensitive lipase is activated, the rate limiting enzyme for lipolysis, the breakdown of lipids. Moreover, acetyl-CoA carboxylase is inactivated, the rate limiting enzyme for lipogenesis, an enzyme involved in de novo synthesis of fatty acids and triglycerides (Moody et al., 2000). Although β-agonists are known to increase muscle mass it is unclear how these effects take place. It was

originally thought that there was an increase in muscle protein synthesis combined with a decrease in muscle protein degradation. However, this has not been demonstrated in any experiments (Mersmann, 1998).

Desensitization

As β-AR agonists have continued exposure to β-AR the intensity of the β-AR response tends to diminish. This process is known as desensitization. Desensitization may occur within the first d of administering RAC, as Spurlock et al. (1994) reported the total β-AR response is down-regulated by nearly 25 percent and 50 percent within the first 7 d. However, there was no detection of down-regulation in skeletal muscle, only a trend for decreased down-regulation was observed. According to Mills (2002b), this could be due to the different distribution of β-AR subtypes as adipose tissue is 75 percent β1 and skeletal muscle is only 50 percent β1. Several have reported as chronic stimulation of the β-AR occurs, response is reduced to the β-AR agonist due to removal of the β-AR from the plasma membrane located in the seven transmembrane-domain (Ostrowski et al., 1992; Schwinn et al., 1992; Strosberg, 1992; Kobilka and Hoffman, 1995).

2.3 Factors Effecting Response to Ractopamine

Efficacy

Over the past 12 years, RAC has improved growth performance and carcass composition in the swine industry. Researchers have proven RAC ability to increase

profitability in the swine industry. A summarization of varying levels of inclusion and treatment duration trials can be found below and in Table 2.3.

Watkins et al. (1990) evaluated the effect of various levels of RAC in the diet on the growth performance, efficiency, and carcass characteristics of commercial swine throughout the U.S. Two studies were completed evaluating RAC inclusion levels. Study one treatment levels were 1) control; 0 ppm RAC; 2) 2.5 ppm RAC; 3) 5 ppm RAC; 4) 10 ppm RAC; 5) 20 ppm RAC; and 6) 30 ppm RAC. Pigs were placed on trial at 64.5 kg to a termination weight of 104.3 kg. Following the trial termination, all pigs were placed on a non-medicated control diet for withdrawal for 4 d prior to harvest. Average weight at the conclusion of the withdrawal was 106.1 kg. Study two treatment levels included 1) control; 0 ppm RAC; 2) 5 ppm RAC; 3) 10 ppm RAC; 4) 15 ppm RAC; and 5) 20 ppm RAC. Pigs were placed on trial at 65.9 kg and fed to a harvest weight of 107 kg. No withdrawal period was given in study two. In both study one and two, all RAC treated groups were superior to the control for ADG and feed to gain ratio (F:G) ($P < 0.05$). Linear predictions were produced for ADG and 16 and 14 ppm were shown to be the maximum response in study one ($P < 0.04$) and two ($P < 0.003$) respectively for the dosage that produced the greatest improvement. Linear predictions were also produced for F:G and 20 and 18 ppm were shown to be the maximum response in study one ($P < 0.0001$) and two ($P < 0.0001$) respectively for the dosage that showed superior improvement. Average daily feed intake (ADFI) was decreased ($P < 0.05$) in study one at 30 ppm and in study 2 at 20 ppm when compared to the control. Carcass measures were improved in both studies in pigs fed RAC. Dressing percentage was superior ($P < 0.05$) in both studies for pigs fed RAC levels of 10 to 30 ppm. LMA and

percentage fat-free lean was increased ($P < 0.05$) in both studies for all RAC levels with the exception of pigs fed 5 ppm in study 2. There was a linear increase shown over the dosage levels in LMA and percentage fat-free lean ($P < 0.0007$). No dosage range was documented for BF. In study one, BF was decreased at 20 and 30 ppm ($P < 0.05$) and 20 ppm in study two ($P < 0.05$).

Aalhus et al. (1990) conducted an experiment evaluating the effects of varying levels of RAC (0, 10, 15, and 20 ppm) on growth and carcass composition. Pigs were placed on test at an average weight of 64 kg to an end weight of 100 kg. This study reported that no significant differences were seen on growth rate, feed intake, FE, or days on feed for pigs fed RAC when compared to the control. Dressing percentage was consistent across all treatments. Fat depth at the 3rd to 4th last rib of pigs fed 20 ppm RAC were 10.1 percent less than pigs fed the 0 mg/kg RAC diet ($P = 0.045$). Lean depth was similar across all treatments however, as an increasing amount of RAC was added to the diet at 10, 15, and 20 ppm, percent fat free lean increased by 0.3 percent, 0.7 percent, and 0.9 percent, respectively ($P = 0.009$).

A study was conducted in 2004 by Armstrong et al. on the effect of RAC concentration as well as duration of feeding on growth performance, carcass composition, and pork quality. RAC concentrations of 0, 5, 10, or 20 ppm RAC were fed for durations of 6, 13, 20, 27, and 34 d. After a 6 d feeding period, ADG increased for pigs fed RAC at 5 and 10 ppm ($P < 0.05$). Pigs fed 20 ppm were not different from the pigs fed 0 ppm ($P > 0.33$); however, a pen of pigs assigned to this treatment had to be removed off test due to exhibition of viral symptoms. Feed efficiency was improved in all pigs fed RAC ($P < 0.05$); no differences were found between treatments. ADG was superior for all pigs fed

RAC ($P < 0.05$) following a 13 d feeding period. The control group exhibited superior FE when compared to all pigs fed RAC ($P < 0.05$) after the 13 d feeding period. However, after a 20 d feeding period, pigs fed RAC showed improved ADG and FE when compared to the control pigs ($P < 0.05$). Pigs fed concentrations of 20 ppm RAC had the greatest improvement in ADG and FE when compared to pigs fed 5 ppm RAC ($P < 0.05$). After a 27 d feeding period differences were seen between the dietary concentrations for ADG. Pigs fed 10 and 20 ppm RAC had a greater ADG than control pigs ($P < 0.05$), however pigs fed 5 ppm were not different from pigs fed 0, 10, or 20 ppm RAC ($P > 0.08$). Although all pigs fed RAC had improved FE when compared to control pigs ($P < 0.05$), pigs fed 10 or 20 ppm were superior to pigs receiving 5 ppm RAC ($P < 0.05$). ADG was improved by feeding 5 and 20 ppm RAC when compared to pigs fed 0 and 10 ppm RAC for a 34 d feeding period ($P < 0.05$). Feed efficiency was improved in all RAC fed pigs ($P < 0.05$) with pigs fed 20 ppm RAC being the most efficient when compared to pigs fed 5 and 10 ppm RAC ($P < 0.05$).

Armstrong et al. (2004) reported there were no differences in HCW between the treatments after the 6 d feeding period ($P > 0.07$), although there was an increase in dressing percentage in pigs fed 20 ppm RAC when compared to pigs fed 0 and 5 ppm RAC ($P < 0.05$). No differences were seen between groups for LMA ($P > 0.25$) after the 6 d feeding period. After the 13 d feeding period HCW increased for all treatment levels when compared to the control ($P < 0.05$). Pigs fed 20 ppm RAC had superior dressing percents when compared to the control group ($P < 0.05$). Loin muscle area ($P > 0.25$) remained unaffected by treatment levels after the 13 d feeding period. After a 20 d feeding period pigs fed both 10 and 20 ppm RAC had an increase in HCW and dressing

percentage ($P < 0.05$) when compared to the control. Loin muscle area ($P > 0.25$) remained unaffected. Hot carcass weights were increased for all pigs fed RAC when compared to the control ($P < 0.05$) after 27 d on feed, however only pigs fed 10 and 20 ppm RAC had increased dressing percentages ($P < 0.05$). Pigs fed 20 ppm RAC also had greater dressing percentages than pigs fed 5 ppm RAC ($P < 0.05$). Loin muscle area increased by feeding RAC at 10 and 20 ppm ($P < 0.05$) for 27 d. Following a 34 d feeding period all pigs fed RAC had heavier HCW ($P < 0.05$) but only increased dressing percent for the 10 and 20 ppm RAC fed pigs ($P < 0.05$). All RAC fed pigs showed an increase in LMA after the 34 d feeding period ($P < 0.05$). No feeding concentration of RAC affected 10^{th}-rib BF ($P > 0.16$), regardless of the feeding period. Fat-free lean percentage was only affected by feeding a concentration of 10 or 20 ppm for 27 d ($P < 0.05$), with pigs fed 20 ppm RAC having a greater percent fat free lean than pigs fed 5 ppm RAC ($P < 0.05$). After the 34 d feeding period, only pigs fed 20 ppm RAC had carcasses with a greater percentage of fat-free lean ($P < 0.05$).

Kutzler et al. (2011) completed a study comparing varying levels of RAC and duration time on carcass composition and meat quality. RAC diets included 5.0 and 7.4 ppm as well as a positive and negative control diet. The positive control diet (POS) included the same crude protein (CP) (17.8%) and lysine level (0.94 TID Lys) as the RAC diets. The negative control diet (NEG) was a commercial diet based on NRC requirements for finisher pigs (13% CP, 0.64 TID Lys), giving producers a more applicable comparison to industry standards. Feeding periods included 0, 7, 14, 21, 28, or 35 d. No differences in carcass composition or meat quality were found between the two RAC dosages; therefore data was pooled for the two groups. RAC fed pigs had

HCW 2.5 kg heavier than NEG controls (P = 0.022) and 2.3 kg heavier than POS controls (P = 0.032). A linear increase was observed for HCW over the 35 d RAC treatment period (P = 0.003). Loin depth was increased by 0.48 cm in RAC fed pigs when compared to the NEG control (P = 0.010), BF was unaffected, however there was a trend in linear decrease for BF as the RAC feeding period increased (P = 0.077).

Kutzler et al. (2011) also measured carcass cutting yields to more clearly measure carcass composition. RAC fed pigs yielded a greater amount wholesale cuts compared to the NEG control (P = 0.001). Additionally, RAC fed pigs yielded a greater amount of boneless trimmed retail pork when compared to the NEG control (P = 0.008) and the POS control (P = 0.084). A linear increase was observed for both wholesale yield (P = 0.004) and boneless trimmed retail yield (P = 0.003) as RAC duration increased.

Carr et al. (2005) studied the effects of RAC on lean carcass yields and pork quality characteristics of commercial pigs. Pigs were first separated into six groups by weight and then assigned to one of three treatments, control (0 ppm), 10 ppm RAC, or 20 ppm RAC. The six weight groups were fed RAC treatment for 25, 27, 32, 34, 39, or 41 d at an average starting weight of 84.3, 78.4, 76.6, 73.8, 70.7, and 69.0 kg, respectively. All pigs were fed to an average body weight (BW) of 109 kg. Average daily gain was increased in pigs fed RAC fed pigs, with the pigs fed 20 ppm RAC being superior when compared to pigs fed 10 ppm (P < 0.05). Loin muscle area was greater for pigs as RAC inclusion was increased (P < 0.05). No differences were observed for BF. Carcasses from pigs fed RAC, regardless of dosage had heavier wholesale cuts (P < 0.05) and heavier boneless wholesale cuts (P < 0.05).

In the study completed by Gu et al. (1991) (described in genetic section), RAC fed at 20 ppm increased ADG, dressing percentage, and LMA ($P < 0.001$). However ADG greatly declined in the 86 to 127 kg BW group, while remaining similar in the 59 to 100 and 73 to 114 kg BW groups. Growth rate rapidly declined beginning at 90 to 100 kg BW. Pigs fed RAC became less efficient due to pigs consuming more feed coupled with a declining growth rate, decreased lean percentage, and increased fat percentage.

See et al. (2004) conducted an experiment evaluating the effects of feeding RAC at different inclusion levels throughout the feeding period on growth performance and carcass characteristics. Treatments were as follows: 1) control diet containing no RAC for wk 1-6; 2) step-up RAC diet (wk 1-2 = 5.0 ppm, wk 3-4 = 10.0 ppm, wk 5-6 = 20.0 ppm); 3) step-down RAC diet (wk 1-2 = 20.0 ppm, wk 3-4 = 10.0 ppm, wk 5-6 = 5.0 ppm); and 4) constant RAC diet of 11.7 ppm RAC for wk 1-6. Results of the study showed that feeding RAC, regardless of the concentration, improved average daily gain (ADG) and feed efficiency (FE) over the 41 d feeding trial ($P < 0.05$). During the first 14 d, pigs on the RAC step-down diet (20.0 ppm) exhibited greater improvements in ADG and FE when compared to both the step-up (5.0 ppm) and constant RAC diets ($P < 0.05$). However, during wk 3-4 pigs fed the RAC step-up diet (10.0 ppm) were more efficient when compared to the pigs fed the RAC step-down diet (10.0 ppm) ($P < 0.05$), albeit they were fed the same concentration of RAC during the feeding period. During the final feeding period, pigs fed the RAC step-down diet (5.0 ppm) showed a tendency to have a decreased ADG when compared to the control pigs ($P = 0.10$) as well as being less efficient than the step-up diet (20.0 ppm) or the constant RAC diet ($P < 0.05$). See et al. also reported that hot carcass weight (HCW) and dressing percent were improved with

the RAC step-up and constant diets ($P < 0.05$). There were no differences seen between the step-down diet and control. Percent fat-free lean was increased as well as an increase in loin muscle area (LMA) and decrease in 10^{th} rib backfat (BF) in all pigs fed RAC ($P < 0.05$).

A similar study was conducted by Herr et al. (2001) evaluating the effects of step-up and step-down feeding techniques of RAC. Treatments were similar to those of See et al. (2004) with treatments consisting of 1) consistent control diet; 0 ppm RAC; 2) Step-down RAC diet (wk 1-2 = 20 ppm RAC, wk 3-4 = 10 ppm RAC, wk 5-6 = 5 ppm RAC); 3) Step-up RAC diet (wk 1-2 = 5 ppm RAC, wk 3-4 = 10 ppm RAC, wk 5-6 = 20 ppm RAC); and 4) consistent diet containing 11.6 ppm RAC. Pigs were fed treatment diets for 42 d and then harvested for carcass data. Performance data collected by Herr et al. (2001) during each feeding period was comparable to that of See et al. (2004). Overall, ADG increased for all RAC treatment levels by 10.4 percent compared to the control diet ($P < 0.05$). The step-up treatment had a 6.3 percent advantage in ADG over the step-down treatment ($P < 0.05$).

Ractopamine inclusion at 5 ppm and its effect on growth performance, carcass composition and pork quality was studied by Patience et al. (2009). Pigs were started on test at approximately 86 kg. The two dietary treatments consisted of a control diet and the control diet supplemented with 5 ppm RAC. Gilts and barrows were fed separately to ensure average weight and variation in weight would be similar across treatments. Pigs were fed to an average weight of 118 kg, therefore no treatment duration was given for the experiment. Ractopamine fed pigs were on test for an average of 26.5 d while control pigs were on test for 30.1 d. Ractopamine fed pigs had a 13 percent higher ADG and FE

than control pigs ($P < 0.001$). Patience et al. (2009) reported a decreased BF thickness (18.0 mm to 17.1 mm) in pigs fed 5 ppm RAC ($P < 0.02$). Additionally, a treatment x gender interaction was found to be significant as barrows had decreased BF while gilts did not respond ($P < 0.10$). Ractopamine fed pigs also had increased LMA and higher percentage of fat-free lean.

Graded levels of ractopamine were fed to 880 commercial pigs to evaluate the effects on growth performance and carcass composition by Main et al. (2001). Pigs were assigned to a diet of 0, 5, 7.5, or 10 ppm RAC inclusion for a 21 d period. Treatment began when an average pig weight of 107 kg was reached. Average daily gain and FE was improved in all pigs fed RAC ($P < 0.01$), no differences were found between RAC treatment groups for ADG ($P > 0.27$), however pigs fed 10 ppm RAC had superior FE when compared to pigs fed 5 ppm ($P < 0.02$). Ractopamine inclusion at any level did not affect BF, LMA, or percentage of fat-free lean, however there was a trend for improved dressing percentage ($P < 0.12$). Hot carcass weight was significantly higher than the control group for all pigs fed RAC ($P < 0.01$). Although an increase in LMA or decrease in BF was not detected in this study, the authors reported than an improved profit margin was observed for RAC fed pigs, regardless of the level.

One hundred twenty-eight crossbred gilts and barrows were fed RAC until they reached a BW of approximately 100 kg by Uttaro and others (1993). Pigs were divided into treatment groups and received diets of either a control or the control diet with 20 ppm RAC. As expected, RAC fed pigs had superior ADG, FE, and took six fewer days to reach market weight ($P < 0.01$). Pigs that received RAC required 0.52 kg less feed per kg of BW gained when compared to control pigs ($P < 0.01$). Carcass composition was

also improved in RAC fed pigs with 1.8 mm less BF ($P < 0.05$) and an increase of 3.4 mm in loin depth ($P < 0.01$) when compared to control pigs.

Stoller et al. (2003) studied RAC's effects on muscle quality and three genetics lines. Purebred Duroc, purebred Berkshire, and high-lean terminal crossbred pigs at an average BW of 85.1 kg were fed a standard commercial diet consisting of either 0 or 20 ppm RAC for 28 d. There was a genetic line x treatment interaction for 10^{th} rib BF as only the RAC fed, high-lean genetic line had decreased BF (18.6 vs 15.6 mm; $P < 0.01$) when compared to the control high-lean genetic line. An increased in LMA was observed in all RAC fed pigs ($P < 0.05$) with no genetic line x treatment interaction. No differences were found for estimated percentage of fat-free lean.

Although studies have shown that growth performance and carcass composition is improved in RAC fed pigs, little work has been done on the β-agonists effects different sexes. Dunshea et al. (1993) completed a study utilizing 20 boars, 20 barrows, and 20 gilts to investigate the effect of sex and RAC on production characteristics and carcass composition. Pigs were fed either 0 or 20 ppm RAC until they reached a live weight of 90 kg. There was a significant interaction of sex and RAC; an increase in ADG was observed in gilts (17 percent) and barrows (21 percent) but not in boars. Protein deposition was increased in boars by 15 percent and 42 and 41 percent in gilts and barrows, respectively, in RAC fed pigs. There was a trend for RAC to decrease fat deposition in boars ($P < 0.10$) that was not seen in gilts or barrows.

Mimbs et al. (2005) sorted 144 crossbred barrows into phenotypically fat and lean groups through ultrasonic measures to assess the effects of RAC on growth performance and ultrasonically measured composition. The difference between the fat and lean groups

was ≥ 0.05 cm. The two treatment groups received a diet of 19 percent CP, 1.1 percent lysine, and 0 or 10 ppm RAC for 28 d. Growth rates and feed intake did not significantly differ between phenotypes. Although ultrasonic BF was lower and LMA was greater in lean pigs, there was no RAC x phenotype interaction. The authors reported that the increase in percentage of fat-free lean was greatly due to change in BF over the 28 d period rather than change in LMA.

Summary of Efficacy Trials

Watkins et al. (1990) reported that feeding RAC to pigs improved growth efficiency at levels of 10 to 20 ppm. Maximal response of ADG was observed at 16 ppm (Study 1) and 14 ppm (Study 2). The inclusion of RAC producing the maximal response of FE was 20 ppm (Study 1) and 18 ppm (Study 2). Although LMA and percentage fat-free lean was increased in levels as low as 10 ppm, a decrease in BF was only observed at 20 and 30 ppm.

Ractopamine has been shown to improve ADG and FE (Watkins et al., 1990; Armstrong et al., 2004; Carr et al., 2005; Gu et al., 1991; See et al., 2004; Herr et al., 2001; Patience et al., 2009; Main et al., 2001; Uttaro et al., 1993), however Aalhus et al. (1990) reported no significant differences on growth rate or feed intake between RAC fed pigs at 10, 15, 20 ppm inclusion and control pigs. Purebred Lacombe gilts and barrows were used in this study which could indicate that genotype plays an important role in the effects of RAC on growth performance.

See et al. (2004) and Herr et al. (2001) conducted RAC step-up studies that reported increased growth performance and efficiency when compared to a control diet,

constant RAC diet, or RAC step-down diet. However, there were no improvements on carcass composition when compared to pigs fed a constant RAC diet.

There have been contradicting reports on RAC's effects on BF. Watkins et al. (1990), Aalhus et al. (1990), Patience et al. (2009), Uttaro et al. (1993), Stoller et al. (2003), and Mimbs et al. (2005) have all reported significant decreases in BF measured on the carcass and ultrasonically. Varying levels of RAC have been reported to decrease BF, however only Patience et al. (2009) reported RAC to decrease BF at 5 ppm. Although decreased BF has been reported in pigs fed varying levels of RAC, Armstrong et al. (2004), Kutzler et al. (2011), Carr et al. (2005), and Main et al. (2001) have all stated no differences in BF measured on the carcass have been observed in pigs fed RAC levels of up to 20 ppm.

Armstrong et al. (2004) concluded that RAC improves LMA after a 27 d feeding period at levels of 10 or 20 ppm. Moreover, including RAC in the diet at 5 ppm will improve LMA after a 34 d feeding period (Armstrong et al., 2004). Watkins et al. (1990) suggest feeding RAC at levels of 10 to 30 ppm to increase LMA and percentage fat-free lean. Main et al. fed RAC at levels of 5, 7.5, or 10 ppm for 21 d and did not report an increase in LMA. This could be due to the fact that the feeding period was not long enough to see results in carcass composition (Armstrong et al., 2004).

Gender has also played an important role in how RAC effects growth performance and carcass composition. Patience et al. (2009) noted a treatment x gender interaction as barrows fed 5 ppm RAC had decreased BF while gilts were not different from control fed gilts. Moreover, Dunshea et al. (1993) observed ADG increases in gilts and barrows fed RAC but not boars. Protein deposition was increased by 42 and 41

percent in gilts and barrows respectively, however an increase of only 15 percent was seen in boars.

Diet

A summary of diet trials can be found in Table 2.4. Due to RAC causing pigs to increase skeletal muscle growth, diets containing RAC require an increase in nutrients such as dietary crude protein (CP) and the lysine:energy (Lys:ME) ratio (Apple et al., 2004) to reach the maximal benefits of feeding RAC. Studies have indicated that RAC will improve growth rate in pigs fed 17.0 to 18.0 percent CP, however pigs fed RAC in a diet containing 13.0 percent CP, typical of a regular commercial diet, growth rate was not improved (Xiao et al., 1999; Adeola et al., 1990; Dunshea et al., 1993b). The Paylean® 9 label states that pigs fed RAC must include a diet containing a minimum of 16 percent CP. Xiao et al. (1999) reported that feeding a higher CP diet (180 g CP/kg) improved FE by 15 percent ($P < 0.05$). These results are consistent with Adeola et al. (1990), however it was also reported that ADG was improved 10 to 25 percent and FE was improved by 12 to 25 percent at 17 percent CP.

Xiao et al. (1999) and Crenshaw et al. (1987) reported a higher CP diet (>16 percent) containing RAC, would improve percent fat-free lean by approximately 8.5 to 8.8 percent when compared to a lower CP diet (<16 percent) containing RAC, which only improved percent fat-free lean by approximately 4.0 to 4.3 percent. However, RAC increased LMA and reduced carcass fat regardless of protein concentration (Xiao et al., 1999; Crenshaw et al., 1987; and Adeola et al., 1990).

Williams and others (1994) studied energy intake on pig growth and its effects on RAC fed pigs. They reported that although lower energy diets decreased ADG, FE was unaffected. More importantly, LMA was increased while BF decreased. The authors hypothesized that energy intakes above the minimal level to deposit skeletal muscle were deposited as fat (Williams et al., 1994). Apple et al. (2004) suggested that a low energy diet would not affect ADG, while improving carcass composition. However, it is suggested that the Lys:ME be much higher than levels suggested, which could have negative effects on intramuscular fat and tenderness values (Apple et al., 2004).

Rate of muscle accumulation increases in RAC fed pigs, therefore it is necessary to increase the amount of dietary lysine fed due to high concentrations of lysine and other essential amino acids (Schinckel et al., 2003). Commercial finishing diets are often decreased for essential amino acids to maximize profitability during the final phase of feeding, however, the diets are supplemented with synthetic amino acids (Apple et al., 2004; Schinckel et al., 2002; Webster et al., 2002). This lowers the nitrogen secretion in the feces and urine due to the nitrogen requirements of the pig being more closely balanced to the nitrogen in the diet (Carr et al., 2009). These diets, while appropriate for finishing pigs, may not be sufficient for pigs fed ractopamine to maximize performance and lean growth capabilities (Apple et al., 2004). Schinckel et al. (2000) suggest feeding lysine at a Lys:ME ratio of 2.4 g/Mcal for optimal performance, a typical commercial finishing operation feeds lysine at a Lys:ME ratio of 1.7 g/Mcal (Apple et al., 2004). However, Apple et al. (2004) reported that the level suggested by Schinckel et al. (2000) may not be sufficient enough, as the authors and Webster et al. (2002) have suggested pigs be fed at least 1.0 percent dietary lysine to optimize performance.

Genotype

A summary of genotype trials can be found in Table 2.5. Yen et al. (1990) designed an experiment to test RAC effects on genetically obese and lean pigs. Each genotype was assigned to one of two treatments, a control diet with 0 ppm RAC or the control diet with 20 ppm RAC. There was no genotype x RAC interaction for ADG, ADFI, or FE ($P > 0.05$). RAC fed pigs and the control fed pigs had similar ADG ($P > 0.05$) but RAC fed pigs did have reduced ADFI ($P < 0.05$) and superior FE ($P < 0.05$). No genotype x RAC interactions were found for carcass composition. Obese pigs exhibited a greater average BF and smaller LMA ($P < 0.05$). Pigs fed RAC had an increased HCW, dressing percentage, and LMA ($P < 0.05$), with no differences found in BF ($P > 0.05$). Percent of predicted FFL was increased in pigs fed RAC ($P < 0.05$). RAC supplementation also increased weights of untrimmed and trimmed picnic shoulder and boston butt, as well as trimmed loin ($P < 0.05$).

Gu et al. (1991) (as described in the Efficacy section previously) studied the effects of ractopamine on different genotypes and body weight ranges. Five genotypes were represented: GT1) Hampshire (H) x (H x Duroc (D)); GT2) Commercial crossbred terminal line; GT3) (H x D) x (Landrace (L) x (Yorkshire (Y) x D)); GT4) L x (Y x D); and GT5) Y x L, representing genotypes typically used in commercial setting across the Midwest. The experiment was set up as a 2 x 3 factorial arrangement with two RAC levels (0 or 20 ppm) and three treatment weight ranges (59 to 100, 73 to 114, and 86 to 127 kg). Genotypes 1 and 2 represent terminal line sires, GT3 was a terminal-cross line, and GT 4 and 5 are maternal line dams. Although the main effect of genotype was highly

significant, RAC x genotype interaction was not significant for growth performance or carcass composition traits.

In an experiment conducted by Bark et al. (1992), pigs of low (LT) and high (HT) lean tissue growth genotypes were fed 20 ppm RAC to study the influence of lean tissue growth by RAC. Pigs were on test from 63 to 104 kg of BW. Both genotypes exhibited improvement in ADG and FE ($P < 0.01$), however due to the slow growth of the LT genotype, these pigs required an extra 21 d to reach the designated BW. The magnitude of improvement in growth performance was diminished over time as BW gains from d 28 to 42 of the trial were similar for the RAC treated and control pigs of the LT genotype ($P < 0.07$). Improvement was seen in carcass composition for both genotypes; 10^{th} rib BF was decreased and LMA was increased however, the magnitude of LMA increase was greater in the LT genotype.

Summary of Genotype Trials

Ractopamine improved growth, performance, and carcass characteristics in the above genetic lines. There have been RAC x genotype interactions reported, indicating low lean tissue growth genotypes demonstrate a greater response to RAC when compared to high lean tissue growth genotypes (Bark et al., 1992). However, RAC fed, high lean tissue growth pigs exhibited larger LMA indicating they could possess a higher concentration of muscle DNA (Bark et al., 1992). Muscle DNA concentration could possibly be an indication of an animal's capacity to respond to RAC (Bark et al., 1992). Yen et al. (1990) and Gu et al. (1991) found no RAC x genotype interactions for growth or composition.

2.3 Meat Quality

A summary of meat quality trials can be found in Table 2.6. Fresh pork quality was studied by Aalhus et al. (1990) (as described in the Efficacy section previously) on 128 purebred Lacombe pigs. Measures of 40 min postmortem pH indicated that pH was lower in carcasses that received the 10 ppm treatments when compared to the control, however the difference was insignificant when measuring 24 hr ultimate pH. Intramuscular fat content was increased in loins from the 15 ppm treatment. Ractopamine treated loins water-holding capacity was inferior to the control group, regardless of treatment ($P = 0.001$). Moreover, WBSF values were increased by 13.7, 16.2, and 15.3 percent as RAC inclusion increased in the diet.

Armstrong et al. (2004) evaluated meat quality in 400 finishing pigs (as described in the Efficacy section previously) and found no differences on subjective marbling scores following a 6, 13, or 20 d feeding period. However, after 27 d on 10 ppm RAC ($P < 0.05$), marbling scores were decreased, pigs fed 20 ppm RAC were similar to the control. Pigs fed 10 or 20 ppm RAC for 34 d had decreased marbling scores ($P < 0.05$). Subjective color scores were lower for pigs fed RAC at 20 ppm for 20 d or 27 d ($P < 0.05$). Minolta L* values agreed were similar to the subjective color scores.

Kutzler et al. (2011) (as described in the Efficacy section previously) studied RAC duration time and its effects on pork quality. Subjective marbling scores ($P = 0.002$) and extractable lipid content ($P \leq 0.05$) linearly decreased as RAC duration increased when compared to both NEG and POS controls. As the feeding period of RAC increased, objective color and Minolta L* values linearly increased ($P = 0.027$). No

differences were found between groups for Warner Bratzler shear force (WBSF) or cook loss.

In the study completed by Carr et al. (2005) (as described in the Efficacy section previously), postmortem pH was measured at 45 min and 20 h as well as at 1.5, 3.0, 4.5, and 8.0 h on six randomly selected carcasses from each treatment. No pH differences were found at any of the collection times across any of the treatments, however, pigs fed 10 mg/kg RAC tended to have numerically greater pH values at 3, 8, and 24 h postmortem and pigs fed 20 mg/kg RAC tended to have numerically greater pH values at all collection times. No differences were shown in Minolta L* values on the loin muscle however, Minolta a* and b* values were lower for RAC fed pigs when compared to the control ($P < 0.05$). Water-holding capacity (WHC) was improved in loins from pigs treated with 20 mg/kg RAC ($P < 0.05$) when compared to the control. Loins from each carcass were non-enhanced and enhanced and aged for 14 d. The enhanced loins had a linear increase in purge loss as RAC dosage increased ($P = 0.005$) and purge loss decreased linearly as RAC dosage decreased for non-enhanced loins ($P < 0.05$). No differences were seen for cooking weight loss for any treatment differences for both enhanced and non-enhanced loins. Warner Bratzler shear force values of non-enhanced loins were higher for RAC treated pigs when compared to the control ($P < 0.001$). Enhanced chops did not differ among treatments for WBSF values but there was a linear increase in WBSF values as RAC dosage increased ($P = 0.003$). Trained sensory panelists also rated loins from RAC treated pigs tougher when compared to the control group for non-enhanced chops ($P = 0.004$) and enhanced chops ($P = 0.04$). No

differences were found between treatment groups in either the non-enhanced loins or enhanced loins for juiciness or flavor.

Patience et al. (2009) studied RAC supplemented at 5 ppm and its effect on fresh pork quality (as described in the Efficacy section previously). Ultimate loin pH, drip loss, and L* values were unaffected by the addition of RAC to the diet however, a* and b* values were lower in loins from pigs fed RAC. Subjective color and marbling scores were unaffected. Gilts fed RAC had higher shear force values when compared to the control, however, no differences were found in barrows. Sensory results indicated that consumers could detect a higher initial and overall tenderness ($P < 0.06$) in loins from RAC fed pigs. There was also a decreased pork flavor in the RAC group ($P < 0.10$).

Uttaro et al. (1993) also studied the effects of feeding 20 ppm RAC on pork quality (as described in the Efficacy section previously). Drip loss was unaffected by the treatment, however cook loss was greater for RAC fed pigs ($P < 0.05$). Warner Bratzler shear force values were 0.49 kg higher for RAC fed pigs ($P < 0.05$). No effect was found on L* values, however a* ($P < 0.01$) and b* ($P < 0.05$) were found to be significantly higher in RAC fed pigs.

In the study completed by Stoller et al. (2003) (as described in the Efficacy section previously), no differences in subjective or objective color, firmness, or marbling were found between loins of RAC fed pigs and the control diet. Moreover, loin ultimate pH and drip loss were unaffected by RAC inclusion in the diet and there were no genetic line x treatment interactions. Warner Bratzler shear force results indicated that there was a trend for loins from RAC fed pigs to be tougher ($P = 0.07$). Taste panel results of loin tenderness, juiciness, and chewiness were not significantly different between RAC and

control pigs. There was a genetic line x treatment interaction seen in Berkshire IMF, as Berkshire pigs fed RAC had loin IMF values when compared to Berkshire pigs fed the control diet ($P < 0.05$).

Scramlin et al. (2008) studied the effects of RAC on belly and bacon quality. Levels of 0, 5.0, and 7.4 ppm RAC were fed for a period of 21 or 28 d prior to harvest. Ractopamine had no effect on untrimmed or trimmed belly weight, length, firmness, thickness, or pump uptake. Moreover, bellies from the 5.0 ppm RAC treated group had increased belly yield regardless of feeding duration ($P < 0.05$). Inclusion of RAC at 5.0 ppm also had positive effects on composite slice total slice area, total slice length, secondary lean area, and percent lean area ($P < 0.05$). This slice composite would have greater consumer acceptance when compared to the other two treatments (Scramlin et al., 2008). No affect on belly characteristics or quality were observed for treatment duration.

Ractopamine effects on tenderness

Ractopamine and its effects on tenderness have been a concern of the industry due to the increased rate of protein accretion. No significant effect on tenderness of *Longissimus dorsi* was reported by Kutzler et al. (2004), however Aalhus et al. (1990) reported increases in WBSF values by 13.7, 16.2, and 15.3 percent in loins from pigs fed 10, 15, and 29 ppm RAC respectively. An increase in WBSF of 15 percent represents approximately one kg of shear force, which is on the borderline of a consumer consistently rating meat as tough (Aalhus et al., 1990). Carr et al. (2005) reported non-enhanced loins from RAC fed pigs having higher WBSF values; however enhanced chops did not differ among treatments. Patience et al. (2009) noted a RAC x sex

interaction as gilts fed RAC had increased WBSF values; however barrows fed RAC were similar to the control.

Ractopamine effects on pH

Measures of ultimate pH in loins obtained from RAC fed pigs have been noted to be similar to the ultimate pH in loins of control fed pigs (Aalhus et al., 1990; Carr et al., 2005; Patience et al., 2009; Stoller et al., 2003). Although Carr et al. (2005) indicated a trend was observed for ultimate pH to be numerically greater from pigs fed 10 or 20 ppm RAC, results were still insignificant when compared to control pigs.

Ractopamine effects on sensory analysis

Stoller et al. (2003) noted sensory results comparing loin chops from RAC and control fed pigs were perceived as similar by consumers for loin tenderness, juiciness, and chewiness. However, Carr et al. (2005) and Patience et al. (2009) reported differing sensory results. Trained sensory panelists were able to detect an increase in perceived toughness for all RAC treatments in both non-enhanced and enhanced loins (Carr et al., 2005). Moreover, gilts fed RAC at 5 ppm exhibited higher WBSF values when compared to the control group (Patience et al., 2009).

Ractopamine effects on color, water-holding capacity and intramuscular fat

Subjective color scores and Minolta L* values were reported to be lower for loins from pigs fed 20 ppm RAC for a duration of 20 or 27 d (Armstrong et al., 2004). Moreover, after 27 d of RAC treatment at 20 ppm, marbling scores (Armstrong et al.,

2004) and extractable lipid content decreased (Kutzler et al., 2004). Carr et al., (2005) and Patience et al., (2009) noted no differences were found on Minolta L* between RAC fed pigs and control pigs, however Minolta a* and b* were lower for RAC treated pigs. Aalhus et al. (1990) and Carr et al. (2005) observed an increase in WHC in loins from pigs treated with RAC at up to 20 ppm. Drip loss was not affected by RAC inclusion in the diet (Patience et al., 2009; Uttaro et al., 1993; Stoller et al., 2003), however a linear increase in purge loss was displayed as dosage of RAC increased (Carr et al., 2005).

2.4 Pig Behavior and Handling

Patience et al. (2009) observed a higher rate of pigs lost or condemned during the transportation process in pigs fed RAC when compared to a control group. Two RAC fed pigs were condemned upon arrival at the harvest facility, while three gilts were found dead on arrival. No control pigs were lost or condemned during the study.

Baszczak et al. (2006) completed a study evaluating the effects of RAC on behavior of 3 genotypes of steers. Four hundred twenty British, Continental crossbred, and Brahman crossbred steers were assigned to a treatment of either 20 ppm RAC or a control diet for a 28 d period. At the end of the feeding period, temperament and behavior scores were assessed as individual BW was obtained on each animal. Subjective scores were given for entry into a squeeze chute (entry score), while the steer was restrained in the squeeze chute (chute score), and as the animal was exiting the squeeze chute (exit score). Scores were also given for the speed of entry and exit into and out of the squeeze chute. Inclusion of RAC in the diet did not impact entry score,

chute score, exit score, or exit speed. However, steers fed RAC did enter the chute at greater speeds ($P < 0.05$) which the authors reported as non-problematic.

Poletto and others (2010) completed a study on RAC and its effects on behavior and hormone concentrations of 64 crossbred finishing pigs. Pigs were assigned to one of two treatments: 1) RAC step-up diet for 28 d (wk 1 and 2: 5 ppm RAC; wk 3 and 4: 10 ppm RAC) or 2) control diet and treatments began at an average BW of 78 kg. A total of 16 pens were utilized in this trial with 4 pigs to a pen; pens consisted of either barrows or gilts. Pigs were assigned to treatment 14 d prior to the commencement of the study to assign dominant, intermediate, and bottom subordinate pigs in each pen through video observation. During the RAC feeding period pigs were recorded for a 24 h continuous period on d 2, 5, 8, 12, 15, 19, 22, and 26. Videos were analyzed by an observer using 10 min instantaneous scan-sampling methods to analyze the behavior and posture of the dominant and subordinate pigs in each pen. Moreover, behavior from all pigs in each pen was recorded for a 3 hr period on d 5, 12, 19, and 26 to observe aggressive behavior within the pen. Blood samples were collected from the dominant and subordinate pig in each pen for analysis of norepinephrine, epinephrine, and dopamine concentrations.

Gilts fed RAC exhibited a higher number of bites and pursuits towards other gilts in the pen ($P < 0.001$) as well as an increase in total actions (bites, head knocks, and pursuits) over the 28 d feeding period. Towards the end of the 5 ppm RAC feeding step (d 12) and continuing through the end d 28, all RAC fed pigs began to show a greater state of arousal when compared to control pigs ($P < 0.05$). Pigs showed an increased level of alertness, specifically with more oral-nasal behaviors including sham chewing and bar biting ($P < 0.05$). There was a tendency for RAC fed pigs to spend less time

laying when compared to control pigs ($P = 0.07$). Dominant, RAC fed pigs tended to have the highest plasma norepinephrine concentrations ($P = 0.08$).

Marchant-Forde et al. (2003) examined the effects RAC has on pig behavior and circulating hormone concentrations. Seventy two gilts were blocked by weight and placed into pens, three pigs per pen. Pigs were assigned to one of two treatments within block: 1) finishing feed plus 10 ppm RAC or 2) control diet (finishing feed) for a 28 d period. Behavior was recorded one a week for a 22 hr period. Moreover, pigs were weighed once per week with the weighing process recorded to observe handling interactions. Heart rate monitors were placed on pigs once during the 28 d period as well as blood samples taken on a day other than when heart rate was measured. Pigs fed RAC spent more time active and alert, and lying in sterna recumbency rather than lying in lateral recumbency during wk 1 and 2. No differences in time allocations between RAC fed pigs and control pigs were found for wk 3 and 4. Prior to the start of the feeding trial, no differences were seen in handling between the control and RAC fed pigs. However, over the four week period, RAC fed pigs took 136% longer to remove from their pen, 83% longer to handle into the scale, and received 52% more pats, slaps, pushes from the handler. This continued over the four week period, therefore pigs did not become familiar with the consistent handler. Ractopamine fed pigs also had increased concentrations of plasma epinephrine ($P < 0.05$) and norepinephrine ($P < 0.01$). Plasma cortisol did not differ between the control and RAC fed pigs. Additionally, RAC fed pigs had higher mean heart rates when compared to control pigs ($P < 0.05$).

Schaefer et al. (1992) studied the effects of RAC on 128 Lacombe pigs behavior. These pigs were assigned to one of four treatments: 1) RAC fed at 10 ppm; 2) RAC fed

at 15 ppm; 3) RAC fed at 20 ppm; or 4) control. Pigs were kept on treatment until they reached at BW of 100 kg; an average of 6 wks. One week prior to harvest behavioral observations were recorded for four hours per day between the hours of 8:00 AM to 12:00 PM. Observations of pig behavior and activity were recorded at intervals of every 5 minutes. No abnormal or negative behavior was witnessed due to feeding of RAC.

Summary of Behavioral Studies

Although reports have been mixed on the effects of RAC on animal behavior and handling, there are some note-worthy differences. The study completed by Schaefer et al. (1992) only examined pig behavior in wk 6 of the study. Mersmann (1998) and Mills (2002) have both observed β-receptor burnout in as few as 6 d of pigs being fed RAC. Therefore, behavioral analysis needs to take place throughout the feeding trial, not just in the final week. When Paylean® was approved for use in 1999, the label stated it could be fed at up to 20 ppm. Currently, the label reads it can be fed at a concentration of 5 to 10 ppm. The decrease in concentration was partially due to observed dead on arrival pigs as well as downer pigs as they arrived at the harvest facility. Patience et al. (2009) witnessed the effect RAC has on pigs during transportation as they lost a total of five RAC fed pigs during transportation to the harvest facility when compared to no losses for non-RAC fed pigs. Poletto et al. (2010) and Marchant-Forde et al. (2003) observed a higher incidence of aggressive behavior towards other pigs treated with RAC as well as being more difficult to handle (Marchant-Forde et al., 2003). As pigs become more difficult to handle they are more susceptible to stress during loading, transportation, and

unloading at the harvest facility which could could lead to meat quality issues (Poletto et al., 2010).

2.5 Ractopamine effects on environment

Sutton et al. (2001), DeCamp et al. (2001), and Hankins et al. (2001) evaluated the effects of a RAC supplemented diet on nitrogen (N) excretion, phosphorus (P) excretion, and odors in stored manure. Four treatments were included in all studies: 1) Standard (13.8% CP, 0.80% Lys), 2) RAC1 (13.8% CP, 1.10% Lys, 20 ppm RAC), 3) HighCP (16.1% CP, 1.10% Lys), and 4) RAC2 (16.1% CP, 1.10% Lys, 20 ppm RAC).

Sutton et al. (2001) reported RAC2 fed pigs had a 12.6 percent decrease in urine excretion when compared to Standard fed pigs ($P < 0.05$). Furthermore, RAC decreased urine volume regardless of CP levels ($P < 0.05$) (DeCamp, 2001). Both Sutton et al. (2001) and DeCamp et al. (2001) observed a trend for RAC inclusion to decrease the total manure output. All RAC fed pigs excreted less N, however RAC1 fed pigs excreted less total N ($P < 0.05$) (DeCamp et al., 2001). Pigs that consumed the Standard diet excreted the highest levels of urinary phosphorus ($P < 0.05$) while RAC2 fed pigs excreted the lowest levels ($P < 0.05$) (DeCamp et al., 2001).

Slurry and air samples were taken on d 0, 17, 35, and 64 of the feeding trial by Hankins et al. (2001) and analyzed for ammonia nitrogen (AMN) and volatile fatty acids (VFA). Ammonia nitrogen was reduced in RAC fed pigs, regardless of CP or time point ($P < 0.05$), however RAC1 fed pigs had the lowest AMN values throughout the feeding trial ($P < 0.05$). Pigs fed the HighCP diet had higher total VFA production when

compared to the Standard diet ($P < 0.05$) and was 21, 28, and 23 percent higher in total VFA at d 17, 35, and 64 respectively when compared to the RAC fed pigs.

Table 2.1. Means for pork quality traits from pork *Longissimus* muscle by breed from the National Barrow Show Progeny Test (1991 to 2004).

Breed	IMF % (1)	Ultimate pH (1)	Minolta L*, (2)	Cooking Loss % (2)	Juiciness (1)	Tenderness (1)
Berkshire	2.51^{b}	5.68^{a}	49.8^{a}	20.8^{a}	6.1^{a}	7.3^{a}
Chester White	2.39^{bc}	5.70^{a}	51.3^{b}	22.2^{b}	5.8^{b}	6.6^{bc}
Duroc	3.07^{a}	5.58^{b}	51.6^{b}	23.4^{cd}	5.4^{c}	6.3^{cd}
Hampshire	2.09^{de}	5.58^{b}	49.0^{a}	22.9^{bc}	5.8^{ab}	6.8^{b}
Landrace	1.90^{e}	5.47^{c}	54.2^{d}	24.0^{d}	5.0^{d}	6.6^{bc}
Poland China	2.18^{cd}	5.61^{b}	50.9^{b}	22.3^{b}	5.4^{c}	6.3^{cd}
Spot	2.37^{bc}	5.55^{b}	51.9^{b}	22.9^{bc}	5.3^{cd}	5.9^{d}
Yorkshire	1.70^{f}	5.47^{c}	53.4^{c}	23.8^{cd}	4.9^{d}	6.3^{cd}

$^{a, b, c, d, e, f}$ Means with same superscript are not statistically different ($P < 0.05$)

(1) High score desired

(2) Low score desired

Table 2.2. Means for growth performance traits by breed from the National Barrow Show Progeny Test (1991 to 2004).

Breed	ADG, lbs/day	Yield %	LMA, sq. in.	BF10,in.
Berkshire	1.74[bc]	72.8[d]	5.53[e]	1.13[d]
Chester White	1.71[cd]	73.4[ab]	5.75[d]	1.13[d]
Duroc	1.79[a]	72.4[e]	6.12[bc]	0.90[b]
Hampshire	1.68[d]	73.0[cd]	6.56[a]	0.85[a]
Landrace	1.79[a]	73.2[bc]	6.03[bd]	0.93[b]
Poland China	1.77[ab]	72.6[de]	5.74[d]	1.08[cd]
Spot	1.71[cd]	73.4[ab]	5.95[cd]	1.02[c]
Yorkshire	1.76[ab]	73.6[a]	6.17[b]	0.90[b]

[a, b, c, d, e] Means with same superscript are not statistically different ($P < 0.05$)

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Watkins et al. (1990) (Study 1)	2.5	0.06*	0	-0.25*		1.0	0.1	2.0*	-0.11	1.1*
	5	0.06*	0	-0.29*		1.1	0.4	2.6*	-0.13*	1.4*
	10	0.06*	-0.09	-0.34*		1.6	0.6*	3.6*	-0.18*	2.1*
	20	0.07*	-0.08	-0.42*		1.4	0.9*	4.6*	-0.31*	2.9*
	30	0.04*	-0.17	-0.39*		1.2	1.1*	4.5*	-0.36*	3.0*
Watkins et al. (1990) (Study 2)	5	0.05*	-0.07	-0.31*		-0.4	0.3	2.7	0.12	0.5
	10	0.08*	-0.06	-0.44*		0.1	0.5*	5.0*	-0.18	2.6*
	15	0.09*	-0.09	-0.50*		0.4	0.9*	4.0*	-0.13	2.0*
	20	0.07*	-0.19	-0.55*		0.2	0.9*	5.6*	-0.44*	3.7*

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Aalhus et al. (1990)	10	0.01	-0.11	-0.13	0.19	-0.15		0.2[a]	-0.05	0.3
	15	0.03	-0.17	-0.24	0.4	0.44		0.5[a]	-0.19*	0.7*
	20	0.00	-0.19	-0.19	-0.49	-0.29		1.7[a]	-0.22*	0.9*
Armstrong et al. (2004) (feeding duration of 6 d)	5	0.27*	-0.19	-0.11*	1.6	1.0	0.0	1.8[a]	0.0	1.0[c]
	10	0.32*	-0.07	-0.11*	2.3	2.4	0.6	1.1[a]	0.2	0.6[c]
	20	0.12	-0.41*	-0.09*	-0.6	0.6	1.4	2.2[a]	0.11	1.8[c]
Armstrong et al. (2004) (feeding duration of 13 d)	5	0.23*	0.16	-0.09*	4.9*	4.5*	0.8	1.1[a]	0.05	2.2
	10	0.19*	0.09	-0.09*	3.4*	3.1*	0.4	1.1[a]	-0.03	1.9
	20	0.26*	0.02	-0.08*	2.9*	3.4*	1.2	1.6[a]	0.0	1.7

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Armstrong et al. (2004) (feeding duration of 20 d)	5	0.17*	0.18	-0.04*	0.8	1.2	0.6	-0.1[a]	0.25	-0.3
	10	0.23*	0.14	-0.06*	3.4*	3.7*	1.1*	2.2[a]	0.05	1.8
	20	0.26*	0.09	-0.08*	3.8*	3.5*	1.3*	0.4[a]	0.28	1.3
Armstrong et al. (2004) (feeding duration of 27 d)	5	0.1	0.0	-0.04*	4.3*	3.8*	0.8	3.3[a]	0.18	1.5
	10	0.17*	0.01	-0.06*	4.9*	5.2*	1.5*	5.1[a]*	0.03	3.4*
	20	0.16*	-0.17	-0.08*	4.5*	5.7*	2.1*	5.6[a]*	-0.05	4.0*
Armstrong et al. (2004) (feeding duration of 34 d)	5	0.21*	0.32	-0.04*	8.1*	6.0*	0.4	5.0[a]*	0.18	3.0
	10	0.09	-0.01	-0.03*	4.6*	4.8*	1.2*	4.3[a]*	0.13	2.7
	20	0.2	0.03	-0.07*	9.4*	8.3*	1.4*	9.6[a]*	0.0	5.9*
Kutzler et al. (2011)	6.2					2.5*	0.91*	0.48**	-0.08	1.0**

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Carr et al. (2005)	10	0.14*	-0.01	-0.06*	4.19*	4.66*	1.25*	3.45*	-0.08	
	20	0.20*	0.01	-0.08*	6.32*	6.54*	1.65*	5.52*	-0.14	
Gu et al. (1991)	20	0.027	-0.014	-0.1			1.28	2.77	-0.14	
See et al. (2004)	Step-down (20-10-5)	0.07*	-0.2	-0.05*		0.3		3.9*	-3.8*	2.7*
	Step-up (5-10-20)	0.07*	-0.23	-0.05*		2.0*		7.1*	-4.0*	3.5*
	Constant 11.7	0.07*	-0.23	-0.05*		2.7*		6.0*	-3.0*	2.7*

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Herr et al. (2001)	Step-down (20-10-5)	0.13*	-0.36	-0.34*	3.6	6.0*		0.24	0.0	0.23
	Step-up (5-10-20)	0.27*	-0.53*	-0.58*	13.8*	15.3*		1.05*	-0.18*	3.04*
	Constant 11.6	0.25*	-0.4	-0.51*	9.7*	12.8*		0.97*	-0.15*	2.71*
Patience et al. (2009)	5	0.14***	-0.01	-0.04***	-0.3	0.3	0.2	2.48***	-0.91*	0.97***
Main et al. (2001)	5	0.12*	0.0	-0.44*	2.0*	2.0*	0.5	0.2	0.0	0.3
	7.5	0.14*	-0.1	-0.63*	2.0*	2.0*	0.6	0.5	0.0	0.6
	10	0.16*	-0.1	-0.71*	2.5*	3.0*	0.9	0.3	-0.1	0.7
Uttaro et al. (1993)	20	0.15**		-0.52**	1.35	-0.37		3.4**	-1.8*	0.86**

Table 2.3. The effects of feeding RAC on growth performance traits and carcass composition in efficacy trials (reported as difference from control)

	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Stoller et al. (2003)	10	0.095*						1.4*	-0.1	0.6
Dunshea et al. (1993) (boars)	20	0.0	-0.13*	-0.12**	-0.2	0.1	0.2	1.1	-0.39*	
Dunshea et al. (1993) (gilts)	20	0.17*	0.07*	-0.39	0.2	1.2	1.1*	1.6	-0.09*	
Dunshea et al. (1993) (barrows)	20	0.24*	0.10*	-0.49	-0.1	0.8	0.9	2.3	-0.32	
Mimbs et al. (2005)	10	-0.01	-0.21**	-0.02**				0.0	-0.7**	

[a] 12^{th} rib LMA
[b] 3^{rd} to 4^{th} last rib BF
[c] Fat-free carcass lean (kg)
*P < 0.05 compared to control
**P < 0.01 compared to control
***P < 0.001 compared to control

Table 2.4. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	Nutritional Variable	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)
Apple et al. (2004)[#]	3.30 Mcal/kg	10	0.64[a]	2.15[a]	0.30[a]	105.6[a]	78.1[a]
	3.48 Mcal/kg	10	0.68[a]	2.08[a]	0.33[b]	106.7[a]	78.3[a]
	1.7 g/Mcal Lys	10	0.58[a]	2.12[a]	0.27[c]	103.7[b]	76.2[b]
	2.4 g/Mcal Lys	10	0.66[b]	2.13[a]	0.31[a]	106.6[c]	79.4[c]
	3.1 g Mcal Lys	10	0.74[c]	2.09[a]	0.36[b]	108.1[c]	79.0[c]
Xiao et al. (1999)	13% CP	20	0.01	-0.02	-0.03	0.84	
	18% CP	20	0.06*	-0.17	-0.53*	2.45	
Adeola et al. (1990)	13% CP	20	-0.09	0.02	0.62*	-2.70*	-1.30*
	17% CP	20	0.09	-0.39*	-0.66*	3.70*	1.40*

Table 2.4 continued. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	Nutritional Variable	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)
Dunshea et al. (1993)	8.5% CP	20	0.01		0.08		-2.20*
	11.2% CP	20	-0.02		0.13		1.00
	14.0% CP	20	0.03		-0.17		-0.50
	16.7% CP	20	0.03		-0.15		1.40**
	19.5% CP	20	0.06		-0.24		2.50**
	22.2% CP	20	0.02		-0.14		4.00**

Table 2.4 continued. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	Nutritional Variable	RAC dosage (ppm)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)	Fat-free lean %
Apple et al. (2004)[#]	3.30 Mcal/kg	10	73.74[a]	42.74[a]	1.91[a]	51.4[a]
	3.48 Mcal/kg	10	73.63[a]	42.64[a]	2.02[b]	50.6[b]
	1.7 g/Mcal Lys	10	73.38[a]	40.52[b]	2.07[b]	50.1[b]
	2.4 g/Mcal Lys	10	74.17[a]	43.63[c]	1.93[ab]	51.2[a]
	3.1 g Mcal Lys	10	73.49[a]	43.91[c]	1.89[a]	51.7[a]
Xiao et al. (1999)	13% CP	20	0.07	3.31*	-0.49*	
	18% CP	20	0.78	3.54**	-0.45*	
Adeola et al. (1990)	13% CP	20		2.66	-0.30	
	17% CP	20		3.93	-0.10	
Dunshea et al. (1993)	8.5% CP	20	-1.30		0.36	
	11.2% CP	20	0.50		-0.10	
	16.7% CP	20	1.60		0.0	
	19.5% CP	20	2.40		0.28	
	22.2% CP	20	4.60		0.40	

[#]reported as least square means
[a-c]Within a column, means with different superscripts differ ($P < 0.05$)
*$P < 0.05$ compared to control

Table 2.5. The effects of feeding RAC on growth performance and carcass composition in genetic line trials (reported as different from the control)

	Genetic line	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)
Yen et al. (1990)	Obese	20	0.0[a]	-0.15[b]	-0.02[ab]	0.4[a]	0.6[ab]	0.7[ab]	5.4[ab]	-0.8[ab]
	Lean	20	0.3[a]	-0.24[b]	-0.3[ab]	-0.5[a]	1.4[ab]	1.4[ab]	7.4[ab]	-0.6[ab]
Gu et al. (1991)[c]	H x (H x D)	20	0.92	3.15	3.44			73.8	33.5	3.22
	Synthetic Terminal Line	20	0.92	3.02	3.32			77.0	38.6	3.12
	(H x D) x (L x Y x D)	20	1.01	3.06	3.06			74.9	35.0	3.09
	L x (Y x D)	20	1.00	3.24	3.28			74.6	31.0	3.69
	Y x L	20	1.02	3.03	3.02			75.3	31.6	3.22

Table 2.5 continued. The effects of feeding RAC on growth performance and carcass composition in genetic line trials (reported as different from the control)

	Genetic line	RAC dosage (ppm)	ADG (kg/d)	ADFI (kg/d)	Feed:Gain (kg feed: kg gain)	Harvest Live Weight (kg)	HCW (kg)	Dressing %	10^{th} rib LMA (cm^2)	10^{th} rib BF (cm)
Bark et al. (1992)	Low lean capacity	20						-0.1	5.0^{ab}	-0.62^{ab}
	High lean capacity	20	0.10^{a}	-0.20	-0.48^{ab}			-0.1	8.2^{ab}	-0.76^{ab}

[a]Genotype effect for main effect
[b]RAC effect for main effect
[c]reported as least square means

Table 2.6. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	RAC Dosage (ppm)	Visual Color	Visual Firmness	Visual Marbling	Ultimate pH	WBSF (kg)
Aalhus et al. (1990)	10	-0.03		-0.35	0.03	0.76*
	15	-0.03		-0.84*	0.05	0.90*
	20	-0.03		-0.55*	0.02	0.85*
Armstrong et al. (2004) (feeding duration of 6 d)	5	0.1		0.3		
	10	-0.1		0.0		
	20	0.0		0.2		
Armstrong et al. (2004) (feeding duration of 13 d)	5	-0.1		0.0		
	10	0.0		0.2		
	20	0.2		0.0		
Armstrong et al. (2004) (feeding duration of 20 d)	5	0.1		0.2		
	10	0.0		-0.4		
	20	-0.5*		0.3*		
Armstrong et al. (2004) (feeding duration of 27 d)	5	-0.2		0.1		
	10	0.1		-0.4		
	20	-0.5*		0.3		
Armstrong et al. (2004) (feeding duration of 34 d)	5	-0.1		-0.5		
	10	0.0		-0.7*		
	20	-0.2		-0.8*		

Table 2.6 continued. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	RAC Dosage (ppm)	Visual Color	Visual Firmness	Visual Marbling	Ultimate pH	WBSF (kg)
Kutzler et al. (2011)	6.2	-0.07	-0.12	-0.49	-0.04	0.03
Carr et al. (2005)	10	0.01	-0.04	0.13	0.03	0.53*
	20	-0.03	0.03	0.10	0.03	0.66*
Patience et al. (2009)	5	0.1			0.0	-0.4
Uttaro et al. (1993)	20					0.49*
Stoller et al. (2003)	10	-0.05	0.0	-0.02	0.3	0.23

Table 2.6. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	RAC Dosage (ppm)	Visual Color	Visual Firmness	Visual Marbling	Ultimate pH	WBSF (kg)
Aalhus et al. (1990)	10	-0.03		-0.35	0.03	0.76*
	15	-0.03		-0.84*	0.05	0.90*
	20	-0.03		-0.55*	0.02	0.85*
Armstrong et al. (2004) (feeding duration of 6 d)	5	0.1		0.3		
	10	-0.1		0.0		
	20	0.0		0.2		
Armstrong et al. (2004) (feeding duration of 13 d)	5	-0.1		0.0		
	10	0.0		0.2		
	20	0.2		0.0		
Armstrong et al. (2004) (feeding duration of 20 d)	5	0.1		0.2		
	10	0.0		-0.4		
	20	-0.5*		0.3*		
Armstrong et al. (2004) (feeding duration of 27 d)	5	-0.2		0.1		
	10	0.1		-0.4		
	20	-0.5*		0.3		
Armstrong et al. (2004) (feeding duration of 34 d)	5	-0.1		-0.5		
	10	0.0		-0.7*		
	20	-0.2		-0.8*		

Table 2.6 continued. The effects of feeding RAC on growth performance and carcass composition in nutritional (energy, dietary protein, and lysine) trials (reported as difference from the control)

	RAC Dosage (ppm)	Visual Color	Visual Firmness	Visual Marbling	Ultimate pH	WBSF (kg)
Kutzler et al. (2011)	6.2	-0.07	-0.12	-0.49	-0.04	0.03
Carr et al. (2005)	10	0.01	-0.04	0.13	0.03	0.53*
	20	-0.03	0.03	0.10	0.03	0.66*
Patience et al. (2009)	5	0.1			0.0	-0.4
Uttaro et al. (1993)	20					0.49*
Stoller et al. (2003)	10	-0.05	0.0	-0.02	0.3	0.23

[x]reported as a percentage
*P < 0.05 compared to control
**P < 0.01 compared to control
***P < 0.001 compared to control

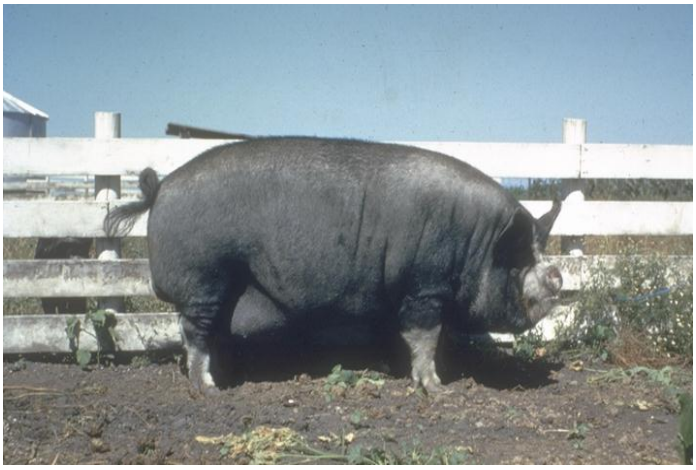

Figure 2.1: Lard-type hog (Photo courtesy of the American Berkshire Association, 2011)

Figure 2.2: High-lean boar (Photo courtesy of Shipley Swine Genetics, 2011)

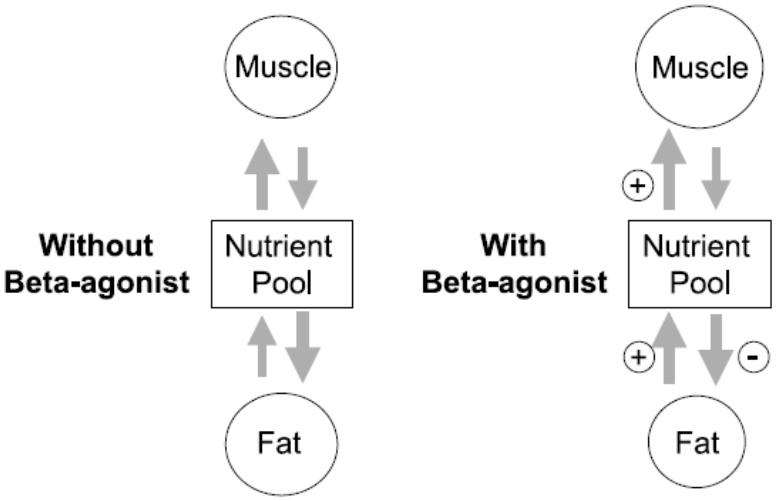

Figure 2.3: Beta-agonist effect on livestock (Anderson et al. 2005)

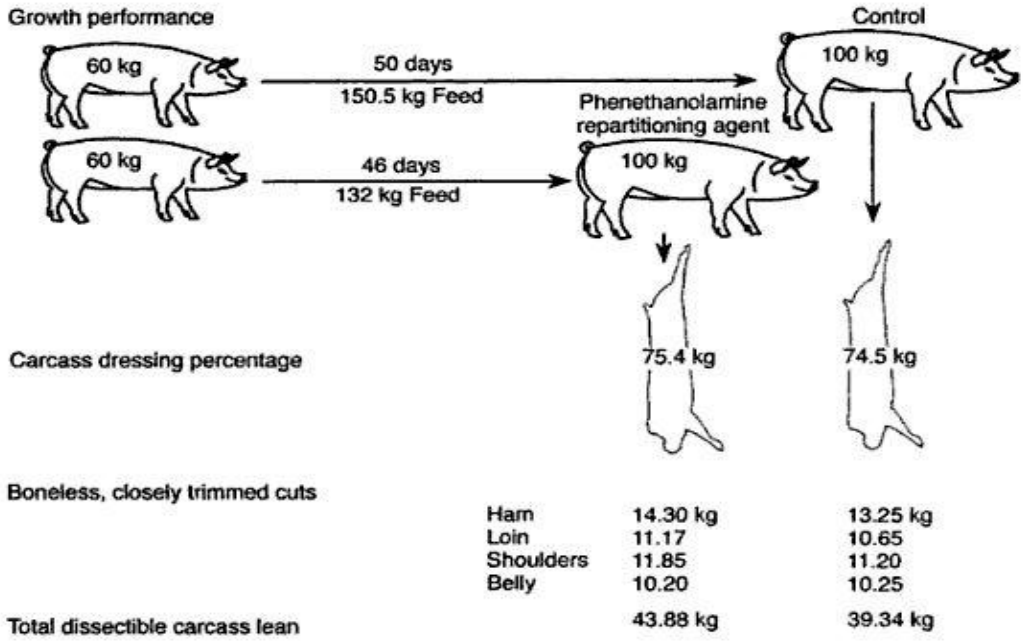

Figure 2.4: RAC mode of action (Moody et al. 2000)

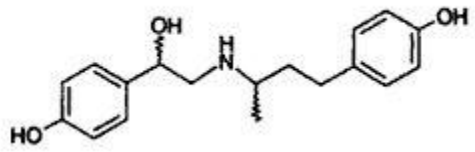

Figure 2.5: Structure of RAC (Moody et al. 2000)

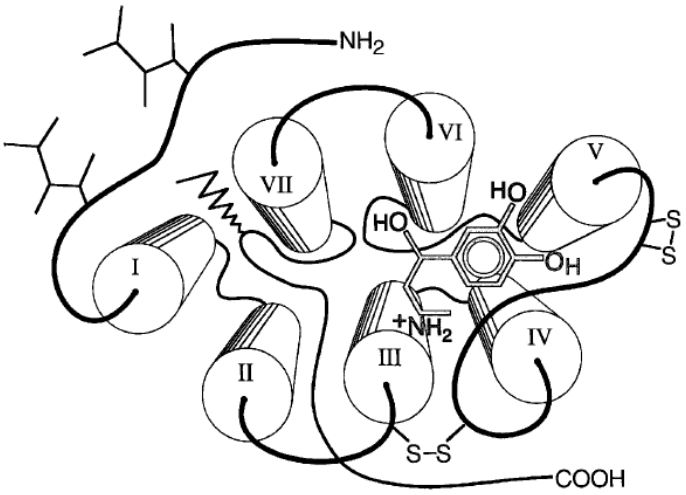

Figure 2.6: Structure of a β-adrenergic receptor, including the seven transmembrane domain (Mersmann 1998)

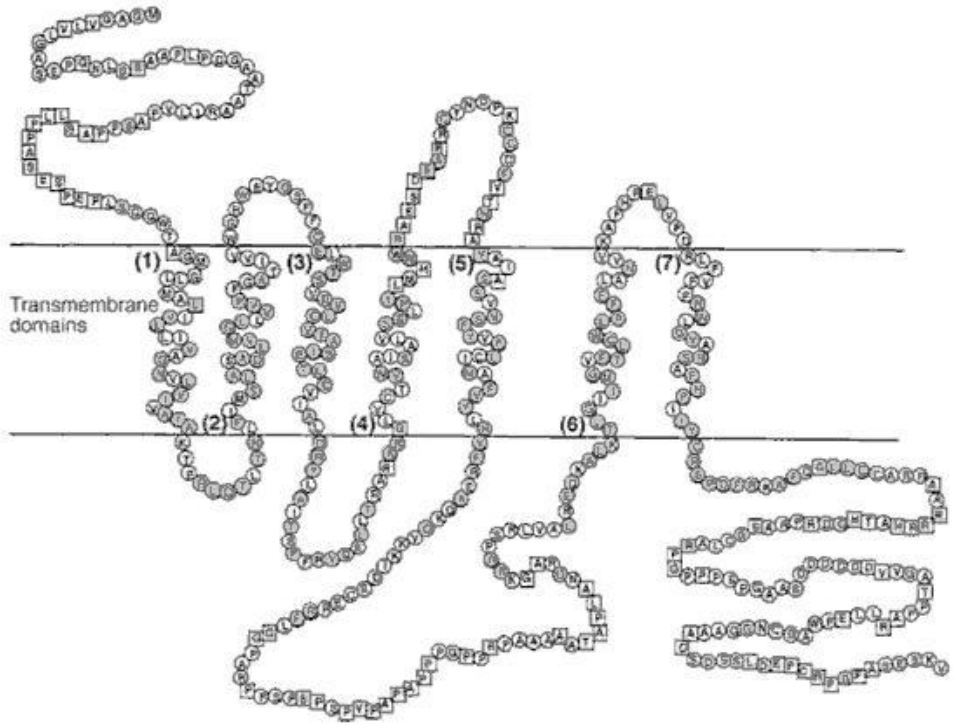

Figure 2.7: Amino acid sequence of β1-adrenergic receptor, seven trans-membrane domains are labeled in parentheses (Moody et al. 2000)

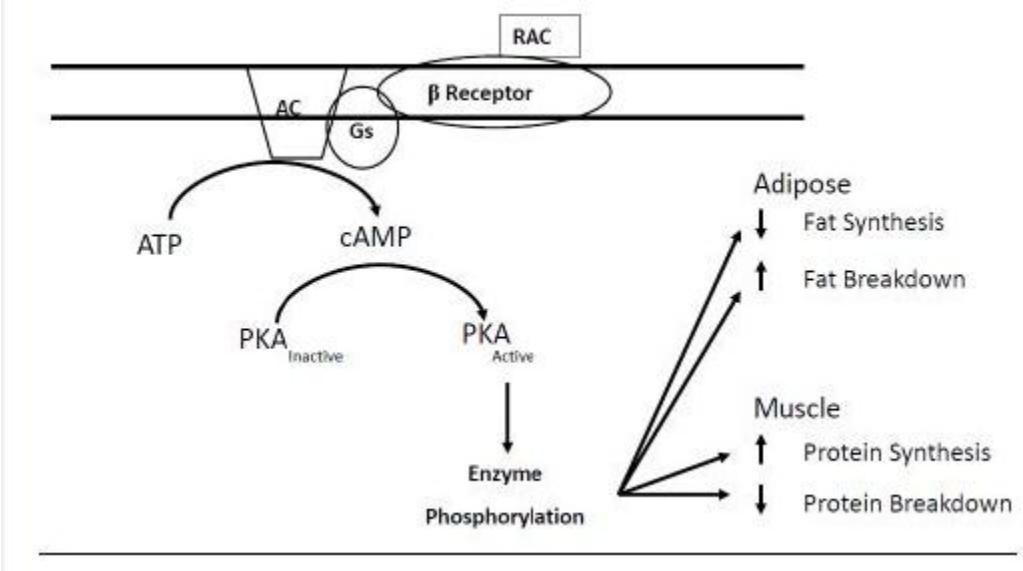

Figure 2.8: Ractopamine mode of action (Hancock et al., 2006)

CHAPTER 3

The effect of feeding ractopamine on growth performance, carcass composition, meat quality and cortisol concentration in purebred Berkshire swine

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ABSTRACT

The study evaluated the effects of a 28 d pre-harvest ractopamine (RAC) feeding program on average daily gain (ADG), feed conversion efficiency (FC), backfat (BF) and loin muscle area (LMA), pork loin quality, and cortisol concentration in purebred Berkshire pigs (n = 117) utilizing a randomized complete block design with three treatments (Control (C), 0 ppm; RAC5, 5.0 ppm; RAC10; 10 ppm) in four replicates. Litter-mate pigs were randomly assigned to each of the three treatments within a replicate. Ultrasonic BF and LMA, pig weight, and salivary cortisol concentrations were measured at days 0, 7, 14, 21, and 28 of the feeding period. Blood was collected during harvest at exsanguination for plasma cortisol measurements. Carcass composition and pork quality (NPPC, 2000; visual color, marbling, firmness, and wetness and instrumental measures of ultimate pH and Minolta L*, a*, and b* were assessed at 24h post-harvest. Mixed model procedures of SAS were used in analyses. Fixed effects were treatment, sex, and a treatment × sex interaction, with sex and interaction effects removed if not significant ($P > 0.10$). Random effects included replication and litter nested within replication. Individual ADG was greater ($P < 0.05$) for RAC10 when compared with C and RAC5 by d 14 and through d 28, while pigs fed RAC5 had greater ADG than the C from d 1 to 14 and d 1 to 21 ($P < 0.05$) only. However, when assessed on a pen basis, ADG was not different across the 28 d feeding period. Feeding RAC5 or RAC10 improved pen FC throughout the trial when compared with pens fed the C diet ($P < 0.05$);

however, no differences were observed between RAC5 and RAC10. Serial ultrasonic measures of BF were significantly decreased in RAC10 pigs from 95 to 120 kg of BW when compared to C pigs and from 115 to 120 kg BW when compared to RAC5 pigs. Pigs fed RAC5 had decreased BF from 110 to 120 kg BW when compared to C. Ultrasonic measures of LMA were increased in RAC10 pigs from 105 to 120 kg BW when compared to C, however no differences were seen between RAC5 and RAC10 fed pigs throughout the trial. Carcass LMA of RAC10 was greater than C ($P < 0.05$) and BF was less than RAC5 and C ($P < 0.05$). Carcass fat-free lean percentage was greater for pigs fed RAC10 ($P < 0.05$) when compared with carcasses of pigs fed C and RAC5 diets. Neither RAC5 nor RAC10 diets influenced fresh loin quality, as there were no differences in visual color, marbling, firmness, wetness, or L*. However, ultimate pH was greater for the RAC10 treatment when compared with C. On d 0, baseline cortisol concentrations did not differ between treatment groups. No differences in salivary or plasma cortisol concentrations were observed between treatments regardless of day. Final results indicate feeding ractopamine improved feed conversion efficiency, maintained (RAC5) or improved (RAC10) carcass lean content and, therefore, value without negatively influencing pig cortisol concentrations or pork loin quality.

INTRODUCTION

Purebred Berkshire swine are well known for producing high quality pork that has been historically noted to have exceptional eating quality that is consistently tender, juicy and palatable (Goodwin, 2004). Asian markets, chefs and consumers are willing to pay a market premium for the high quality product (Honeyman, 2006). Unfortunately, Berkshires are also known to have poor growth performance and carcass composition when compared to commercial crossbred swine, resulting in a greater breakeven price for Berkshire swine producers. Ractopamine hydrochloride (RAC), a β-adrenergic agonist, is a feed additive that has been widely researched over the past 30 years. The use of RAC in swine diets in the last phase of feeding has been shown to improve growth rate (See et al., 2002; Watkins et al., 1990; Armstrong et al., 2004; Gu et al., 1991; Stoller et al., 2003), gain:feed ratio (G:F) (Main et al., 2002; Watkins et al., 1990; Armstrong et al., 2004), and carcass fat-free lean percentage (Aalhus et al., 1990; Carr et al., 2005), providing producers the opportunity to increase profits. However, limited research is available on the effects of RAC on an early-maturing breed with the ability to deposit above average fat depths when compared to commercial lines of swine. Moreover, due to the fact the Berkshire breed is highly valued for its high quality pork, RAC effects on muscle quality need to be further evaluated. Utilizing this technology could have negative effects on pig behavior and well-being. Ractopamine is marketed to pig producers as Paylean® 9 by Elanco. The product label states that RAC may increase the

number of injured and/or fatigued pigs during marketing. Berridge (2008) reported RAC has comparable effects of epinephrine and norepinephrine, as these β-adrenoreceptor agonists enhance arousal, thus increasing the potential to stimulate aggression in pigs. In results reported by Marchant-Forde (2003), RAC has potential to negatively affect animal behavior as RAC fed pigs exhibited negative behaviors towards handlers and other pigs and were overall more difficult to handle. Pigs that were negatively handled for 5 d prior to harvest had lower muscle glycogen concentration post-harvest when compared to pigs positively handled (D'Souza et al., 1998). Ractopamine fed pigs are more susceptible to the negative impacts of increased stress during transport, which could result in a negative impact on fresh pork quality. Thus, we hypothesized that 1) feeding RAC would improve ADG, G:F, and carcass composition of purebred Berkshire swine; 2) feeding RAC would increase salivary and plasma cortisol levels; and 3) pigs with greater cortisol levels would exhibit poorer fresh pork quality. Therefore, our objective was to evaluate the effects of a 28 d pre-harvest RAC feeding program on ADG, feed conversion efficiency, carcass composition, pork quality, and cortisol concentrations in purebred Berkshire pigs.

MATERIALS AND METHODS

Standard operating procedures of the Ohio Agricultural Research and Development Center's Western Agricultural Research Station (OARDC-WARS), derived in compliance with Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010) and containing site specific addendums, were followed for all live animal assessment procedures. Pigs were harvested under USDA inspection, following guidelines established in the Humane Methods of Slaughter Act (USDA, 2009).

Experimental Design and Treatments

Purebred Berkshire barrows (n = 111) and gilts (n = 9), reared at the OARDC-WARS (South Charleston, OH) were utilized in the present study. The experiment was conducted as a randomized complete block design with three dietary treatments in four replicates, with two replications conducted in each of two independent contemporary farrowing groups (CG) separated by 5 months. Littermate pigs were randomly assigned to a dietary treatment pen within a replicate to maintain common genetic ties within each treatment group. Treatments were randomly assigned within replicates to available pens within the grow-finish facility. Treatments consisted of: 1) Control (C, 0 ppm RAC); 2) Phase III finishing diet supplemented with 5.0 ppm RAC (RAC5); and 3) Phase III finishing diet supplemented with 10.0 ppm RAC (RAC10). Replicate one (R1, n = 28

barrows and 3 gilts) and two (R2, n = 23 barrows and 6 gilts) pigs were fed in the summer through early fall (CG1). Replicate three (R3, n = 29 barrows) and four (R4, n = 28 barrows) pigs were fed in the late fall and winter (CG2). Pigs were housed within adjacent pens, approximately 10 pigs per pen, in a naturally ventilated grower-finisher facility with partially slotted floors and provided ad libitum access to pelleted feed and water.

Diets

Diets used in this study were designed using Kansas State University swine nutrition diet formulation software (Table 3.1) and were fed in three phases (Phase I, 32 to 64 kg; Phase II, 64 to 91 kg; and Phase III, 91 kg to market weight). Phase I (3,245 kcal/kg ME, 17.5% CP, 1.02% Lys) and Phase II (3,256 kcal/kg ME, 15.5% CP, 0.88% Lys) diets were consistent across all treatments and were formulated based on National Research Council (NRC, 1998) dietary requirements for pigs with moderate lean growth potential. Trial diets were fed for 28 d and included a phase III control (C; 3,263 kcal/kg ME, 13.7% CP, 0.75% Lys, 0 ppm RAC) and phase III treatment (3,263 kcal/kg ME, 17.4% CP, 1.01% Lys) containing either 5.0 ppm (RAC5) or 10 ppm (RAC10) ractopamine with formulations based on NRC (1998) recommendations. In R1 and R2, Phase III treatment diets (RAC 5 and RAC10) were formulated to similar amino acid specifications using either synthetic amino acids (R1; DL-Methionine, L-Threonine and Lysine HCl) or partial synthetic amino acid (R2; Lysine HCl) in substitution for corn. Because the diets were offered prior to discovery of this error, the study was continued and similar diets were offered in R3 and R4 and the influence of amino acid form tested

for statistical significance. Choice white grease was the source of added fat in all diets. Pigs were weighed weekly and diet transitions were made when all pens in a replicate obtained the target average pen diet transition weight.

Pig Growth and Performance

Individual pig weights were measured weekly and pen feed disappearance was measured one week prior (R1 and R2) and weekly (R1, R2, R3, and R4) over the 28 d test period. Weight and feed measurements were used to calculate pen-based ADFI and G:F, and both individual- and pen-based ADG. Pigs were ultrasonically evaluated for tenth rib backfat depth and loin muscle area (Aloka 500V SSD, 3.5 MHz 12.5-cm long linear array transducer; Corometrics Medical Systems, Inc. Wallingford, CT) at the time of weighing by a certified swine ultrasound technician.

Saliva Collection

Saliva was collected from each pig on d 0, 7, 14, 21, and 28 during the 28 d RAC feeding period. Sampling was initiated at the same time (0600 h) on all collection days. Pigs were sampled by pen and order of pen was randomly selected on each collection day. Pigs entered a familiar holding area where they were not provided room to turn around or move back and forth; however pigs were not physically restrained during collection. From the time each pig entered the holding area a 120 s period was given to collect the saliva sample. A person who was consistent throughout the trial collected the salivary sample with a Salivette® (Sarstedt, Newton, NC). Time and pig order was recorded for sample collection as well as a difficulty score on a scale of one (sample very

easily collected) to ten (no sample obtained). When sample collection was complete, samples were placed ice during further sample collections and transport. Prior to freezing, samples were placed in a centrifuge at 1500 x g for 15 min at 4° C. Samples were frozen at -20° C.

Carcass Composition and Pork Quality

Within a replicate, all pigs were harvested on the same date. Pigs were loaded and maintained as intact treatment groups throughout transport (69 km) to The Ohio State University Meat Science Laboratory and in lairage (15 h). Pigs were harvested individually, following a standard rotation between treatment groups to avoid confounding treatment with time or order of harvest. Pigs were electrically stunned followed by exsanguination, dehairing, and evisceration. During exsanguinations, blood was collected in 10-mL Vacutainer EDTA treated tubes (BD, Franklin Heights, NJ). Immediately after collection, blood was stored at 4° C until all samples were collected. Blood was centrifuged at 760 x g for 30 min at 4° C and plasma aliquoted into 5-mL vials and frozen at -40° C until further processing. Hot carcass weight (HCW) was recorded and carcasses were chilled at 4° C for 24 h.

In R3 and R4 only, at forty-five min post-stun, loin pH and temperature measurements were taken using a portable pH meter (H198140, Hanna Instruments, Italy) equipped with a glass tipped pH probe (FC201D Hanna Instruments, Italy) inserted through the intercostal space between the 12^{th} and 13^{th} rib and placed approximately 3 cm into the loin muscle.

At 24 h post-mortem, carcasses were ribbed between the 10th and 11th rib and BF and LMA were measured following industry accepted standards (NPPC Composition and Quality Assessment Procedures, 2000). Fat-free lean percentage was estimated using HCW, BF and LMA in an equation for ribbed carcasses (NPPC, 2000).

The fresh cut loin surface was allowed to bloom for 20 min prior to subjective and objective loin quality assessment. Fresh loin visual color (1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red; NPPC, 2000) marbling (1 = 1% IMF, 2 = 2% IMF, 3 = 3% IMF, 4 = 4% IMF, 5 = 5% IMF, 6 = 6% IMF; NPPC, 2000), firmness (1 = soft, cut surface distorts easily, 2 = firm, cut surface tends to hold shape, 3 = very firm, cut surface very smooth and no distortion of shape; NPPC, 2000), and wetness (1 = exudative with excess fluid on the cut surface, 2 = moist surface with little or no free water, 3 = no evidence of free water; NPPC, 2000) scores were taken by a trained evaluator and recorded in whole numbers. Instrumental Minolta L*, a*, and b* values were obtained using a Minolta Colorimeter (Minolta Chroma Meter CR-310 colorimeter (Minolta Corp., Osaka, Japan). Ultimate pH was obtained by inserting the glass tipped pH probe one cm under the surface of the loin.

A 1.25 cm-thick loin sample, with all subcutaneous fat and connective tissue removed, was obtained for assessment of intramuscular fat content (IMF). Samples were homogenized (Hobart model 4822, Hobart Co., Troy, OH) three times to acquire a consistent form. Samples were then weighed into glass plates and placed in a freeze dryer (Freezone 6 Freeze Dry System, Labconco Co., Kansas City, MO) for 36 h at -55° C.

Samples were reweighed to calculate moisture loss and then ground to a fine consistency and frozen. Percentage of IMF was determined by ether extraction (AOAC, 1984).

A 2.54 cm-thick loin chop, encompassing approximately the 10^{th} to 11^{th} rib location was removed, aged for 7 d and frozen for subsequent assessment of Warner-Bratzler Shear Force (WBSF). Chops for WBSF assessment were thawed for 24 h at 4° C prior to cooking. Chop weight was recorded prior to and following cooking to assess cook loss. A thermocoupler (Digi-sense, K-type probe, Omega Engineering, Inc, Stamford, CT) was placed in the geometric center of each chop and chops were placed on a clam-style cooker (George Forman Grill) preheated to 191° C. Chops were removed from the grill at an internal temperature of 71° C and allowed to cool to room temperature. Six, 1.25 cm diameter cores were taken from each chop parallel to the longitudinal orientation of the muscle fibers. Peak shear force was measured on a Texture Analyzer Plus (Model TA XT^{plus}) with an attached WBSF blade and a machine cross head speed of 200 mm/min and a force of 5 g. Maximum force was recorded for all cores obtained from an individual chop and averaged to obtain a single WBSF value.

Cortisol Assays

Salivary cortisol was measured in duplicate using an enzyme immunoassay kit (High Sensitivity Salivary Cortisol, Salimetrics, State College, PA) following the manufacturer's protocol. The concentration of cortisol was calculated from a reference curve that ranged from 0.012 µg/dL (78.89% binding) to 3.0 µg/dL (6.85% binding) with a correlation coefficient of 0.9922. All individual pigs were measured for salivary

cortisol concentrations on d 0, 7, 14, 21, and 28 in R1 and R2 however, for R3 and R4 six randomly selected pigs per treatment were measured for the duration of the trial.

Plasma cortisol was measured in duplicate using a competitive binding radioimmunoassay kit (Coat-a-Count Cortisol, Los Angeles, CA) following the manufacturer's protocol. Briefly, 25 µL sample or antibody was added to antibody coated tubes. I^{25} radiolabeled cortisol was added to all tubes and placed in a 37° C water bath for 45 min for incubation. The liquid phase was removed and radioactivity was counted using a gamma counter. A standard curve of 0, 10, 50, 100, 200, and 500 µg/mL with a correlation coefficient of 0.9987 was used to calculate cortisol concentrations.

Statistical Analysis

Data were analyzed as a randomized complete block design using mixed model procedures in SAS (SAS, Inst. Inc., Cary, NC). Due to the initial error in feed identification (described above), the analyses were carried out in two steps. Of note, five pigs were removed from all analyses due to live weight growth rate being greater than two standard deviations below the pen, within replicate, mean. Therefore, the number of pigs within each sub-cell is not the same across treatments and replicates, resulting in slightly unbalanced data. Pen was the experimental unit for G:F, ADG, and ADFI. Pig was the experimental unit for ADG and all measures of carcass, pork quality, and cortisol concentrations.

Preliminary statistical analyses assessed the influence of synthetic and partial synthetic amino acid formulated diets containing RAC within each CG. Fixed effects included amino acid source (synthetic, partial synthetic, and control), contemporary

group (CG1 and CG2) and the interaction of dietary treatment and CG. Using $\alpha \leq 0.20$ as a cut-off point for significance as the test of an amino acid treatment × CG interaction, the amino acid treatment × CG interaction was not significant ($P > 0.20$) for all dependent variables, indicating that the differences among dietary amino acid sources were consistent across CGs. Therefore, subsequent analyses were conducted without amino acid source as an effect in the model.

Subsequent data analysis models included fixed effects of treatment (C, RAC5, RAC10), sex (Barrow or Gilt), and the treatment × sex interaction. Sex and the interaction effect were removed if not significant ($P > 0.10$). A linear covariate for initial weight (d 0) was included when assessing ADG on an individual pig basis. Serial BF and LMA measurements were analyzed as repeated measures with random intercept and autoregression, with the subject being the individual pig measurements. Model fixed effects were treatment, sex, and weight x treatment interaction. Replication and litter of origin nested within replication were included in the model as random effects. Least squares means were estimated at 5 kg intervals from 90 to 120 kg. Day of harvest was included as a fixed effect for measures of pork quality. Differences among means were separated using the PDIFF option.

RESULTS

Growth Performance

Results of growth rate, feed efficiency on a pen basis, and ultrasonic BF and LMA depositions are presented in Table 3.2, 3.3, and 3.4 respectively. Average daily gain was improved for pigs fed RAC10 by d 14 and continued to be significantly greater throughout the 28 d period compared with pigs fed the RAC5 or C diet ($P < 0.001$). Although overall ADG was not improved in pigs fed the RAC5 diet when compared to pigs fed the control diet, RAC5 fed pigs exhibited an increase in ADG during d 14 to 21($P < 0.001$). However, when assessed on a pen basis, ADG was no different across the 28 d feeding period ($P \leq 0.2$). Throughout the 28 d feeding period, all RAC fed pigs had a superior G:F when compared to control fed pigs ($P < 0.05$). Average daily feed intake was decreased in all pigs fed RAC during d 1 to 7 ($P < 0.05$) of the 28 d feeding period, however, ADFI was similar amongst treatments for the remainder of the trial ($P \leq 0.1$).

Graphs of BW as well as serial ultrasonography measurements of BF and LMA are presented in Appendixes A, B, and C, respectively. Throughout the feeding trial BW between the three treatment groups remained similar. Serial ultrasonic measures of BF were significantly decreased in RAC10 pigs from 95 to 120 kg of BW when compared to C pigs and from 115 to 120 kg BW when compared to RAC5 pigs. Pigs fed RAC5 had decreased BF from 110 to 120 kg BW when compared to C. Ultrasonic measures of

LMA were increased in RAC10 pigs from 105 to 120 kg BW when compared to C, however no differences were seen between RAC5 and RAC10 fed pigs throughout the trial.

Carcass Composition

Results of carcass traits are presented in Table 3.5. There were no differences in HCW or dressing percentage between treatment groups ($P > 0.05$). Feeding RAC at 10 ppm decreased 10^{th} rib BF ($P < 0.05$) by 0.27 cm when compared to the C fed pigs. No BF differences were observed between the RAC5 (2.51 cm) and C (2.53 cm) treatment groups ($P > 0.05$). Tenth rib LMA was improved by 1.32 cm^2 and 2.96 cm^2 for RAC10 fed pigs when compared to RAC5 and C treated pigs, respectively ($P \leq 0.01$). Moreover, predicted fat-free lean percentage was improved in RAC10 treated pigs when compared to RAC5 and C treated pigs ($P \leq 0.01$).

Muscle Quality Characteristics

Results of fresh pork quality measurements are presented in Table 3.6. Subjective color, marbling, firmness, and wetness scores, IMF content, Minolta L*, b*, and WBSF values were unaffected by RAC inclusion in the diet ($P > 0.05$). Ultimate pH in loins from RAC10 treated pigs was greater when compared to control treated pigs ($P < 0.05$). Minolta a* values were lower in loins from RAC fed pigs ($P < 0.05$). No differences in 45- min pH were observed between treatments (R3 and R4; $P > 0.05$). Percentage cook loss was improved in loins from RAC fed pigs ($P < 0.05$) when compared to those of C treated pigs.

Cortisol Concentrations

Results of salivary and plasma cortisol concentrations are presented in Table 3.7. Salivary or plasma cortisol concentrations did not differ between treatments, regardless of day ($P > 0.05$). Pigs fed the RAC5 diet were in the holding area longer on d 14 ($P < 0.05$). Results of cortisol and quality correlations are presented in Table 3.8. No significant correlations between plasma cortisol concentrations and quality measurements were of note.

Economic Implications

An economic analysis of total production costs for Berkshire pigs across all treatments is presented in Table 3.9. Utilizing May 27th market prices, production costs were determined. Ractopamine fortified diets did have a greater price when compared to C diets. Therefore, the total cost of production per pig for RAC5 and RAC10 fed pigs was $2.66 and $3.44 greater, respectively when compared to C fed pigs.

Table 3.10 represents the carcass value of Berkshire pigs across all treatments, marketed on two value based systems. Market prices were determined for May 27th base carcass price. Ractopamine fed pigs marketed on a live weight basis (non-grid) did produce greater value carcasses, based on the treatment least squares mean for hot carcass weight. However, 75 percent of all pork carcasses marketed in the U.S. are marketed on an individual carcass merit base system (Kansas State University, 2004). Using the February 2011 Tyson grid (Appendix D) C and RAC5 fed pigs received lean discounts of $-3.71 and $-1.88, respectively. No discount or premium was received for RAC10 fed

pigs. While it is recognized by the authors that the purebred Berkshire genetics utilized in this study would typically be marketed through a market channel that provides additional premiums for quality, for an industry perspective, the profitability of the scenarios in this experiment were assessed using both a non-grid system and the Tyson grid.

Profit margins of Berkshire pigs across all treatments for both value based systems are presented in Table 3.11. Utilizing the non-grid system, all treatment groups recorded earnings. Of note, C fed pigs had a greater profit margin ($4.24) when compared to RAC5 ($3.97) fed pigs. Pigs fed the RAC10 diet recorded the greatest profit margin of $4.79. However, when analyzed on the Tyson grid, C and RAC5 fed pigs recorded losses of $-2.61 and $-1.07, respectively. Pigs that received the RAC10 diet had an equal profit margin if marketed on a non-grid or grid basis ($4.79).

DISCUSSION

Growth performance was improved for RAC10 pigs as well as improved feed conversion efficiency for all RAC fed pigs. The addition of RAC at 10 ppm has shown to improve growth rates in purebred Berkshires in previous work completed by Stoller et al. (2003). Pigs fed the RAC5 diet had an improved ADG during weeks 2 and 3 ($P < 0.05$) during the 28 d feeding period, however overall ADG was not improved when compared to the control ($P > 0.05$). The results of the present study support previous research findings where the addition of RAC in the diet at 5 ppm improved ADG in as few as 6 d on trial, however after 27 d on trial, pigs had a growth rate similar to that of control fed pigs.

Pigs fed the RAC10 diet had superior carcass measures of 10^{th} rib BF and LMA when compared to carcasses of RAC5 and control fed pigs ($P < 0.05$). Moreover, RAC10 treated pigs had carcasses with a greater percentage of fat-free lean ($P \leq 0.01$). Inclusion of RAC in the diet at 10 ppm has been reported to be superior to inclusion of 5 ppm on LMA (Watkins et al., 1990; Armstrong et al., 2004) and fat-free lean percentage (Watkins et al., 1990), however Stoller et al. (2003) reported including RAC in the diet at 10 ppm did not affect 10^{th} rib BF of Berkshire pigs. This finding was not consistent with the results of the present study.

There were no differences among treatments for subjective color, marbling, firmness, or wetness ($P > 0.05$) which is consistent with the findings of Patience et al. (2009) and Stoller et al. (2003). Minolta L* values were not significant among treatments ($P > 0.05$), however a* values were decreased in loins from RAC fed pigs ($P < 0.05$). McKeith et al. (1988) hypothesized that lower a* values caused by RAC treatment could be due to the shift of Type IIa, intermediate fibers to Type IIb, white fibers. The findings of the present study support research findings of Carr et al. (2005) as RAC treated loins had decreased Minolta a* and b* values. The authors hypothesized decreased a* values were observed because of a dilution effect due to hypertrophy of muscle fibers (Carr et al., 2005).

Ultimate pH in loins from RAC10 treated pigs was greater when compared to control pigs ($P < 0.05$). The authors hypothesize that there were higher concentrations of epinephrine released in these pigs during transport due to stressors present. As epinephrine is released in the bloodstream, glycogen breakdown takes place, leading to the formation of lactic acid. Due to the 15-h rest period provided to the pigs prior to harvest, lactic acid was removed however, muscle tissue remained glycogen deficient leading to a higher ultimate pH.

Similar results of cortisol concentrations were reported by Marchant-Forde et al. (2003). This study also reported no differences in cortisol concentration in response to transportation. The present study measured plasma cortisol concentrations post-stun following a 15-hr rest period, post transportation. Although there was variation among all pigs, no treatment differences were found ($P > 0.05$). Pigs fed the RAC5 diet were in the holding area longer on d 14 ($P < 0.05$) which could be due to increased aggression

that has been reported by Marchant-Forde et al. (2003) and Poletto et al. (2010), however it should be noted that the difficulty score assigned to the RAC5 pigs was numerically higher but not significant ($P > 0.05$).

CONCLUSIONS

Final results indicate ractopamine should be fed at 10.0 ppm to purebred Berkshire pigs to increase growth rate, improve feed conversion rate, increase carcass fat-free lean percentage, and increase producer profitability without negatively impacting fresh pork quality or cortisol concentrations. However, it should be noted that although cortisol concentrations did not differ throughout the study, other catecholamines could have negatively impacted animal behavior. Future research must further address the interaction of ractopamine and pig behavior and well-being.

Table 3.1. Composition of diets (as fed basis) fed to pigs.

	Standard Diet			RAC Inclusion Diet	
Item	Phase I Pre-Trial All pigs (32-64 kg of BW)	Phase II Pre-Trial All pigs (64-91 kg of BW)	Phase III Control (91-114 kg of BW)	RAC Diet Synthetic (91-114 kg of BW)	RAC Diet Non-Synthetic (91-114 kg of BW)
Ingredient, %					
Corn	61.05	66.50	71.45	61.95	59.75
Soybean meal (46.5% CP)	22.70	17.55	12.75	22.30	24.60
Wheat middlings	10.0	10.0	10.0	10.0	10.0
Choice White Grease	1.00	1.00	1.00	1.00	1.00
Dicalcium Phosphate, 18.5% P	1.20	0.90	0.75	0.60	0.60
Limestone	0.825	0.875	0.875	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.50	0.50	0.50	0.50	0.50
Trace mineral premix	0.05	0.05	0.05	0.05	0.05
Lysine HCl	0.15	0.15	0.15	0.15	0.075
DL-Methionine	-	-	-	0.01	-
L-Threonine	-	-	-	0.03	-
RAC HCl, 9 g/lb	-	-	-	0.025/0.05	0.025/0.05
Pellet Binder	2.00	2.00	2.00	2.00	2.00
Selenium	0.15	0.15	0.15	0.15	0.15
TOTAL	100	100	100	100	100
Calculated composition					
Crude protein, %	17.50	15.50	13.70	17.40	17.40
Crude fat, %	4.10	4.30	4.40	4.20	4.20
Crude fiber, %	2.90	2.80	2.80	2.90	2.90
TID Lysine:ME ratio, g/Mcal	3.14	2.69	2.29	3.09	3.09
Available P:calorie ratio g/mcal	0.88	0.77	0.73	0.88	0.77
ME, kcal/kg	3245	3256	3263	3263	3263

Table 3.2. Least squares means for weekly body weight (BW) and average daily gain (ADG) of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine-fortified diet for 28 d.

	Treatment			Pooled SEM	Model Prob
	Control n=39	RAC5[d] n=39	RAC10[e] n=37		
Day 0					
BW, kg	89.0	89.7	89.5	2.85	0.81
Day 7					
BW, kg	96.3	97.5	97.8	2.93	0.47
ADG, kg/d (d 1 to 7)	1.06	1.12	1.18	0.09	0.14
Day 14					
BW, kg	101.0	102.7	103.4	3.27	0.19
ADG, kg/d (d 1 to 14)	0.88[a]	0.95[b]	1.01[c]	0.05	0.0004
Day 21					
BW, kg	107.0	109.2	110.2	3.19	0.09
ADG, kg/d (d 1 to 21)	0.88[a]	0.94[b]	1.00[c]	0.04	0.0002
Day 28					
BW, kg	114.5	116.5	117.6	3.34	0.13
ADG, kg/d (d 1 to 28)	0.94[a]	0.98[a]	1.03[b]	0.03	0.0004

[a-c]Within a row, means with different superscripts differ ($P < 0.05$).
[d]Ractopamine supplemented at 5.0 ppm
[e]Ractopamine supplemented at 10.0 ppm

Table 3.3. Least squares means of pen average feed consumption, gain:feed ratio, and daily gain of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine fortified diet for 28 d.

	Treatment				
	Control n=4	RAC5[c] n=4	RAC10[d] n=4	Pooled SEM	Model Prob
Day 0 (Rep 1 and 2)					
ADFI, kg/d	3.47	3.38	3.36	0.07	0.50
Gain:Feed, kg/kg	0.24	0.25	0.22	0.01	0.14
Pen Gain, kg/day	0.81	0.85	0.75	0.03	0.31
Day 1 to 7					
ADFI, kg/d	3.21[a]	2.91[b]	2.98[b]	0.10	0.03
Gain:Feed, kg/kg	0.31[a]	0.37[b]	0.38[b]	0.03	0.03
Pen Gain, kg/day	1.00	1.08	1.13	0.08	0.15
Day 1 to 14					
ADFI, kg/d	3.31	3.13	3.09	0.09	0.08
Gain:Feed, kg/kg	0.27[a]	0.31[b]	0.33[b]	0.01	0.01
Pen Gain, kg/day	0.90	0.98	1.02	0.05	0.11
Day 1 to 21					
ADFI, kg/d	3.26	3.13	3.06	0.13	0.10
Gain:Feed, kg/kg	0.27[a]	0.30[b]	0.32[b]	0.02	0.01
Pen Gain, kg/day	0.87	0.94	0.97	0.04	0.15
Day 1 to 28					
ADFI, kg/d	3.31	3.21	3.14	0.14	0.09
Gain:Feed, kg/kg	0.27[a]	0.29[b]	0.31[b]	0.01	0.01
Pen Gain, kg/day	0.89	0.93	0.97	0.04	0.22

[a-b]Within a row, means with different superscripts differ ($P < 0.05$).
[c]Ractopamine supplemented at 5.0 ppm
[d]Ractopamine supplemented at 10.0 ppm

Table 3.4. Least squares means for weekly ultrasonic measures of backfat (BF[c]) and loin muscle area (LMA[d]) of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine-fortified diet for 28 d.

	Treatment				
	Control n=39	RAC5[c] n=39	RAC10[d] n=37	Pooled SEM	Model Prob
90 kg BW					
BF, cm	2.06	2.05	2.03	0.04	0.0001
LMA, cm^2	33.2	34.0	33.4	0.80	0.01
95 kg BW					
BF, cm	2.18[b]	2.14[ab]	2.10[a]	0.04	0.0001
LMA, cm^2	34.4	35.2	34.9	0.80	0.01
100 kg BW					
BF, cm	2.29[b]	2.23[ab]	2.17[a]	0.04	0.0001
LMA, cm^2	35.5	36.4	36.5	0.80	0.01
105 kg BW					
BF, cm	2.41[b]	2.32[ab]	2.24[a]	0.05	0.0001
LMA, cm^2	36.6[b]	37.5[ab]	38.0[a]	0.81	0.01
110 kg BW					
BF, cm	2.52[b]	2.41[a]	2.31[a]	0.05	0.0001
LMA, cm^2	37.8[b]	38.7[ab]	39.5[a]	0.83	0.01
115 kg BW					
BF, cm	2.64[c]	2.50[b]	2.37[a]	0.05	0.0001
LMA, cm^2	38.9[b]	39.9[ab]	41.0[a]	0.86	0.01
120 kg BW					
BF, cm	2.75[c]	2.59[b]	2.44[a]	0.05	0.0001
LMA, cm^2	40.0[b]	41.1[ab]	42.6[a]	0.90	0.01

[a-b]Within a row, means with different superscripts differ ($P < 0.05$).
[c]Ractopamine supplemented at 5.0 ppm
[d]Ractopamine supplemented at 10.0 ppm

Table 3.5. Least squares means for carcass characteristics of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) diet for 28 d.

	Treatment				
Trait	Control n=39	RAC5[c] n=39	RAC10[d] n=37	Pooled SEM	Model Prob
Live Wt, kg	110.4	111.6	112.5	2.84	0.38
HCW, kg	84.4	85.6	86.4	2.64	0.33
Dress, %	76.4	76.7	76.9	0.65	0.75
10^{th} rib Backfat, cm	2.53[a]	2.51[a]	2.26[b]	0.18	0.02
10^{th} rib LMA, cm^2	39.1[a]	40.8[ab]	42.1[b]	1.57	0.01
Predicted fat-free lean, %	49.3[a]	49.8[a]	51.2[b]	1.12	0.01

[a-b]Within a row, means with different superscripts differ ($P < 0.05$).
[c]Ractopamine supplemented at 5.0 ppm
[d]Ractopamine supplemented at 10.0 ppm

Table 3.6. Least squares means for fresh pork quality of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) diet for 28 d.

	Treatment				
Trait	Control n=39	RAC5[c] n=39	RAC10[d] n=37	Pooled SEM	Model Prob
pH, 45 min (R3 and R4)					
pH, 24 h	5.57[a]	5.60[ab]	5.63[b]	0.032	0.04
L*	55.02	54.91	54.95	0.59	0.98
a*	18.17[a]	17.77[b]	17.63[b]	0.29	0.02
b*	6.87	6.83	6.47	0.63	0.10
Color	2.65	2.61	2.60	0.13	0.93
Marbling	2.45	2.20	2.29	0.25	0.46
Firmness	2.21	2.24	2.29	0.15	0.87
Wetness	2.36	2.24	2.45	0.18	0.38
Intramuscular fat, %	1.83	1.65	1.62	0.15	0.21
WBSF tenderness, kg	2.45	2.60	2.53	0.11	0.37
Cook loss, %	18.5[a]	16.8[b]	15.8[b]	1.82	0.002

[a-b]Within a row, means with different superscripts differ ($P < 0.05$).
[c]Ractopamine supplemented at 5.0 ppm
[d]Ractopamine supplemented at 10.0 ppm

Table 3.7. Least squares means for salivary and plasma cortisol levels of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) diet for 28 d.

	Treatment			Pooled SEM	Model Prob
	Control n=21	RAC5[c] n=21	RAC10[d] n=20		
Day 0					
Salivary cortisol, µL/mL	2.33	1.61	2.02	0.29	0.23
Time, sec	61.3	59.0	59.9	5.28	0.95
Difficulty Score	2.38	2.37	2.25	0.58	0.96
Day 7					
Salivary cortisol, µL/mL	1.59	1.42	2.08	0.23	0.11
Time, sec	64.9	67.2	75.7	5.41	0.34
Difficulty Score	2.20	3.32	3.24	0.78	0.17
Day 14					
Salivary cortisol, µL/mL	1.55	1.77	1.89	0.27	0.53
Time, sec	64.7[a]	82.2[b]	64.9[a]	5.46	0.04
Difficulty Score	2.19	2.86	1.90	0.46	0.18
Day 21					
Salivary cortisol, µL/mL	2.09	2.63	2.36	0.40	0.63
Time, sec	56.7	62.5	56.0	4.86	0.59
Difficulty Score	1.73	2.83	1.71	0.38	0.07
Day 28					
Salivary cortisol, µL/mL	1.86	2.06	2.39	0.24	0.31
Time, sec	58.6	52.0	49.3	4.61	0.31
Difficulty Score	2.15	1.65	1.51	0.40	0.43
Harvest					
Plasma cortisol, µL/mL	7.43	8.30	8.64	0.83	0.41

[a-b]Within a row, means with different superscripts differ ($P < 0.05$).
[c]Ractopamine supplemented at 5.0 ppm
[d]Ractopamine supplemented at 10.0 ppm

Table 3.8. Significant correlations for quality measurements (pH and WBSF) and plasma cortisol concentrations of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) diet for 28 d.

	Ultimate pH	WBSF	Plasma Cortisol Conc.
45 min pH	0.03	0.17	0.10
Plasma Cortisol Conc.	-0.04	0.18	1.0

Table 3.9. Economic analysis of production costs of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine fortified diet for 28 d.

			Phase III		
Item	Phase I[a]	Phase II[a]	Control	RAC5[d]	RAC10[e]
Diet cost[b] ($/ton)	312.06	301.91	292.96	327.95	343.63
Diet cost[b] ($/kg)	0.344	0.333	0.323	0.362	0.379
Days on Diet	30	40	28	28	28
Average Daily Feed Intake (kg)	1.97	2.94	3.31	3.21	3.14
Feed Cost ($/pig)	20.33	39.13	29.93	32.54	33.32
Total Feed Cost ($/pig)			$89.39	$92.00	$92.78
Fixed Cost/day ($/pig)[c]			0.15	0.15	0.15
Labor cost ($/pig)			10.00	10.00	10.00
Feeder pig cost ($/pig)[b]			50.17	50.17	50.17
Total cost of production			**$164.21**	**$166.87**	**$167.65**

[a]Phase I and II were consistent across all treatments and included in all treatment diet costs.
[b]Feed cost and feed pig cost were determined using May 27th market prices.
[c]Fixed cost is an industry estimate for non-feed costs.
[d]Ractopamine supplemented at 5.0 ppm.
[e]Ractopamine supplemented at 10.0 ppm.

Table 3.10. Economic analysis of carcass value of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine fortified diet for 28 d.

	Phase III		
	Control	RAC5[b]	RAC10[c]
Non-grid analysis			
Base carcass price[a] ($/cwt)	90.72	90.72	90.72
Average carcass weight (lb)	185.68	188.32	190.08
Non-grid carcass value	**$168.45**	**$170.84**	**$172.44**
Tyson grid analysis			
Base carcass price[a]($/cwt)	90.72	90.72	90.72
Average carcass weight (lb)	185.68	188.32	190.08
Total Sort premium/discount ($)	0.00	0.00	0.00
Average carcass percent lean	49.3	49.8	51.2
Total percent lean premium/discount ($)	-3.71	-1.88	0.00
Adjusted carcass price ($/cwt)	87.01	88.84	90.72
Total carcass value ($/pig)	**$161.56**	**$165.80**	**$172.46**

[a]Base carcass price was determined using May 27th market prices.
[b]Ractopamine supplemented at 5.0 ppm.
[c]Ractopamine supplemented at 10.0 ppm.

Table 3.11. Economic analysis of profit margin of purebred Berkshire pigs fed a control (0 ppm), RAC5 (5.0 ppm), or RAC10 (10.0 ppm) ractopamine fortified diet for 28 d.

	Phase III		
	Control	RAC5[a]	RAC10[b]
Non-grid analysis profit margin			
Cost of production ($/pig)	$164.21	$166.87	$167.65
Non-grid carcass value ($/pig)	$168.45	$170.84	$172.44
Profit margin ($/pig)	**$4.24**	**$3.97**	**$4.79**
Tyson grid analysis profit margin			
Cost of production ($/pig)	$164.21	$166.87	$167.65
Tyson carcass value ($/pig)	$161.56	$165.80	$172.44
Profit margin ($/pig)	**$-2.61**	**$-1.07**	**$4.79**

[a]Ractopamine supplemented at 5.0 ppm.
[b]Ractopamine supplemented at 10.0 ppm.

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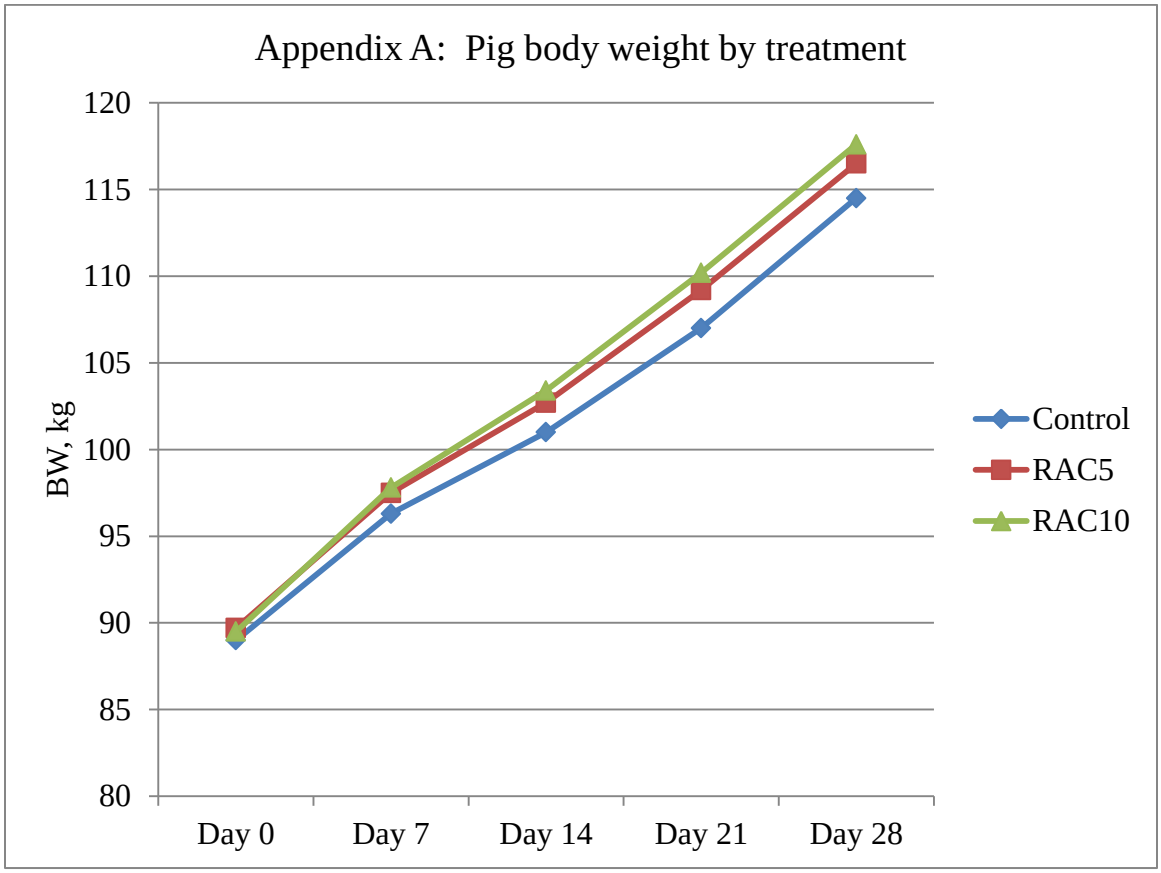
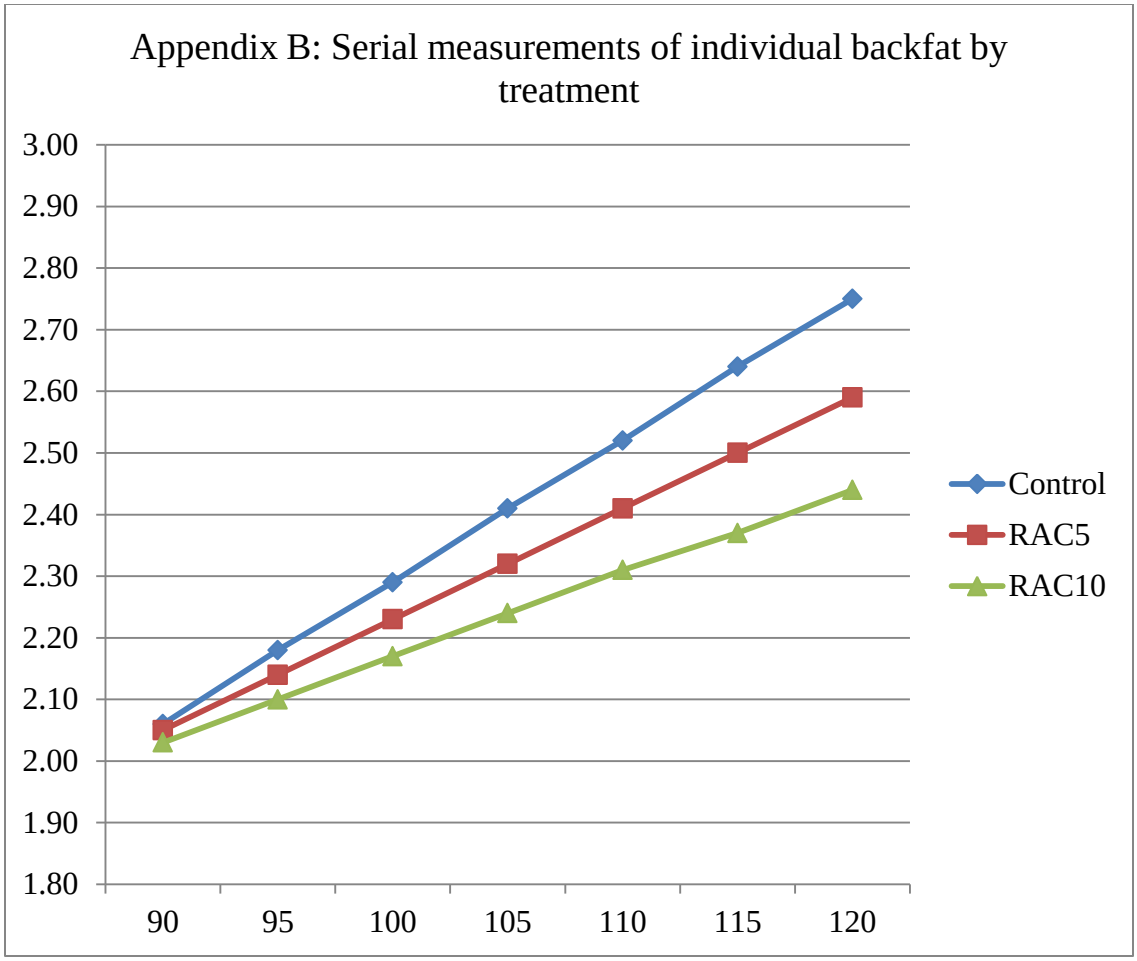
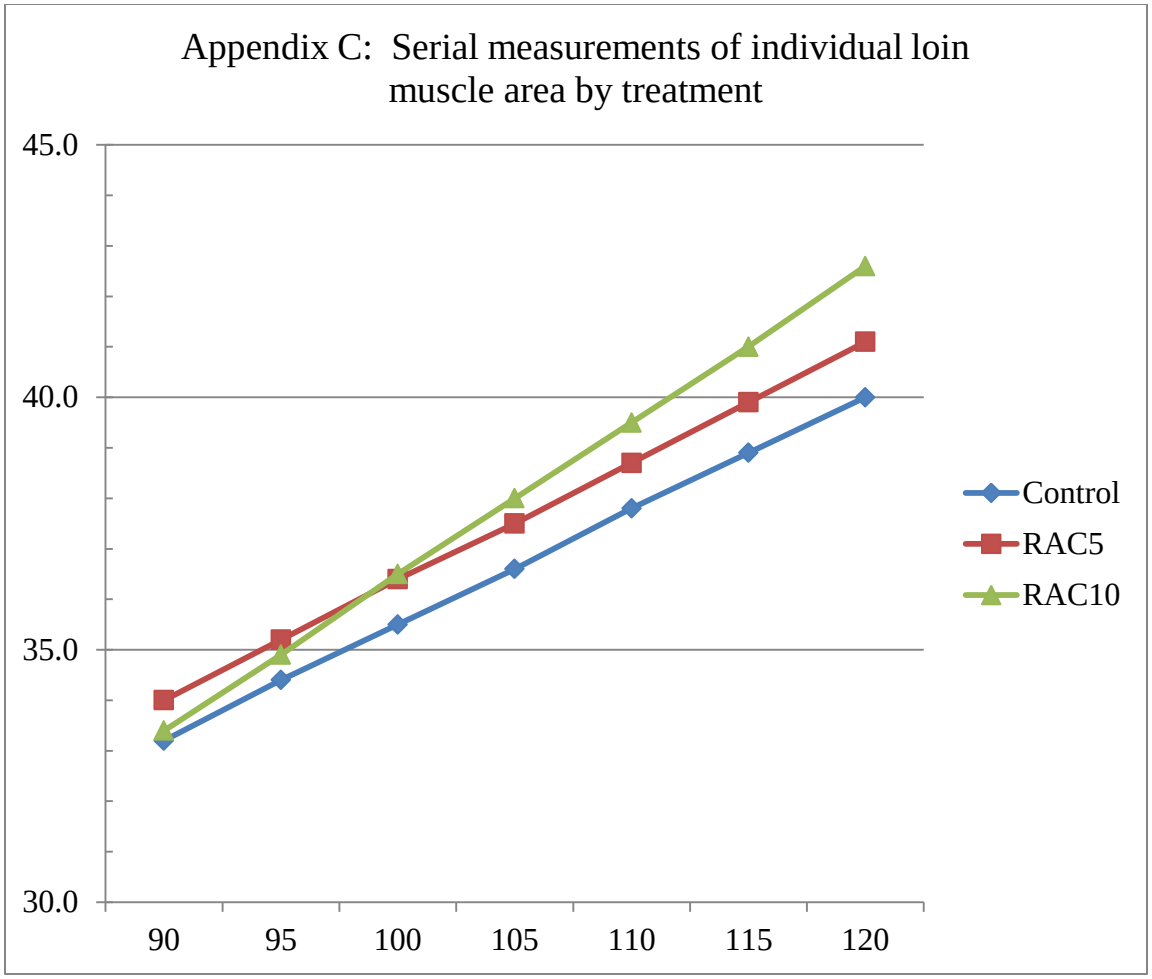

Appendix A: Pig body weight by treatment
120
115
110
105
100
95
90
85
80
BW, kg
Day 0
Day 7
Day 14
Day 21
Day 28
Control
RAC5
RAC10


Appendix B: Serial measurements of individual backfat by treatment
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
90
95
100
105
110
115
120
Control
RAC5
RAC10


Appendix C: Serial measurements of individual loin muscle area by treatment
45.0
40.0
35.0
30.0
90
95
100
105
110
115
120
Control
RAC5
RAC10

Appendix D. Tyson Grade Premium Schedule (effective February 7, 2011).													
	Percent Lean												
HCW Range	48%	49%	50%	51%	52%	53%	54%	55%	56%	57%	58%	59%	60%
Under 155	($3.00)	($2.00)	($1.00)		$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00
156-163	($3.00)	($2.00)	($1.00)		$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00
164-171	($3.00)	($2.00)			$2.50	$2.50	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
172-178	($3.00)	($2.00)			$2.50	$2.75	$3.25	$3.50	$4.00	$4.00	$4.00	$3.50	$3.50
179-186	($3.00)	($2.00)			$2.50	$3.00	$4.00	$4.50	$4.75	$5.00	$5.00	$5.00	$4.75
187-194	($3.00)	($1.00)			$3.00	$4.00	$5.00	$5.50	$5.75	$6.25	$6.50	$6.50	$6.50
195-202	($3.00)	($1.00)			$3.00	$4.50	$5.50	$6.00	$6.50	$7.00	$7.00	$7.50	$7.50
203-209	($3.00)	($1.00)			$4.00	$5.00	$6.50	$6.50	$7.00	$7.00	$7.00	$7.50	$7.50
210-218	($3.00)	($1.00)			$4.00	$5.50	$7.00	$7.00	$7.50	$7.50	$7.50	$7.50	$7.50
219-225	($3.00)	($1.00)	$1.00	$2.00	$4.00	$5.50	$7.00	$8.00	$8.50	$8.50	$8.50	$8.50	$8.50
226-233	($3.00)	($1.00)	$1.00	$2.00	$3.50	$5.50	$8.00	$8.50	$8.50	$8.50	$8.50	$8.50	$8.50
234-240	($3.00)	($1.00)	$1.00	$2.00	$3.50	$5.50	$8.00	$8.50	$8.50	$8.50	$8.50	$8.50	$8.50
241-248	($3.00)	($1.00)	$1.00	$2.00	$4.00	$6.00	$8.00	$8.50	$8.50	$8.50	$8.50	$8.50	$8.50
249-255	($3.00)	($1.00)	$1.00	$2.00	$4.00	$6.00	$8.00	$8.50	$8.50	$8.50	$8.50	$8.50	$8.50
256-up	($3.00)	($1.00)	$1.00	$2.00	$4.00	$6.00	$8.00	$9.00	$9.00	$10.00	$10.00	$10.00	$10.00