Effect of Nursery Feeding Program on Wean-to-Finish Growth Performance, Growth-Related Plasma Hormone Levels, Chemical Body Composition and Carcass Traits of Pigs

by

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ABSTRACT

EFFECT OF NURSERY FEEDING PROGRAM ON WEAN-TO-FINISH GROWTH PERFORMANCE, GROWTH-RELATED PLASMA HORMONE LEVELS, CHEMICAL BODY COMPOSITION AND CARCASS TRAITS OF PIGS

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Experiments were conducted to assess effects of nursery feeding programs (using complex or simple diets, including or excluding antibiotics) on growth performance of barrows and gilts up to market weight (approximately 115 kg body weight), plasma levels of growth-related hormones, chemical body composition and carcass traits at market weight. Reducing nursery diet complexity decreased (P < 0.05) growth performance and plasma levels of triiodothyronine during the nursery period, but had no negative carry-over effects on growth performance or hormone plasma levels thereafter. Excluding antibiotics from nursery diets reduced nursery growth performance and plasma levels of insulin-like growth factor-1 and triiodothyronine but appeared to induce subsequent compensatory growth. In general, nursery feeding programs had no effect on body composition and carcass traits at market weight and no effect on wean-to-finish growth performance or carcass value at market weight. This represents an opportunity to improve profitability in commercial pork production.

DEDICATION

This thesis is dedicated to my parents and to all of my family who have supported me and instilled in me the confidence that has helped drive me in every step of my educational journey. Also, to my fiancé, Heather, who has put up with a career student and endless hours of talk about pigs and the things they eat.

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Chapter 1

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List of abbreviations

+AB	including antibiotics
-AB	not including antibiotics
ADFI	average daily feed intake
ADG	average daily gain
bio-markers	biological markers
BW	body weight
°C	degrees Celsius
CF	crude fat
CG%	compensatory growth index
CP	crude protein
CV	coefficient of variation
DM	dry matter
d	Day
eBW	empty carcass body weight
G:F	feed efficiency (ADG/ADFI)
G-F	grower-finisher (periods)
GH	growth hormone
h	Hour
IGF-1	insulin-like growth factor 1
IL-1β	interleukin-1 beta
IL-6	interleukin-6

kg	Kilogram
LB	whole body lipid mass
LB/PB	whole body lipid mass to whole body protein mass
Ld	lipid deposition
Ld/Pd	whole body lipid deposition to whole body protein deposition
mL	milliliter
N	Nitrogen
P	Probability
PB	whole body protein mass
Pd	protein deposition
$\mathbf{r^2}$	coefficient of determination
r	coefficient of correlation
RIA	radioimmunoassay
SAS	statistical analysis system
$\mathbf{T_3}$	Triiodothyronine
$\mathbf{T_4}$	Thyroxine
TNF-α	tumor necrosis factor alpha
TSH	thyroid stimulating hormone
wean-to-finish	period of time from weaning until week 17 post-weaning
wk	Week

1.0. Literature review

1.1. Introduction

For a variety of reasons, it has become increasingly difficult for pork producers to make a profit. Although many factors that cause poor economic returns, such as frequent changes in input costs or hog market prices, are beyond the control of the producer, it is important to minimize production costs in order to increase profits.

Feed costs are the largest expense incurred in commercial pork production. According to the budget for swine production provided by the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) in October 2012, the feed costs associated with producing a market hog from farrow to finish are $141.92. This accounts for over 70% of the total cost of production for a market hog, which is estimated at $200.58 (OMAFRA, 2012). As such, practices that reduce feed costs without compromising lifetime growth performance would greatly benefit Canadian pork producers.

In conventional pork production systems, nursery pig diets are often formulated to be highly digestible because newly weaned pigs are unaccustomed to solid feedstuffs. The digestive tract of newly weaned pigs is not fully developed with respect to digestive enzymes or absorptive capacity (Richert et al., 1994; Kim et al., 2003). Consequently, nursery diets often contain substantial levels of highly digestible animal protein sources, such as blood plasma, blood meal and milk proteins (Mahan and Lepine, 1991), and these ingredients are often expensive. A typical nursery feeding program involves three or more diets that are fed in sequence, with an average diet cost of $700 per tonne (personal communication; Ontario feed industry; March 2012). The cost of a typical Phase I or Phase II nursery diet is closer to $900 per tonne because of increased inclusion of expensive, highly digestible protein sources and feed additives that stimulate digestive capacity and gut health in pigs. Feed costs may be reduced by removing some of these expensive ingredients and replacing them with cheaper protein sources, such as soybean meal.

Research has shown that feeding complex diets that contain highly digestible ingredients to newly weaned pigs allows for rapid growth following weaning (Mahan et al., 2004; Jones et al., 2010). The common view is that rapid growth during the nursery period is the best way to produce a market hog as quickly and as efficiently as possible (Lawlor et al., 2002). However, in recent years the use of alternative feeding strategies that include less complex, lower cost nursery diets has challenged traditional nursery pig feeding programs as a way to reduce feed costs and increase on-farm profits. These alternative feeding strategies are based on evidence that a period of reduced growth in the nursery can initiate subsequent compensatory growth if the period of reduced growth is followed by an adequate realimentation period (Zimmerman and Khajarern, 1973; Whang et al., 2000; Fabian et al., 2002; Wolter et al., 2003). The use of alternative nursery pig feeding strategies may significantly reduce the overall cost of producing a market hog. However, it is important to ensure that the diets being used to impose restrictions do not permanently inhibit the expression of long-term pig growth performance potential.

This review will examine compensatory growth and multiple feeding programs that are used to reduce pig growth performance as well as examine potential biomarkers of pig health, immune function and growth that may be used as predictors of pig growth performance.

1.2. Compensatory growth

1.2.1 Introduction to compensatory growth

Compensatory growth is defined as a period of increased weight gain that follows a period of reduced growth, whereby the rate of body weight gain during compensatory growth is greater than that in animals that have not experienced periods of reduced growth (Wiecek et al., 2011). This increased gain occurs when animals that had previous reductions in growth are provided access to adequate nutrients and a favourable environment during the subsequent recovery or realimentation period. The underlying physiological control of the compensatory growth phenomenon has not been well characterized. However, it has been suggested that following a period of restricted nutrient intake, access to adequate nutrients during the realimentation period may lead to increased feed intake or to improved feed efficiency, which can result in compensatory growth (Fabian et al., 2004; Martinez-Ramirez et al., 2008).

A number of studies have been carried out to examine whether or not compensatory growth is consistently exhibited in pigs following periods of nutrient intake restriction, but the results have been conflicting. Zimmerman and Khajarern (1973), Whang et al. (2000), Fabian et al. (2002), Wolter et al. (2003), Heyer and Lebret (2007) and Martinez-Ramirez et al. (2008) observed compensatory growth in growing pigs following a period of nutrient intake restriction. However, Lovatto et al. (2006) and Kamalakar et al. (2009) found no, or only partial, compensatory growth following nutritional challenges.

The different results reported across these studies may be due to the nutritional and environmental conditions imposed on the animals during the restriction and realimentation periods, as well as to varying pig types and stage of growth.

1.2.2. Compensatory growth: mechanism of action

The underlying mechanisms involved with the compensatory growth phenomenon are not well understood. Even in cases where complete compensatory growth is achieved, there are conflicting opinions in regards to how, and in which tissues, compensatory gain occurs. Nutrient intake restriction may be induced by restricting total feed intake (Lovatto et al. 2006; Heyer and Lebret, 2007), constraining protein or amino acid intake (Zimmerman and Khajarern, 1973; Fabian et al., 2002; Martinez-Ramirez et al., 2008; Kamalakar et al., 2009) or by reducing diet complexity (i.e. protein complexity; Whang et al. 2000; Wolter et al. 2003). In all cases, the overall goal is to invoke a period of restricted nutrient intake in order to reduce pig growth performance. This is followed by a realimentation period designed to provide the nutrients needed in order to sustain a compensatory growth response.

Compensatory growth responses following total feed intake restriction may be due to increases in organ weight and body lipid deposition rather than improved lean tissue gain (Lovatto et al., 2006; Heyer and Lebret, 2007; Chaosap et al., 2011). Chaosap et al. (2011) indicated that while pigs experiencing previous feed intake restrictions did exhibit compensatory growth during realimentation, these gains were due to an increase in the weight of visceral organs rather than valuable muscle tissue. Heyer and Lebret (2007) also concluded that compensatory growth was due to an increase in the weight of visceral organs as well as an increase in body lipid deposition with no compensatory growth response in lean tissue. It was further noted that increased body lipid deposition was related to an increase in subcutaneous fat deposition rather than intramuscular fat deposition.

When growth has been restricted by reductions in protein or amino acid intake, the increased gains associated with compensatory growth may be due to an increase in body protein gain, closely related to muscle or lean tissue gain (Zimmerman and Khajarern, 1973; Whang et al., 2003; Therkildsen et al., 2004; Martinez-Ramirez et al., 2008). Protein intake restriction, as a result of either amino acid intake restriction or feeding low complexity diets, may cause an increase in the ratio of body lipid to body protein in pigs during the restriction period. As a consequence, when pigs gain access to adequate nutrient levels during realimentation, a greater proportion of lean tissue may be deposited in order to satisfy a genetically predetermined ratio between body protein and body lipid content (Martinez-Ramirez et al., 2008). This is further supported by an improvement in feed efficiency witnessed during realimentation in pigs following a protein intake restriction (Mitchell, 2009). Animals that are fed restrictively early on and then adequately during the finishing period may experience increased muscle growth as a result of increased satellite cell proliferation and increased protein synthesis (Oksbjerg et al., 2002). Furthermore, increased efficiency of protein utilization may occur as a result of decreased protein turnover during feed restriction followed by an increase in protein turnover during realimentation (Therkildsen et al. 2004).

Reducing pig performance by restricting feed intake appears more likely to affect tissues that are more sensitive to energy intake, such as adipose tissue, while instituting protein intake restrictions seems to have a greater influence on lean tissue development. Furthermore, Martinez-Ramirez et al. (2008) suggests that compensatory growth is most likely to occur when pigs are in the energy-dependent phase of growth, i.e. when energy intake, rather than the pig's potential for body protein deposition, determines the rate and composition of body weight gain.

The compensatory growth phenomenon implies that there is no long-term negative effect of previous growth reductions on a pig's ability to express lifetime growth performance that is similar to pigs that have not experienced reductions in growth performance. This is likely the case when only mild feed or nutrient intake restrictions are imposed. However, when feed intake or nutrient intake is severely restricted, or if pigs are subject to a poor environment or disease conditions, the animal's physiology may be altered permanently and compensatory growth may not occur (Kamalakar et al., 2009). Severe nutrient intake restriction or feeding inexpensive proteins to young pigs may induce responses that are similar to those witnessed when young pigs are exposed to disease; in these cases, compensatory growth is unlikely to occur (Nelssen et al., 1999). It is important to be able to estimate the likelihood of a successful compensatory growth response if pigs are subject to poor conditions. Within this context, the effect of factors that restrict growth, such as simple nursery diets or disease, on a pig's ability to handle environmental stresses should be considered.

1.2.3. Effects of compensatory growth on meat quality

Altering feeding strategies in an attempt to restrict the nutrient intake of pigs and, in turn initiate a period of compensatory growth, can positively influence meat quality (Lebret, 2008; Skiba, 2010). Restricted nutrient intake reduces growth rates initially but, during compensatory growth, the dynamics of body weight gain may be altered in a manner that improves meat tenderness as a result of increased in-vivo muscle protein turnover (Lebret, 2008). The increased rate of muscle protein synthesis and degradation that occurs during compensatory growth may increase the activity of m-calpain, and thus proteolytic potential, in muscle tissue. Consequently, this may result in increased meat tenderness and better overall eating quality (Kristensen et al., 2004). Lebret (2008) also suggests that decreasing the protein-to-energy ratio in the diet will increase intramuscular fat deposition and improve pork eating quality.

Feeding strategies that initiate compensatory growth responses through restricted protein intake or decreased diet complexity may reduce production costs and induce alterations in growth mechanisms that improve meat quality and the efficiency of protein deposition.

1.3. Biomarkers of pig growth performance

As mentioned earlier, it may be possible to restrict a pig's nutrient intake so severely that an animal's ability to exhibit compensatory growth is limited. The identification of biological markers (**bio-markers**) of animal performance (i.e. plasma cytokines or growth-related hormones) may provide a way to predict the effect of external stressors, such as nutrient restriction, on pig performance during the restriction and subsequent re-alimentation phase.

1.3.1. Cytokines

There are a number of stressors imposed on piglets at weaning and these are associated with a number of changes in growth and hormone responses (Colson et al., 2006; Niekamp et al., 2007). The stress associated with weaning may result in increased immune system stimulation and this may adversely affect growth performance by reducing feed intake or altering nutrient intake partitioning (Dritz et al., 1996b). The use of simple nursery diets with decreased levels of expensive animal protein ingredients may enhance this negative effect. Piglets that are fed simple nursery diets may be further stressed and, thus, more susceptible to the stressors associated with weaning.

Interleukins are cytokines that function as part of the immune system and also have the ability to influence tissue growth. Interleukin-1 (**IL-1**) and interleukin-6 (**IL-6**) are pro-inflammatory cytokines that are specifically involved in the catabolism of skeletal muscle tissue.

These hormones may also divert nutrients from anabolic pathways in an effort to support the immune system during an immune challenge (Dionissopoulos et al., 2006). Interleukin-1 increases the uptake of amino acids in the liver and alters hepatic protein synthesis by stimulating the production of acute phase proteins (Johnson, 1997). Interleukin-6 is responsible for stimulating the production of certain acute phase proteins, increasing T-cell proliferation and promoting the synthesis of B-cells in conjunction with IL-1 (Schindler et al., 1990). Furthermore, IL-6 can modulate the metabolism of fat, protein and carbohydrate substrates, regulate hypothalamic-pituitary hormone production and act in the brain to initiate a decrease in feed intake (Johnson, 1997). The actions of IL-1 and IL-6 are carried out in an effort to mitigate the health problems that can arise as a result of exposure to disease causing organisms. However, the resulting diversion of nutrients to the immune system has a negative effect on growth performance (Dionissopoulos et al., 2006).

Tumor necrosis factor alpha (**TNF-α**) is another pro-inflammatory cytokine that can influence animal metabolism and behaviour as well as adipose tissue growth by inhibiting lipoprotein lipase, stimulating hormone-sensitive lipase and by decreasing the stimulatory effect of insulin on glucose uptake (Coppack, 2001). Metabolic changes induced by TNF-α may be initiated by IL-1 and can decrease growth performance (Bluthé et al. 2006).

The actions of these pro-inflammatory cytokines are linked and they are responsible for instigating a cascade of responses that result in the clinical signs of an immune response and inflammation (Elsasser et al., 2008). Following a challenge to the immune system, all three of these hormones have been shown to stimulate the hypothalamic-pituitary-adrenal axis and, in doing so, initiate a number of endocrine responses that can cause increased proteolysis (Webel et al., 1997). Interleukin-1, IL-6 and TNF-α are released at the beginning of an immune response and, although the level of these hormones in the blood may not stay elevated long term, the cascade of reactions associated with them can continue to cause reductions in growth performance for a substantial period of time (Elsasser et al., 2008).

Certain feeding strategies may be implemented to mitigate the effect of increased immune system stimulation and cytokine activity in young piglets. However, these methods may only be successful if used in conjunction with complex nursery rations (Gaines et al., 2003). The link between diet complexity and the effect of cytokine responses on growth performance is not well understood.

1.3.2. Metabolic hormones

Dietary restrictions, whether imposed through feed intake restriction or altering diet nutritive content, may change endocrine status. This may impact growth responses as growth is under endocrine control (Wiecek et al., 2011). Dietary protein or energy restrictions have been shown to reduce circulating levels of triiodothyronine (**T_3**) and insulin-like growth factor 1 (**IGF-1**) and this has a negative effect on cell growth and proliferation (Martinez-Ramirez et al., 2009). Conversely, during realimentation, IGF-1 levels can increase drastically and this may be associated with increases in body weight gain and lean tissue growth (Martinez-Ramirez et al., 2009). The majority of studies examining the relationship between dietary restrictions and metabolic hormones have done so through feed intake restriction, reducing crude protein intake, or restricting the intake of specific amino acids. The effect of reduced nursery diet complexity on metabolic hormones is not well understood.

Insulin-like growth factor 1 is a hormone involved in the metabolic regulation of animal growth. The plasma level of IGF-1 appears to be positively related to pig growth rate

(Lamberson et al. 1995). The positive relationship between IGF-1 and growth performance is most noticeable during the energy intake-dependent phase of growth and the plasma level of IGF-1 in the blood is directly linked to feed intake, feed efficiency and lean growth rate (Owens et al. 1999). The heritability of plasma IGF-1 levels is low and the plasma level of IGF-1 in young growing pigs appears to be significantly influenced by environmental conditions, including nutrient intake (Suzuki et al., 2004). The use of IGF-1 as a consistent physiological predictor may be limited as the influence of environmental conditions can result in variable plasma levels. However, Sangel and Roxas (2011) indicated that circulating IGF-1 levels were positively correlated to average daily gains and lean tissue growth. Therefore, it is reasonable to hypothesize that plasma levels of IGF-1 present in growing pigs are closely associated with the proportion of body weight gain that is attributed to lean tissue accretion.

Cortisol is a steroid hormone that is released in response to stress (Spurlock et al., 1997). It works to regulate animal immune function so that the immune system does not overreact to a stressor, such as nutrient intake restriction. Cortisol also plays a role in fat, protein and carbohydrate metabolism. Interleukin-1 may stimulate the release of corticotropin-releasing hormone, which in turn initiates the secretion of cortisol (Webel et al., 1997). The plasma level of cortisol in an animal increases shortly after an immunological stress occurs and this is followed by an increase in body protein degradation. It has been suggested that the subsequent proteolysis that occurs is carried out to provide fuel for the production of hepatic acute phase proteins, which may increase by as much as 25% following an infection or tissue damage (Webel et al., 1997).

Stresses that occur at weaning, such as removal from the sow, the effect of mixing and an abrupt change in diet form from sow’s milk to solid feed have been shown to initiate an increase in plasma cortisol levels and this is often associated with a decrease in piglet growth rate (Merlot et al., 2004). It is important to understand the significance of this relationship in order to determine whether or not post-weaning stressors, such as nutrient restrictions, that increase the release of cortisol are responsible for hindering the long-term growth performance of a growing pig.

Leptin is recognized as a key regulator of an animal's energy balance. It is an appetite-suppressing hormone that specifically regulates caloric intake and energy expenditure (Jacobi et al., 2006). Leptin is produced by adipocytes that are directly involved in the animal's innate immune response (Jacobi et al., 2006). Furthermore, leptin can act to inhibit lipogenesis and suppress the inhibition of lipolysis by altering responses to various hormones, such as insulin (Hausman et al., 2009).

Leptin production in an animal is positively correlated to body lipid content; this relationship is used to monitor body lipid content by regulating animal appetite (Kojima et al., 2007). As such, it may be possible to use an animal's plasma level of leptin as an indicator of the composition of body growth, specifically body lipid tissue accretion.

Triiodothyronine and thyroxine (**T_4**) are hormones that are involved in controlling the rate of metabolic processes and both can influence animal tissue growth (Carroll et al., 1998). These thyroid hormones are vital for the normal growth and development of mammals and cases of deficiency of these hormones can result in diminished growth capabilities (Hocquette et al., 1998). Triiodothyronine and T_4 are stimulators of IGF-1 production and, while growth hormone (**GH**) is the primary stimulator of IGF-1 synthesis, the role of thyroid hormones in this task becomes increasingly important during times of decreased nutritional intake (Buonomo and Baile, 1991). Nutrient intake restriction causes an increase in the level of plasma GH and a reduction in the circulating amount of thyroid hormones. Although the level of T_3 drops more quickly than that of T_4, the level of both hormones in the blood is significantly reduced 48 hours after nutrient intake restriction occurs. This decrease is followed by a return to normal levels of thyroid hormones in the blood once the energy balance is restored (Swenne et al., 2009). Furthermore, periods of nutrient intake restriction may increase resistance to GH in IGF-1 production pathways, indicating that these thyroid hormones become more important to the production IGF-1, and consequently lean tissue gain, during a nutritional challenge (Buonomo and Baile et al., 1991). As such, it is possible that they may be used as indicators of nutritional status.

Thyroid hormone status and incidences of hypothyroidism are influenced by feed intake as well as the composition of the diet (Harrison et al., 1996). Hypothyroidism is marked by decreased activity of the thyroid gland and mild hypothyroidism, which may occur as a result of nutrient restrictions, can cause the down-regulation of the sodium/potassium ATPase pump and the calcium ATPase pump. These changes may result in altered muscle tissue development. Therefore, it is important to understand how the plasma levels of T_3 and T_4 are related, not only to growth, but to lean tissue development as well.

1.4. Summary

As detailed above, there have been a number of studies that examined compensatory growth in pigs following nutrient intake-induced challenges. Dietary challenges may be imposed by restricting feed intake, constraining the intake of crude protein or specific amino acids or by altering the complexity of swine diets. However, results observed by researchers vary across studies. Numerous studies have shown that pigs can achieve compensatory growth following total feed or protein and amino acid intake restriction but there are few studies that have examined compensatory growth following nutrient intake restrictions that are imposed by reductions in nursery diet complexity.

Substituting lower cost protein sources for expensive, highly digestible protein sources in nursery diets may reduce feed costs and impose a period of growth reduction in newly-weaned pigs. If this period of reduced growth performance is followed by an adequate realimentation phase then compensatory growth may occur. In order to better understand when, and to what extent compensatory growth occurs following a period of reduced growth, the underlying physiological control of growth needs to be explored. If biological markers that can be used as predictors of growth are identified, it could improve understanding of the underlying mechanisms associated with compensatory growth. In doing so, it may improve the possibility of identifying methods that will allow for the production of market hogs with lower feed costs and increase the profitability of pork producers.

2.0. Research hypothesis and objectives:

The hypothesis for the research reported in this thesis is that growing pigs will be able to exhibit compensatory growth following a period of reduced growth performance induced by feeding simple nursery diets. The main objective of the experiment was to assess the effect of diet complexity and the use of in-feed antibiotics during the nursery period on growth performance in the nursery and subsequent performance up to market weight (approximately 115 kg BW). A second objective of this experiment was to evaluate the effect of nursery feeding programs on the plasma levels of growth-related hormones in an effort to identify various hormones that may be used as predictors of potential pig growth performance. A third objective was to examine the effect of nursery feeding programs on carcass quality, changes in chemical body composition and meat quality.

3.0. Effect of nursery feeding program on subsequent growth performance and carcass quality in growing pigs

3.1. Abstract

An experiment was conducted to examine the effect of nursery feeding programs on growth performance and carcass quality in growing pigs. Four dietary treatments were used in a 2 × 2 factorial design based on diet complexity (complex vs. simple) and in-feed antibiotics (600 [+AB] vs. 0 [-AB] ppm chlortetracycline). A total of 552 pigs, in 5 blocks, were weaned at approximately 3 wk of age with an initial BW of 7.03 ± 0.07 kg. Nursery diets were used in a 3-phase feeding program (Phase I, II, and III fed for 7, 14, and 21 d, respectively). All pigs were fed common grower-finisher (G-F) diets thereafter. Pigs had free access to feed and water. There were 3 pens per treatment per block; blocks 1 and 2 had 8 pigs per pen while blocks 3 to 5 had 10 pigs per pen with the additional animals being removed for serial tissue sampling. At approximately 115 kg BW, pigs were slaughtered and carcasses evaluated according to the Canadian grading system. During the nursery period, ADG was lower ($P < 0.05$) for pigs fed simple nursery diets than for pigs fed complex nursery diets (491 vs. 528 g/d for simple vs. complex, respectively). The use of in-feed antibiotics improved ($P < 0.05$) ADG in Phase II (408 vs. 438 g/d for –AB and +AB, respectively) and III (689 vs. 720 g/d for -AB and +AB, respectively). In Phase I and II, G:F was lower ($P < 0.05$) for pigs fed simple nursery diets than pigs fed complex nursery diets (0.46 vs. 0.58 g/g and 0.75 vs. 0.78 g/g for simple vs. complex in phase I and II, respectively). During the grower phase, pigs fed nursery diets excluding antibiotics grew faster than pigs fed nursery diets that included antibiotics ($P < 0.05$; 1,009 vs. 971 g/d for -AB and +AB, respectively). There were no treatment effects on overall ADG or G:F between weaning and market BW (approximately 115 kg BW). At slaughter, there were no treatment effects on loin eye area, fat depth, estimated carcass lean yield or days from weaning to market BW. These results indicate that feeding simple nursery diets or nursery diets that do not include antibiotics compromises growth performance during the nursery period but does not affect growth performance between weaning and market BW or carcass value. Furthermore, the use of nursery diets that do not include antibiotics induces compensatory growth following a period of reduced growth. Feed costs for nursery pigs can be reduced by feeding simple diets without compromising lifetime growth performance up to market weight or carcass value. Further research is required to evaluate the cost-benefit of feeding simple nursery diets under varying conditions that better represent commercial pork production practices and the effect this has on the pig's ability to deal with environmental stressors.

Key words: compensatory growth, diet complexity, growth performance, nursery, pigs

3.2. Introduction

Feed costs represent the largest proportion of total costs in commercial pork production. It is important to identify opportunities to reduce feed costs without compromising long-term animal productivity. The cost of swine diets is highest during the nursery phase of production. This is because of increased diet complexity that is due to increased use of highly digestible feed ingredients and feed additives that help young pigs transition from sow's milk to solid diets (Mahan and Lepine, 1991). While it is commonly accepted that the lifetime performance of growing pigs is positively related to performance during the nursery period, there is evidence that reducing diet complexity in the nursery may reduce post-weaning performance without compromising long-term growth performance or carcass quality (Whang et al., 2000; Wolter et al., 2003).

Reducing the complexity or amino acid content of nursery diets may reduce lean tissue gain and increase the body lipid:protein ratio of a growing pig, which in turn may alter growth patterns during the subsequent realimentation period (Skiba, 2005). During realimentation, pigs that previously experienced reduced growth performance may have better feed conversion ratios than pigs that did not have reduced growth and may deposit greater levels of protein as opposed to lipid in adipose tissue (Whang et al., 2003; Skiba, 2005; Martinez-Ramirez et al., 2008). As a further consideration, the growth response of nursery pigs to diet complexity is likely to be influenced by the use of in-feed antibiotics (de Lange et al., 2010)

An experiment was conducted to test the hypothesis that feeding less complex nursery diets would decrease post-weaning growth performance and induce a subsequent compensatory growth response with no effect of nursery feeding program on growth rates from weaning to market weight (approximately 115 kg BW) or carcass value. The objective of this study was to assess the effect of nursery diet complexity, with or without in-feed antibiotics, on growth performance up to market weight and carcass quality.

3.3. Materials and methods

3.3.1. Animals, housing, diet and experimental design

Five hundred and fifty-two Yorkshire barrows and gilts (248 and 304 barrows and gilts, respectively) were weaned at approximately 3 wk of age (7.03 ± 0.07 kg BW) in 5 blocks at the Arkell Swine Research Station (University of Guelph, Guelph, ON, Canada). The experimental protocol was approved by the University of Guelph Animal Care Committee (AUP # 09RO43). At weaning, pigs were sorted into randomized complete blocks and were housed in an environmentally controlled (26°C at weaning to 22°C at 6 wk post-weaning) nursery. Nursery pens measured 296 cm × 107 cm and contained fully slatted, tenderfoot floors. Nursery feeders were stainless steel trough ad-libitum feeders with 8 feeding spaces per pen. Water was provided via two nipple drinkers per pen. Pigs were housed in the nursery for 6 wks post-weaning at which point they were moved to environmentally controlled (22°C) grower-finisher (**G-F**) rooms. Pens in the G-F rooms had partially slatted concrete floors and were 424 cm × 197 cm. Grower-finisher feeders were stainless steel trough ad-libitum feeders with 3 feeding spaces per pen. In each pen, water was provided in a single bowl drinker.

At weaning, pigs were assigned to 1 of 4 dietary treatments in a 2 × 2 factorial design based on diet complexity (complex vs. simple) and in-feed antibiotic usage (600 [**+AB**] vs. 0 [**-AB**] ppm chlortetracycline [Aureomycin 220 G ®, Alpharma, Mississauga, ON, Canada]; Table 1). It is important to note that the current study only examined the use of chlortetracycline at one dosage level. Moreover, the inclusion rate was at a level that is considered a therapeutic dosage and the observed responses may have varied if other antibiotics or other dosage levels were used. Due to variable numbers of barrows and gilts available at the time of weaning, the number of barrows and gilts weaned were not equal but were split as evenly as possible across treatments (77 gilts and 61 barrows; 75 gilts and 63 barrows; 76 gilts and 62 barrows; 75 gilts and 63 barrows for treatments complex –AB, complex +AB, simple –AB and simple +AB, respectively). Nursery diets were provided in a 3-phase feeding program with Phase I, II, and III diets being fed for 7, 14, and 21 d, respectively (Table 3.1). The complex diets contained typical levels of highly digestible, complex animal protein sources (i.e. whey, fishmeal, spray-dried blood meal, and blood plasma), acidifiers, feed flavouring as well as more easily digestible cereal grains. Simple diets contained primarily corn and soybean meal with whey and fishmeal being included in Phase I diets only. Within each phase, calculated nutrient levels were similar for the complex and simple diets, with the exception of amino acid levels in Phase I (Table 3.1). Calculated amino acid levels were lower in the Phase I simple diet than those in the Phase I complex diet. During the G-F phase, pigs were fed common, non-limiting corn and soybean meal based diets in a two-phase feeding program (Table 3.1). Nursery diets were fed as a crumble while G-F diets were pelleted; pigs had free access to feed and water throughout the experiment.

Each experimental block had 3 pens per treatment with 8 pigs per pen in blocks 1 and 2 and 10 pigs per pen in the remaining 3 blocks. In blocks 3 to 5, 2 pigs per treatment per block were euthanized at wk 2, 4, 8, or 12 for body composition and gene expression analysis. The data from euthanized pigs are not presented here. At approximately 115 kg BW, 6 pigs per treatment in blocks 3 to 5 were slaughtered at an abattoir in the meat wing of the Animal and Poultry Science Building of the University of Guelph. Carcasses were used for chemical body composition analysis, carcass dissection, and meat quality analysis. Upon reaching 115 kg BW, all remaining pigs were processed at a commercial slaughter facility.

3.3.2. Experimental observations

Pigs were weighed individually each wk in the nursery period and every other wk in the G-F period. When pigs approached market weight, BW measurements were once again taken weekly. Average daily feed intake (**ADFI**) was calculated on the basis of per pen feed usage; ADFI measurements were taken when pigs were weighed.

Animal growth performance was measured until BW of individual pigs reached 110 kg. At this time, pigs were shipped to a processing plant and carcasses were evaluated according to the Canadian grading system (Anonymous, 1986). Growth performance is reported from weaning until wk 17 post-weaning, which was chosen as the end point for evaluating growth performance. At wk 17 post-weaning, approximately 25% of pigs were shipped for slaughter and subsequent growth performance was strongly influenced by altered pen group dynamics.

3.3.3. Calculations and statistical analysis

Growth performance measurements were calculated for each of the 3 phases during the nursery period, the grower and finisher periods, as well as the entire period from weaning until wk 17 post-weaning (**wean-to-finish**). Data were analyzed statistically as a randomized block design with repeated measures in the MIXED procedure of SAS (V 9.2 SAS Inst. Inc., Cary, NC, USA) with pen as the experimental unit. Nursery diet complexity and the use of in-feed antibiotics were considered main effects with block being regarded as a random effect. Initial BW was used as a covariant when growth performance was evaluated. Differences were determined for the least squares mean values using orthogonal contrasts at various stages of growth. Given the large number of comparisons as well as the absence of clear interactions of main effects (nursery diet complexity and the use of in-feed antibiotics) on response variables, it was deemed inappropriate to statistically analyze differences between individual treatment means within time periods. However, when interactions between the main effects were present, numerical differences between the treatment means were discussed.

Carcass quality measurements were analyzed using the MIXED procedure in SAS with pig as the experimental unit. Nursery diet complexity and the use of in-feed antibiotics were considered the main effects while date of slaughter and block were regarded as random effects. Hot carcass weight was used as a covariant for carcass quality analysis. The Tukey-Kramer adjustment was used to assess differences among treatment means. In all cases, means were considered to be significantly different at $P < 0.05$, while $0.05 < P < 0.10$ was considered to indicate a trend.

To assess the extent of compensatory gains, the compensatory growth index (**CG%**) was calculated based on treatment BW means as defined by Wiecek et al. (2011): CG% = 100 × (A-B)/A, where A is defined as the difference in BW between restricted and non-restricted animals following the period of reduced growth (i.e., at wk 6 post-weaning) and B is the difference in BW between these same groups at the end of realimentation (i.e., at wk 17 post-weaning). Compensatory growth is deemed to occur when this CG% is greater than 50% (Wiecek et al., 2011).

3.4. Results

3.4.1 General observations

The analyzed nutrient contents of the experimental diets were reasonably consistent with anticipated values (Table 2). In the current study, the physical appearance of pigs in the nursery was affected by feeding program; animals fed simple diets were more likely to have loose stool and appear poor-doing (e.g., rough hair coat and gaunt) during the first 3 wks post-weaning.

A disease challenge (i.e. a farm-wide epidemic of *Streptococcus suis* infection in the nursery period and *Erysipelothrix rhusiopathiae* infection [swine erysipelas] during the G-F period) caused elevated mortality levels in all blocks. However, the disease challenge was most extreme in the 5th experimental block. Statistical analysis indicated no treatment effects on mortality rate. Mortality in block 5 was 21% of total pigs weaned compared to 11% of total pigs weaned in blocks 1 to 4. While statistical analysis indicated no interactive effect of block and treatments on response variables, the growth response to treatments differed in block 5 and this was likely due to the disease challenge. This will be further discussed in section 3.4.5.

3.4.2. Growth performance during the nursery period

Pigs fed simple diets had decreased ($P < 0.01$) BW and average daily gain (**ADG**) in all phases of the nursery period (Table 3). Feeding simple nursery diets decreased ADG by 30%, 7.4%, and 5.7% as compared to complex diets during Phase I, II, and III, respectively. Including in-feed antibiotics in nursery diets increased ($P < 0.05$) BW and ADG during Phase II and III but had no effect on ADFI or feed efficiency (**G:F**) during the nursery period. Feeding simple nursery diets reduced ($P < 0.05$) G:F during Phase I and II and ADFI in Phase III. There was no difference in G:F between pigs fed simple or complex nursery diets in Phase III. During the nursery period, there were no interactive effects of diet complexity and the use of in-feed antibiotics on growth performance, except for ADG during Phase I. During Phase I, the use of in-feed antibiotics tended to numerically increase ($P = 0.09$) ADG when included in complex nursery diets, while such a response was not observed when antibiotics were included in simple nursery diets.

3.4.3. Growth performance during the grower-finisher period

There was no effect of nursery diet complexity or feeding antibiotics on BW or G:F during the grower or finisher phases (Table 3) nor did nursery diet complexity have an effect on ADG or ADFI. However, the inclusion of in-feed antibiotics in nursery diets decreased ($P = 0.02$) ADG in the grower period and reduced ($P = 0.03$) ADFI in the finisher period. During the

G-F period there were no interactive effects of nursery diet complexity and use of in-feed antibiotics on growth performance.

3.4.4. Wean-to-finish growth performance, carcass quality and the compensatory growth index

There was no effect of nursery feeding programs on final BW or wean-to-finish ADG, ADFI, or G:F (Table 3). Furthermore, dietary treatment had no effect on carcass quality characteristics, with the exception of loin muscle depth, or days from weaning to slaughter (Table 4). Feeding simple nursery diets tended to be associated with decreased (P = 0.07) depth of the loin muscle.

Pigs fed complex nursery diets that included antibiotics had superior nursery growth performance to that of pigs in the other treatment groups. Therefore, in order to assess the extent of compensatory growth between wk 6 and wk 17 after weaning, CG% was calculated for each of the other three dietary treatments relative to the pigs that were fed complex nursery +AB. Based on treatment mean levels of performance, CG% was 213%, 135% and 12% for complex –AB, simple –AB and simple +AB, respectively.

3.4.5. Growth performance in block 5

As mentioned earlier, pigs in block 5 were severely challenged by disease and the response to dietary treatment was numerically different for this group of pigs as compared to the responses observed when data were combined across all blocks. Based on statistical analyses of results obtained in block 5 only, overall wean-to-finish ADG was decreased (P = 0.04) when pigs were fed simple nursery diets (829 g/d vs. 876 g/d for pigs fed simple and complex diets, respectively) and overall wean-to-finish G:F was lower (P < 0.01) for pigs fed simple nursery diets (0.48 g/g vs. 0.50 g/g for pigs fed simple and complex diets, respectively). In block 5, CG% was 98%, 43% and – 48% for pigs that were fed complex –AB, simple –AB and simple +AB, respectively when compared to pigs fed complex +AB.

3.5. Discussion

There are few studies that evaluate the effect of diet complexity and the use of in-feed antibiotics during the nursery period on lifetime pig growth performance and carcass quality at slaughter. As such, the objective of this study was to assess the effect of feeding simple nursery diets, with or without in-feed antibiotics, on nursery growth performance and subsequent G-F performance and carcass quality.

Feeding simple diets to newly weaned pigs decreased growth performance during the nursery period and this is in accordance with a number of studies that have shown improved nursery performance when expensive animal protein sources, such as blood plasma and whey, are included in nursery diets (Dritz et al., 1996; Mavromichalis et al., 2001; Sulabo et al., 2010). Furthermore, the inclusion of antibiotics in nursery diets improved nursery ADG during Phase II and III. This is consistent with the findings of other studies (Coffey and Cromwell, 1995; Dritz et al, 2002; Ragland et al., 2008).

Weaning is associated with a number of stressors that cause alterations in piglet growth performance, hormonal responses and behaviour (Colson et al., 2006; Niekamp et al., 2007). The decrease in nursery growth performance observed in pigs fed simple nursery diets may indicate that simple diets provide an insufficient amount of available nutrients or that they hinder the ability of a piglet to cope with the various stressors present at weaning (de Lange et al., 2010). The latter is further supported by the observed positive effect of in-feed antibiotic inclusion on nursery growth performance as well as the poorer physical appearance of nursery pigs fed simple diets as compared to pigs fed complex diets. Compromised performance of nursery pigs fed simple diets may be due, in part, to an allergic reaction that occurs in young piglets fed high dietary levels of soybean meal (Li et al., 1991; Chen et al., 2011). The elevated levels of soybean meal in the simple nursery diets may have initiated an immune response that altered the physical condition of pigs and reduced their growth capacity.

Compensatory growth is defined as a period of increased weight gain that follows a period of reduced growth, whereby the rate of body weight gain of previously compromised animals is higher than that of animals that have not experienced periods of reduced growth (e.g., Skiba, 2005; Wiecek et al., 2011). The compensatory growth index can be used to identify whether or not compensatory growth is achieved; if CG% exceeds 50% then compensatory growth is deemed to have occurred (Wiecek et al., 2011). According to calculated CG%, when all other treatments are compared to the group with superior nursery performance (pigs fed complex diets containing antibiotics), compensatory growth was achieved in pigs fed complex and simple nursery diets without antibiotics but was not achieved in pigs that were fed simple nursery diets that included antibiotics. Therefore, while the inclusion of in-feed antibiotics in nursery diets improved growth performance in the nursery, based on the CG%, compensatory growth was achieved by pigs that were fed nursery diets that excluded antibiotics. Furthermore, pigs fed simple nursery diets exhibited compensatory growth when in-feed antibiotics were excluded but not when in-feed antibiotics were included. When compared to pigs fed complex nursery diets, the performance of pigs fed simple nursery diets wean-to-finish growth performance was similar, indicating no negative carry-over effect of feeding simple nursery diets during the nursery phase. It is important to note that the reference group chosen for CG%

calculations (complex, +AB) had the slowest rate of gain during the G-F period. As such, the use of CG% values to identify compensatory growth incidences may have led to overestimating the overall extent of compensatory growth.

The occurrence of compensatory growth in pigs fed nursery diets that did not include antibiotics, along with the lack of dietary treatment effect on ADG, ADFI, or G:F during the entire wean-to-finish period is consistent with other studies showing that, following a period of reduced growth, pigs that are provided access to adequate nutrient levels are able to compensate for previous reductions in growth performance (Zimmerman and Khajarern, 1973; Whang et al., 2000; Fabian et al., 2002; Wolter et al., 2003). In the current study, use of antibiotics in nursery diets appeared to negatively affect subsequent performance in the G-F period. To our knowledge, there are no other studies that have shown a negative relationship between antibiotic inclusion in nursery diets and subsequent growth performance. It may be that the inclusion of antibiotics in nursery diets created a lesser degree of immune system development in these pigs and, as such, the growth performance of these pigs was more extensively affected by the disease challenges present in the G-F period. However, the current study only examined the use of chlortetracycline at one therapeutic level and the observed responses may have varied if other antibiotics or other dosage levels were used. As such, this effect must be further explored.

According to calculated CG% values for block 5, compensatory growth was achieved early in the G-F period in pigs fed complex nursery diets that excluded antibiotics. However, no compensatory gains occurred in pigs fed simple nursery diets regardless of antibiotic inclusion rate. This is consistent with the growth performance results from the 5th block, which indicated a negative effect of feeding simple diets on wean-to-finish growth performance. It appears that, in the event of a severe health challenge, the use of simple nursery diets may compromise the pig's ability to achieve compensatory growth and recuperate from earlier reductions in performance. In future studies, the effect of nursery feeding programs on the pig's ability to deal with health challenges deserves to be explored further.

To illustrate the effect of the alternative feeding strategies on feed costs, the following feed ingredient costs ($/tonne) were used: corn, $231; soybean meal, $412; wheat, $259; barley, $292; whey, $1,700; herring meal, $2,115; blood plasma. $5,500; blood meal, $1,040; oat groats, $500; L-lysine·HCl, $2,600; DL-methionine, $4,500; L-threonine, $2,700; L-tryptophan, $27,000; limestone, $77; salt, $140; monocalcium phosphate, $730; calcium formate, $1,400; calcium propionate, $2,150; saccharine, $10,000; vitamin/mineral premix, $2,000; and Aureomycin 220 G, $6,400. Based on observed feed efficiencies, feed ingredient costs per pig from wean-to-finish were estimated to be highest ($91.69) for pigs fed the complex +AB; per pig feed costs were $0.78, $5.50 and $10.34 lower for pigs fed complex –AB, simple diets –AB and simple +AB, respectively. Given the observed mean responses during the nursery and G-F periods across blocks 1 to 5, these feed cost estimates indicate the large potential financial impact of considering alternative feeding programs during the nursery period. Even when no compensatory growth was observed (e.g. feeding simple diets that included an antibiotic), a reduction in feeding costs over the entire wean-to-finish period was observed when compared to feeding complex nursery with antibiotics.

3.6. Conclusions and implications

In the current study, the use of simple nursery diets decreased growth performance and adversely affected the physical appearance of pigs early post-weaning. Moreover, feeding simple nursery diets may have increased the pig's susceptibility to weaning-associated stressors and health challenges. However, there was no effect of nursery feeding programs on wean-to-finish growth performance or carcass quality at slaughter and feeding costs were reduced for pigs fed simple nursery diets. Moreover, reductions in nursery growth performance as a result of excluding in-feed antibiotics from nursery diets induced compensatory growth during the grower period.

Further research is required to evaluate the cost-benefit of feeding simple nursery diets under varying conditions that better represent commercial pork production practices and the effect this has on the pig's ability to deal with environmental stressors. In addition, further studies need to be completed to examine the effect of including antibiotics in nursery diets on subsequent growth performance.

Table 3.1. Ingredient composition and calculated nutrient content of experimental diets (as-fed basis) [1]

	Nursery							
	Complex			Simple				
Item	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Grower	Finisher
Ingredient, %								
Corn	18.9	38.7	50.2	47.1	49.6	47.3	45.8	58.1
Soybean meal, dehulled	10.8	15.0	21.0	24.0	34.0	37.0	28.2	16.2
Wheat				10.0	10.0	10.0	20.0	20.0
Barley	25.0	25.0	20.0					
Whey	20.0	8.00		8.00				
Fat, animal vegetable	2.50	2.50	2.50	2.50	2.50	2.50	2.00	2.00
Herring meal	5.00	3.00		5.00				
AP920 blood plasma[2]	4.50	2.00						
Blood meal, spray dried		2.00	2.00					
Oat groats	10.0							
L-Lys·HCl	0.30	0.25	0.35	0.16	0.25	0.05	0.23	0.23
L-Met	0.18	0.18	0.18	0.06	0.11		0.08	0.02
L-Thr	0.10	0.12	0.16	0.04	0.09		0.10	0.08
L-Trp	0.02	0.02	0.02					
Limestone	0.50	0.58	0.86	1.00	1.18	1.10	1.22	1.15
Salt		0.20	0.30	0.20	0.30	0.30	0.40	0.40
Monocalcium phosphate	0.80	1.00	1.35	1.30	1.40	1.20	1.42	1.22
Calcium formate	0.40	0.40	0.20					
Calcium propionate	0.40	0.40	0.20					
Saccharine	0.05	0.05	0.05					
Vitamin and mineral mix[3]	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Calculated composition[4]								
DE, MJ/kg	14.4	14.3	14.5	14.9	14.9	15.0	14.7	14.7
CP, %	20.5	19.8	18.7	21.1	21.8	22.7	19.8	15.1
Lys, %	1.51	1.39	1.29	1.37	1.39	1.30	1.23	0.80

SID Lys, %	1.35	1.25	1.17	1.21	1.25	1.17	1.10	0.80
SID Thr, %	0.85	0.79	0.73	0.75	0.78	0.74	0.73	0.54
SID Trp, %	0.25	0.23	0.21	0.23	0.24	0.26	0.23	0.17
SID Met + Cys, %	0.78	0.73	0.67	0.68	0.72	0.64	0.65	0.48
Ca, %	0.85	0.80	0.74	0.85	0.80	0.75	0.80	0.70
Available P, %	0.70	0.65	0.65	0.75	0.70	0.67	0.69	0.60
Na, %	0.37	0.26	0.15	0.20	0.14	0.14	0.18	0.18
Cl, %	0.55	0.43	0.34	0.37	0.29	0.24	0.36	0.36

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2]Manufactured by APC Nutrition Inc (Ames, IA, USA)

[3]Supplied per kg of diet: vitamin A, 12,000 IU as retinyl acetate; vitamin D_3, 1,200 I|U as cholecalciferol, vitamin E, 48 IU as D,L-α-tocopherol acetate; vitamin K, 3 mg as menadione; vitamin B_{12}, 0.03 mg; d-pantothenic acid, 18 mg; riboflavin, 6 mg; choline, 600 mg; folic acid, 2.4 mg; niacin, 30 mg; thiamine, 18 mg; pyridoxine, 1.8 mg; biotin, 200µg; Cu, 18 mg as $CuSO_4 \cdot 5H_2O$; Fe, 120 mg as $FeSO_4$; Mn, 24 mg as $MnSO_4$; Zn, 126 mg as ZnO; Se, 0.36 mg as $FeSeO_3$; I, 0.6 mg as KI (DSM Nutritional Products Canada Inc., Ayr, ON, Canada).

[4]Calculated based on NRC (1998) ingredient values.

Table 3.2. Analyzed nutrient content (%, as fed) of experimental diets

	Nursery													
	Complex						Simple							
	Phase I		Phase II		Phase III		Phase I		Phase II		Phase III			
Item	+AB	-AB	+AB	-AB	+AB	-AB	+AB	-AB	+AB	-AB	+AB	-AB	Grower	Finisher
Crude protein[1]	19.4	18.1	19.5	19.7	17.9	17.9	20.2	20.8	22.3	22.5	22.3	22.2	20.4	15.0
Lys	1.22	1.36	1.36	1.30	1.17	1.17	1.29	1.32	1.42	1.42	1.28	1.30	1.23	0.88
Met	0.37	0.47	0.47	0.45	0.42	0.41	0.46	0.42	0.43	0.42	0.33	0.33	0.37	0.24
Met + Cys	0.70	0.86	0.82	0.79	0.69	0.68	0.84	0.77	0.80	0.78	0.67	0.68	0.70	0.51
Thr	0.80	0.93	0.91	0.88	0.78	0.78	0.90	0.88	0.93	0.94	0.84	0.83	0.82	0.60
Trp	0.24	0.28	0.27	0.26	0.23	0.23	0.26	0.26	0.27	0.28	0.28	0.29	0.24	0.17
Ile	0.84	0.80	0.78	0.76	0.64	0.63	0.78	0.90	0.94	0.96	0.95	0.95	0.83	0.57
Leu	1.69	1.62	1.75	1.73	1.43	1.38	1.69	1.79	1.88	1.89	1.76	1.78	1.65	1.25
Ca	1.15	1.15	0.88	0.98	0.65	0.74	1.15	1.28	0.74	0.76	0.70	0.65	0.83	0.75
P	0.80	0.83	0.72	0.75	0.67	0.63	0.89	0.91	0.72	0.70	0.69	0.67	0.71	0.61

[1]Analyzed dietary N × 6.25.

Table 3.3. Effect of nursery diet complexity and in-feed antibiotics on pig growth performance[1]

	Treatment[2]					*P*-value[3]		
Item[4]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	AB	Diet	AB x Diet
BW, kg								
Day 0	6.95	6.99	7.07	7.09				
Day 7	7.70	7.92	7.59	7.58	0.08	0.20	0.01	0.14
Day 21	13.6	14.3	13.1	13.6	0.21	0.01	< 0.01	0.76
Day 42	28.8	29.8	27.2	29.0	0.39	< 0.01	< 0.01	0.32
Day 84	71.9	71.5	70.4	70.5	0.70	0.82	0.08	0.68
Day 119	110.9	109.7	110.6	109.0	0.86	0.10	0.56	0.81
ADG, g								
Phase I	99	129	81	78	10.4	0.16	< 0.01	0.09
Phase II	427	451	388	425	14.2	< 0.01	< 0.01	0.50
Phase III	717	733	661	706	23.8	0.03	< 0.01	0.28
Grower	1010	973	1007	969	28.9	0.02	0.82	0.99
Finisher	1170	1152	1188	1129	48.1	0.12	0.92	0.41
Wean-to-Finish	883	872	872	853	28.4	0.13	0.12	0.71
ADFI, g								
Phase I	184	206	175	165	65.7	0.91	0.64	0.76
Phase II	565	592	524	551	65.7	0.54	0.36	0.99
Phase III	1280	1314	1194	1215	49.0	0.25	< 0.01	0.80
Grower	2297	2237	2235	2232	70.0	0.48	0.45	0.52
Finisher	3361	3286	3390	3228	88.0	0.03	0.79	0.43
Wean-to-Finish	2103	2070	2068	2026	69.3	0.19	0.18	0.87
G:F								
Phase I	0.54	0.62	0.45	0.47	0.04	0.16	< 0.01	0.36
Phase II	0.79	0.78	0.74	0.76	0.02	0.40	0.01	0.26
Phase III	0.57	0.57	0.56	0.59	0.02	0.16	0.57	0.08
Grower	0.45	0.45	0.46	0.45	0.01	0.35	0.67	0.66
Finisher	0.35	0.35	0.35	0.36	0.01	0.56	0.36	0.92

Wean-to-Finish	0.42	0.43	0.43	0.43	0.01	0.12	0.15	0.97

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2]Probabilities of effects. AB: effect of in-feed antibiotic inclusion (-AB vs. +AB); Diet: effect of diet complexity (complex vs. simple); AB x Diet: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] Days represent the start and end of the 5 successive experimental periods (n = 15 pens per treatment).

Table 3.4. Effect of diet complexity and in-feed antibiotics on carcass quality characteristics

Item	Treatment[1]				Pooled SEM	P-value[2]		
	Complex -AB	Complex +AB	Simple -AB	Simple +AB		AB	Diet	AB x Diet
n[3]	58	45	50	54				
Final live BW, kg	110.9	109.7	110.6	109.0	0.86	0.10	0.56	0.81
Hot carcass weight, kg	95.5	95.5	95.3	95.2	0.74	0.96	0.68	0.95
Lean yield, %	60.0	60.2	60.3	60.2	0.30	0.79	0.48	0.63
Fat depth, mm	20.4	20.0	19.5	19.4	0.68	0.67	0.19	0.71
Muscle depth, mm	63.2	63.2	61.2	62.3	1.15	0.49	0.07	0.50
Time on trial, days	123.4	124.4	124.5	125.2	0.95	0.31	0.25	0.85

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2]Probabilities of effects. AB: effect of in-feed antibiotic inclusion (-AB vs. +AB); Diet: effect of diet complexity (complex vs. simple); AB x Diet: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] Number of observations (pigs) per treatment.

4.0. Effect of nursery feeding program on the levels of growth regulating hormones in blood plasma of growing pigs

4.1. Abstract

An experiment was conducted to examine the effect of nursery feeding programs on dynamic changes in plasma levels of growth-related hormones in pigs up to 110 kg BW and to identify potential bio-markers that may be used as predictors of pig growth performance. Four dietary treatments were used in a 2 × 2 factorial design based on diet complexity (complex vs. simple) and in-feed antibiotics (600 [+AB] vs. 0 [-AB] ppm chlortetracycline). A total of 552 pigs, in 5 blocks, were weaned at 3 wk of age with an initial BW of 7.03 ± 0.07 kg. Nursery diets were used in a 3-phase feeding program (Phase I, II, and III fed for 7, 14, and 21 d, respectively). All pigs were fed common grower-finisher (G-F) diets thereafter. Pigs had free access to feed and water. Six pigs per treatment in each of blocks 2 to 4 were bled at weaning and wk 2, 4, 6, 10, 14 and 17 post-weaning; 12 mL of blood were collected, processed and stored at – 20°C until analysis for IL-1β, IL-6, TNF-α, cortisol, leptin, IGF-1, T_3 and T_4 was completed. Analyzed plasma levels of IL-1β, IL-6, TNF-α, cortisol and leptin were highly variable and did not appear related to dietary treatments. Feeding -AB nursery diets decreased ($P < 0.01$) IGF-1 plasma levels at wk 4 post-weaning. Similarly, feeding simple nursery diets decreased ($P = 0.02$) T_3 plasma level at wk 4 while feeding an antibiotic during the nursery phase increased ($P < 0.01$) T_3 levels at wk 4. Nursery feeding program had no effect on IGF-1, T_3 or T_4 levels in pig blood plasma during the G-F period, with the exception of T_3 plasma levels at wk 10. There was an interaction ($P = 0.02$) between diet complexity and the use of in-feed antibiotics at wk 10 as the inclusion of antibiotics in complex nursery diets was associated with increased T_3 levels and decreased levels of T_3 when included in simple nursery diets. The level of IGF-1 in pig blood plasma at weaning was positively correlated ($P < 0.05$) to ADG in wk 2 and 6 and tended to be

positively correlated ($P < 0.10$) to ADG at wk 4 and 10. These results indicate that IGF-1 levels measured at weaning may be used as an indicator of future growth potential.

Key Words: nursery, diet complexity, antibiotics, hormone, bio-marker, pigs

4.2. Introduction

Complex animal protein sources and various additives are routinely included in diets designed for newly-weaned piglets to ease the transition from nursing on the sow to consuming dry feed (Dritz et al., 1996a,b; Mavromichalis et al., 2001; Sulabo et al., 2010). Removing these complex protein sources and additives from nursery diets reduces performance in the nursery but may initiate a subsequent compensatory growth response resulting in no overall effect on growth performance up to market weight or carcass quality (Whang et al., 2000; Wolter et al., 2003; Chaosap et al., 2011; Chapter 3).

Altering nursery feeding strategies may induce physiological changes in piglets post-weaning (Martinez-Ramirez et al., 2009; Shen et al., 2012). The influence of nutrition on growth-related hormones appears critical in the early post-weaning period (Morovat and Dauncey, 1998) as physiological changes experienced during this period may influence long-term growth. Moreover, if dietary changes initiate immune system stimulation, this may affect long-term growth performance as well (Che et al., 2011).

There are a number of hormones related to animal nutritional and immune status that can strongly influence animal growth performance (Hornick et al., 2000; Elsasser et al., 2008; Gabler and Spurlock 2008). Understanding the relationship between plasma levels of these hormones and how they influence animal growth capabilities may allow for better manipulation of feeding strategies in order to maximize feed efficiency and reduce feed costs.

The objective of this study was to examine dynamic changes in blood plasma levels of interleukin-1 beta (**IL-1β**), interleukin-6 (**IL-6**), tumor necrosis factor-alpha (**TNF-α**), cortisol, leptin, insulin-like growth factor 1 (**IGF-1**), triiodothyronine (**T_3**) and thyroxine (**T_4**), as influenced by nursery feeding programs, and to relate changing plasma levels of these hormones to growth performance from weaning to market BW (approximately 110 kg). Furthermore, these hormones were evaluated as potential bio-markers that may be used to predict the effect of external stressors on growth performance in the nursery and grower-finisher (**G-F**) phases.

4.3. Materials and methods

4.3.1. Animals, diets and experimental design

The animals used in this study were taken from the population of pigs used in the growth performance study (Chapter 3). Information pertaining to animal handling, housing practices, dietary treatments and general experimental protocol can be found in section 3.3.1 of this thesis.

4.3.2. Experimental procedures – blood sampling and plasma analysis

As per section 3.3.1, the current experiment included 5 experimental blocks; each experimental block had 3 pens per treatment with 8 pigs per pen in blocks 1 and 2 and 10 pigs per pen in the remaining 3 blocks. Blood samples were taken from 2 pigs per pen in each of blocks 2 to 4; pigs were selected from each treatment (3 pens per treatment per block) with 1 barrow and 1 gilt that were representative of the median weight of a given pen being selected for sampling. Blood samples were collected at the time of animal weighing at wk 0 (weaning), 2, 4, 6, 10, 14, and 17 post-weaning. At each sampling period, 12 mL of blood were collected from the orbital sinus into sodium heparinized tubes and were centrifuged at 1500 × **g** for 20 min. Harvested plasma was stored at – 20 °C until further analysis.

All analyses were completed in duplicate. In the case of IL-1β, IL-6, TNF-α and IGF-1 the analysis of individual samples was repeated if the coefficient of variation (**CV**) was greater than 10%; cortisol, leptin, T_3 and T_4 analyses were repeated if the calculated CV was greater than 15%.

Plasma levels of IL-1β and IL-6 were determined using commercially available Quantikine® porcine ELISA kits and IGF-1 plasma levels were analyzed using a commercially available Quantikine® human ELISA kit (R&D Systems, Inc., Minneapolis, MN, USA). TNF-α plasma levels were also measured using an ELISA kit (Invitrogen, Camarillo, CA, USA). Plasma levels of cortisol, total T_3 and total T_4 were determined using Coat-A-Count® radioimmunoassay (**RIA**) kits (Siemens Healthcare Diagnostics Inc., Los Angeles, CA, USA). Plasma levels of leptin were determined using a multi-species leptin RIA kit (Millipore, St. Charles, MO, USA).

4.3.3. Statistical analysis

Statistical analyses were performed in the MIXED procedure of SAS (V 9.2, SAS Inst. Inc., Cary, NC, USA). Data were analyzed using repeated measures with pen as the experimental unit (the analyzed plasma hormone levels of individual pigs nested within pen). Nursery diet complexity and the use of in-feed antibiotics were considered main effects with pen nested within block being regarded as a random effect. Interactive effects between diet complexity, antibiotic usage and time were also examined. Differences were determined for the least squares mean values using orthogonal contrasts at wk 0 (weaning), 2, 4, 6, 10, 14 and 17.

Given the large number of comparisons as well as the absence of clear interactions of main effects (nursery diet complexity and the use of in-feed antibiotics) on response variables, it was deemed inappropriate to statistically analyze differences among individual treatment means within time periods. However, when interactions between the main effects were present, numerical differences between the treatment means were discussed. Means were considered to be significantly different when $P < 0.05$ and were considered to indicate a trend when $0.05 < P < 0.10$.

In an effort to relate plasma hormone levels to growth performance and explore their use as predictors of animal growth performance, correlation analyses were conducted using the general linear model of SAS. Nursery diet complexity and the use of in-feed antibiotics in nursery diets were considered as main effects in the correlation analyses while the effect of block was considered as a random variable. In the correlation analyses, plasma hormone levels were related to the average daily gain (**ADG)** of individual animals. A correlation with $P < 0.05$ was considered statistically significant while $0.05 < P < 0.10$ was deemed to be a trend.

4.4. Results

4.4.1. General observations

Hormone analyses were conducted for all 8 of the hormones previously mentioned using plasma samples obtained in the 2^{nd} experimental block. Due to the variability of results from block 2 and the lack of a relationship between dietary treatments and plasma levels of IL-1β, IL-6, TNF-α, cortisol and leptin, analysis of these 5 hormones was not conducted on samples obtained in blocks 3 and 4. Analyses of plasma levels of IGF-1, T_3 and T_4 were conducted on samples from blocks, 2, 3 and 4, yielding serial observations of 9 pens per dietary treatment at each sampling time (wk 0, 2, 4, 6, 10, 14 and 17 post-weaning).

It should be noted that the level of T_4 was elevated in 2 pigs from block 3 at wk 4; this resulted in a spike in T_4 level for the simple treatment +AB and may have had an effect on the findings at wk 4.

4.4.2. IL-1β, IL-6 and TNF-α

Nursery feeding programs had no effect on plasma levels of IL-1β or IL-6 at any time of sampling throughout the trial (Figures 4.1 and 4.2). Feeding simple nursery diets increased (P = 0.03) plasma levels of TNF-α (Figure 4.3) at wk 4 post-weaning. There was also a trend towards increased levels (P = 0.09) of plasma TNF-α at wk 4 in pigs fed nursery diets that included antibiotics as well as a trend towards an interactive effect (P = 0.06) of diet complexity and in-feed antibiotic usage at wk 4. Feeding antibiotics was associated with a numerical increase in plasma TNF-α level when included in simple nursery diets and decreased plasma TNF-α level when included in complex nursery diets. There was also a trend towards increased (P = 0.096) plasma TNF-α levels at wk 2 in pigs fed simple nursery diets.

4.4.3. Cortisol and Leptin

Feeding antibiotics tended to increase (P = 0.08) plasma levels of cortisol at wk 17 post-weaning (Figure 4.4). At wk 10, there was an interaction between diet complexity and in-feed antibiotic usage (P = 0.02) as the use of in-feed antibiotics numerically increased plasma cortisol levels when included in simple nursery diets and decreased plasma cortisol levels when included in complex nursery diets. There was also a noted increase in the plasma cortisol levels of pigs across all treatments at the time of weaning and when pigs were moved from the nursery to the grower-finisher unit.

There was an interactive effect ($P < 0.05$) of diet complexity and in-feed antibiotic usage on plasma leptin levels at wks 14 and 17 (Figure 4.5) as well as a trend towards an interaction ($P = 0.098$) between nursery diet complexity and in-feed antibiotic usage at wk 6. In these cases, feeding antibiotics tended to numerically decrease plasma leptin levels when included in simple nursery diets and numerically increase plasma leptin levels when included in complex nursery diets.

4.4.4. IGF-1, T_3 and T_4

Feeding nursery diets that did not include antibiotics reduced ($P < 0.01$) IGF-1 plasma levels at wk 4 (Figure 4.6) and there was a trend towards an interaction ($P = 0.06$) between diet complexity and the use of in-feed antibiotics at wk 4. In-feed antibiotic usage in nursery diets resulted in a numerically larger increase in plasma levels of IGF-1 at wk 4 when antibiotics were included in simple nursery diets as compared to complex nursery diets.

The inclusion of antibiotics in nursery diets increased ($P < 0.01$) plasma T_3 levels while feeding simple diets in the nursery decreased ($P = 0.02$) plasma T_3 levels at wk 4 post-weaning (Figure 4.7). Furthermore, there was an interactive effect ($P = 0.02$) of diet complexity and in-feed antibiotic usage at wk 10. The use of in-feed antibiotics increased plasma T_3 levels when included in complex nursery diets and decreased plasma T_3 levels when used in simple nursery diets.

There was an interactive effect of diet complexity and in-feed antibiotic usage (P = 0.02) at wk 4 post-weaning as plasma T_4 levels were increased when antibiotics were included in simple nursery diets and decreased when included in complex nursery diets (Figure 4.8).

4.4.5. Potential bio-markers as predictors of growth performance

The plasma level of IGF-1 at weaning was positively correlated (P < 0.05) with ADG at wk 2 and 6 and tended to be positively correlated (P < 0.10) with ADG at wk 4 and 10 (Table 4.1). The level of IGF-1 in plasma at wk 2 was positively associated (P < 0.01) with ADG at wk 2 and 6. IGF-1 levels in plasma at wk 4 were positively correlated (P < 0.01) with ADG at wk 4. Plasma IGF-1 levels at wk 6 were positively correlated (P < 0.01) with ADG at wk 6 and there was a trend towards a positive correlation (P = 0.09) with ADG at wk 2. Average daily gain at wk 10 was positively correlated (P = 0.05) with IGF-1 levels in plasma at wk 10. Lastly, IGF-1 plasma levels at wk 17 tended to be negatively correlated (P = 0.08) with ADG at wk 14.

The level of T_3 in blood plasma at weaning was positively correlated (P = 0.04) with ADG at wk 2 while T_3 levels in the plasma at wk 2 were positively correlated (P = 0.01) with ADG in wk 2 and tended to be negatively correlated (P = 0.06) with ADG in wk 14 (Table 4.2). Triiodothyronine levels in plasma at wk 4 tended to be positively correlated (P < 0.10) with ADG at wk 2 and 4. The level of T_3 in blood plasma at wk 10 was negatively correlated (P < 0.05) with ADG at wk 2, 4 and 6 while plasma T_3 levels at wk 14 were negatively correlated (P <0.01) with ADG in wk 6.

Thyroxine plasma levels at weaning were positively correlated (P < 0.05) with ADG at wk 2 and 6 while T_4 plasma levels at wk 6 were positively correlated (P = 0.02) with ADG at wk 6.

4.5. Discussion

In this study, simple and complex nursery diets, with or without chlortetracycline, were fed to pigs to assess the effect of nursery diet complexity and in-feed antibiotic usage on growth performance up to market BW and dynamic changes in plasma levels of various growth-related hormones. Blood samples were taken from pigs in each treatment at multiple time points between weaning and market BW to evaluate relationships between nursery feeding programs, plasma levels of various hormones and growth performance. These analyses were conducted to determine whether or not plasma hormone levels may be used as predictors of pig growth performance.

Interleukin-1 beta, IL-6 and TNF-α are pro-inflammatory cytokines that function as part of the immune system and also have the ability to influence tissue growth. Following animal exposure to pathogens, these cytokines may initiate the repartitioning of nutrients away from supporting growth and towards mounting an immune response (Elsasser et al., 2008). Apparently, these cytokines are primarily involved in the short term immune response following an animal's exposure to antigens. Johnson (1997) showed that elevated plasma levels of these cytokines occur within 48 h of the animal's exposure to a pathogen and gradually decline thereafter. In the current experiment, analyzed plasma levels of IL-1β, IL-6 and TNF- α were highly variable and did not appear related to dietary treatments. As a consequence, analysis of these hormones was not conducted for samples obtained from blocks 3 or 4. However, based on plasma levels of IL-1β and TNF-α across all treatments, as compared to levels observed in healthy pigs, the immune system of pigs appeared stimulated (Dionissopoulos et al., 2006; Rakhshandeh and de Lange, 2011).

Cortisol is involved in the animal's stress response and is involved in regulation of animal immune function, energy and metabolism (Webel et al., 1997). Stressors, such as animal handling at weaning or immunological stressors, generally increase plasma cortisol levels which, in turn, increase body protein degradation in order to increase the availability of amino acids for production of hepatic acute phase proteins (Webel et al., 1997). The results of the current study were consistent with the literature as cortisol levels in the plasma were elevated at times of animal handling, e.g. at weaning and when pigs were moved from the nursery to the G-F rooms (Farmer et al., 1991; Lewis, 2008). However, there were no consistent effects of treatment on plasma cortisol levels and analyzed values were highly variable. Therefore, cortisol analysis was not conducted for samples obtained in blocks 3 or 4.

Leptin is an appetite suppressing hormone that is involved in the regulation of caloric intake and energy expenditure (Jacobi et al., 2006). While there were some trends with regard to treatment effects on plasma leptin levels, it is important to note that the kit used for leptin analysis appeared insufficiently sensitive. In 10.3% of samples, plasma leptin levels were below the detection limit and, as such, the results obtained were deemed not informative. Therefore, leptin analysis was not performed on samples obtained from blocks 3 or 4.

Insulin-like growth factor 1 is an important regulator of protein synthesis and, therefore, lean tissue growth (Sangel and Roxas, 2011). In the current study, plasma IGF-1 levels at wk 4 tended to be lower in pigs fed nursery diets that did not include antibiotics and this corresponded to decreased growth performance at the same time. Wang et al. (2011) indicated that reductions in plasma IGF-1 may indicate the repartitioning of nutrients away from growth and towards mounting an immune response. This is consistent with the findings of the current study, as pigs in the nursery were subject to an immune challenge and, in some cases, reduced growth performance that was associated with poor physical appearance. It is of interest to note that, while the plasma levels of IGF-1 in pigs fed nursery diets that did not include antibiotics recovered during the grower phase when compensatory growth occurred, they did not exceed levels observed in the pigs on treatments that did have previous reductions in growth performance. These findings suggest that plasma IGF-1 levels are closely associated with pig growth performance but that there are also factors that may affect the sensitivity of the pig's response to plasma IGF-1 levels during periods of compensatory growth.

The thyroid hormones T_3 and T_4 are involved in regulating whole body energy expenditure and have been shown to have direct effects on metabolic rates in a number of tissues (Hocquette et al., 1998). The role of T_3 and T_4 in stimulating IGF-1 synthesis, and in turn promoting lean tissue growth, becomes increasingly important during periods of decreased nutrient intake (Buonomo and Baile, 1991). Periods of nutrient restriction and decreased growth performance may increase resistance to GH in IGF-1 production pathways, which increases the importance of T_3 and T_4 in stimulating IGF-1 synthesis.

In times of nutritional stress the basal metabolic rate is reduced in an effort to conserve energy and this may be associated with a reduction in the circulating levels of T_3 and T_4 (Hornick et al., 2000; Cabaraux et al., 2003; Rommers et al., 2004). This restriction-induced decline in the levels of T_3 and T_4 is caused, in part, by reduced sensitivity of the thyroid gland to thyroid-stimulating hormone (**TSH**) (Wester et al., 1995), as well as decreased secretion and increased degradation of TSH (Cabaraux et al., 2003). This may explain the association between reduced plasma levels of T_3 and periods of reduced growth, as observed in the current study.

The level of T_3 and T_4 in the plasma returns to the level observed in uncompromised pigs over a period of days or weeks post growth restriction (Blum et al., 1985; Rommers et al., 2004).

The findings of these authors correspond to those of the current study as T_3 levels were reduced in pigs fed simple nursery diets as well as nursery diets that did not include antibiotics at wk 4 post-weaning but returned to the same level as pigs fed complex nursery diets from wk 6 to the end of the G-F period. The same findings were not present for T_4 in the current study. This is consistent with other research which has shown that T_4 is less responsive to nutritional changes than T_3 (Carroll et al., 1998). The lack of significant findings could also be due to observed variability in analyzed plasma T_4 levels.

Apparently, there was a delay from the end of the period of reduced growth to when T_3 levels were normalized. This may be a reflection of a mechanism that is involved with compensatory growth. When the basal metabolic rate decreases, along with the plasma levels of T_3 and T_4, the proportion of dietary energy intake partitioned towards maintenance energy expenditure is reduced. Consequently, if the basal metabolic rate and the level of T_3 and T_4 remain reduced when nutrient intake is no longer restricted, a greater proportion of nutrient intake is available to support growth (Hornick et al., 2000). The levels of plasma T_3 observed throughout the current study and the associated performance of observed pigs is consistent with results of Hornick et al. (2000). The relationship between T_3 and basal metabolic rate may explain the improvement in feed efficiency, for pigs fed simple nursery diets, observed late in the nursery period and during periods of compensatory growth (Chapter 3).

In order to determine whether plasma levels of hormones can be linked to performance and used as predictors of animal growth, correlation analysis was completed, based on growth performance measurements in individual animals, to assess the relationship between ADG and the levels of IGF-1, T_3 and T_4 throughout the duration of the trial. Correlation analyses were not completed for IL-1β, IL-6, TNF-α, cortisol or leptin because of observed variability, as was discussed previously.

Within sampling periods, the relationships between the analyzed plasma levels of IGF-1 and ADG were positive. This correlation appeared to be strongest early post-weaning (e.g. during wks 2-6 post-weaning), and was maintained up to 10 wks post-weaning (Table 4.1). This is in agreement with the findings of Sangel and Roxas (2011). It is of interest to note that plasma IGF-1 levels at weaning and wk 2 post-weaning were positively correlated to ADG up to wk 6 post weaning, and were, numerically more closely correlated to ADG at wk 6 than IGF-1 plasma levels at wk 6. These findings suggest that the plasma levels of IGF-1 at weaning may be used as a predictor of future growth performance. In contrast, levels of IGF-1 in plasma after wk 2 post-weaning appear poorer predictors of subsequent growth performance. These observations provide some support for the concept that the animal's physiology may be permanently affected by the environment during the first few wks post-weaning.

No consistent relationships between T_4 plasma levels and growth performance were apparent in the current study. However, within time periods, the level of T_3 in blood plasma early post-weaning was positively correlated, or tended to be positively correlated, to growth performance up to wk 6 post-weaning. This is in agreement with the findings of Hornick et al. (2000) which indicated that periods of reduced growth, as may be caused by nutrient intake restriction, are associated with decreased levels of circulating T_3. However, the correlation between plasma T_3 levels early post-weaning and growth performance during the G-F period was negative; the level of T_3 in plasma at wk 10 was negatively associated with nursery growth performance as pigs that previously experienced reductions in growth performance had recovered levels of T_3 at wk 10. As such, while the plasma level of T_3 may be a good indication of nutritional status or metabolic condition, it does not appear to be a reliable indicator of future growth performance.

4.6. Conclusion and implications

Based on the results of the current study, there did not appear to be a relationship between either of IL-1β, IL-6, TNF-α, cortisol or leptin and pig growth performance during the nursery and G-F periods when differences in pig growth performance were induced by different nursery feeding programs. However, feeding simple nursery diets to newly-weaned pigs decreased plasma levels of T_3 in the nursery while feeding nursery diets that excluded antibiotics decreased plasma IGF-1 and T_3 levels in the nursery period. Furthermore, this was linked to a reduction in nursery pig growth performance. During the subsequent period of compensatory growth, the plasma levels of these hormones returned to values observed in pigs that did not experience reductions in growth performance. Nursery feeding program had no effect on the plasma levels of IGF-1, T_3 or T_4 after wk 10 post-weaning. Based on plasma T_3 levels observed during periods of compensatory growth, there was an apparent reduction in basal metabolic rate during the period of reduced growth performance. There may have been a delay in recovery of basal metabolic rates to normal levels and this may have allowed pigs that previously experienced decreased basal metabolic rates, marked by reduced levels of $T_{3,}$ to direct more nutrients towards growth and express compensatory growth. Lastly, the apparent correlation between IGF-1 levels in pig blood plasma at weaning and growth performance up to wk 10 post-weaning may indicate that IGF-1 can be used as a bio-marker to predict future pig growth performance.

Further research is required to better understand the relationship between T_3 and basal metabolic rate during periods of reduced growth performance and subsequent periods of compensatory growth. In addition, supplementary research needs to be completed to assess the possibility of using IGF-1 plasma levels at weaning to predict the future growth performance of growing pigs of varying genotypes and under varying environmental conditions.

Table 4.1. Correlation between plasma levels of IGF-1 and performance as measured by ADG in individual growing pigs over time

			IGF-1 level						
			Wk 0	Wk 2	Wk 4	Wk 6	Wk 10	Wk 14	Wk 17
ADG[3]	Wk 2	r[1]	0.26	0.58	0.21	0.21	0.05	-0.04	-0.03
		P[2]	0.04	< 0.01	0.10	0.09	0.69	0.72	0.80
	Wk 4	r	0.22	0.13	0.44	0.16	-0.17	-0.03	0.05
		P	0.08	0.29	< 0.01	0.21	0.17	0.81	0.69
	Wk 6	r	0.39	0.42	0.12	0.37	-0.06	0.06	0.06
		P	< 0.01	< 0.01	0.32	< 0.01	0.61	0.65	0.63
	Wk 10	r	0.21	0.17	0.07	0.04	0.24	-0.03	-0.12
		P	0.09	0.16	0.55	0.73	0.05	0.84	0.32
	Wk 14	r	0.09	0.15	-0.16	0.10	0.16	0.03	-0.22
		P	0.48	0.24	0.19	0.40	0.21	0.79	0.08
	Wk 17	r	-0.03	-0.12	-0.02	-0.08	0.05	-0.06	0.13
		P	0.79	0.35	0.89	0.51	0.71	0.65	0.29

[1] Partial correlation coefficient values (r-value; n = 18 observations [pigs] per treatment).
[2] Probability of correlation effects.
[3] ADG at each individual week refers to the calculated ADG for pigs from the end of the previous time period until the end of the designated week (i.e. 'week 4 ADG' refers to the ADG for the period of time from the end of week 2 until the end of week 4).

Table 4.2. Correlation between plasma levels of T_3 and performance as measured by ADG in individual growing pigs over time

			T_3 level						
			Wk 0	Wk 2	Wk 4	Wk 6	Wk 10	Wk 14	Wk 17
***ADG*[3]**	Wk 2	r[1]	0.25	0.31	0.24	-0.03	-0.38	-0.08	0.06
		P[2]	0.04	0.01	0.05	0.78	< 0.01	0.54	0.65
	Wk 4	r	0.05	0.01	0.22	0.01	-0.27	0.04	0.08
		P	0.69	0.92	0.08	0.96	0.03	0.76	0.50
	Wk 6	r	0.08	0.12	0.02	-0.05	-0.34	-0.38	0.10
		P	0.51	0.92	0.86	0.71	< 0.01	< 0.01	0.42
	Wk 10	r	-0.07	-0.14	-0.07	0.02	-0.09	0.10	< 0.01
		P	0.60	0.27	0.57	0.90	0.45	0.43	0.99
	Wk 14	r	-0.08	-0.24	-0.20	-0.11	-0.18	0.06	-0.07
		P	0.51	0.06	0.11	0.39	0.14	0.63	0.58
	Wk 17	r	-0.15	-0.18	-0.17	-0.20	-0.06	0.03	> -0.01
		P	0.24	0.14	0.18	0.11	0.64	0.82	0.97

[1] Partial correlation coefficients (r-value; n = 18 observations [pigs] per treatment).
[2] Probability of correlation effects.
[3] ADG at each individual week refers to the calculated ADG for pigs from the end of the previous time period until the end of the designated week (i.e. ‘week 4 ADG’ refers to the ADG for the period of time from the end of week 2 until the end of week 4).

Table 4.3. Correlation between plasma levels of T_4 and performance as measured by ADG in individual growing pigs over time

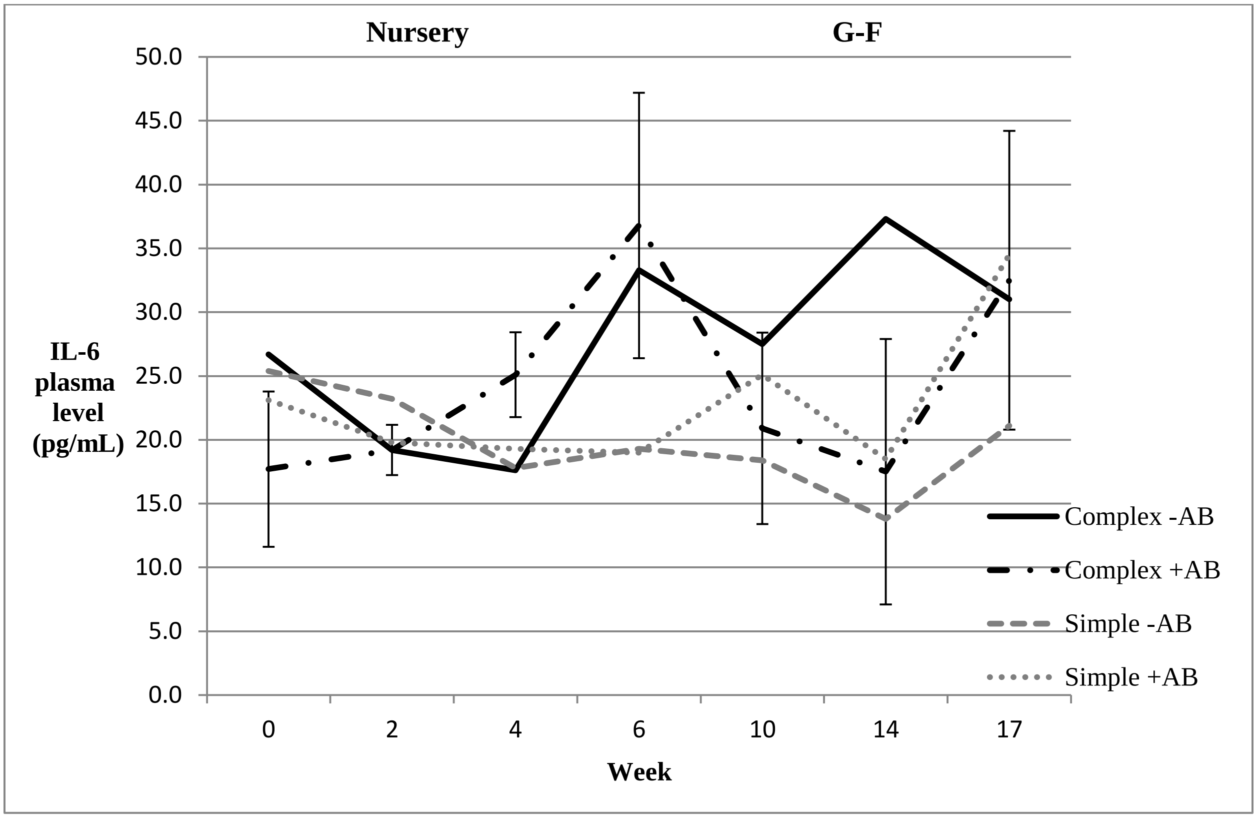
			T_4 level						
			Wk 0	Wk 2	Wk 4	Wk 6	Wk 10	Wk 14	Wk 17
ADG[3]	Wk 2	r[1]	0.31	-0.06	0.04	-0.05	-0.20	-0.15	-0.12
		P[2]	0.01	0.65	0.74	0.68	0.10	0.22	0.34
	Wk 4	r	0.11	-0.13	0.11	0.09	-0.05	0.02	0.04
		P	0.40	0.30	0.36	0.49	0.70	0.88	0.77
	Wk 6	r	0.25	0.03	0.12	0.29	0.14	0.08	0.19
		P	0.04	0.80	0.32	0.02	0.27	0.55	0.14
	Wk 10	r	0.02	-0.17	0.40	0.56	0.23	-0.06	-0.02
		P	0.87	0.17	0.40	0.56	0.23	0.66	0.88
	Wk 14	r	-0.07	-0.10	-0.11	0.05	0.07	0.11	0.06
		P	0.58	0.43	0.38	0.69	0.57	0.39	0.64
	Wk 17	r	-0.11	-0.20	-0.15	-0.14	-0.15	-0.10	-0.09
		P	0.40	0.10	0.22	0.25	0.23	0.41	0.46

[1] Partial correlation coefficient values (r-value; n = 18 observations [pigs] per treatment).
[2] Probability of correlation effects.
[3] ADG at each individual week refers to the calculated ADG for pigs from the end of the previous time period until the end of the designated week (i.e. 'week 4 ADG' refers to the ADG for the period of time from the end of week 2 until the end of week 4).

Figure 4.1. Effect of diet complexity and in-feed antibiotics on plasma level of IL-1β in growing pigs over time[1]

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (block 2, chapter 3). Data are means and SEM (n = 3 observations [pens] per treatment).
Values did not differ between treatments ($P > 0.10$).

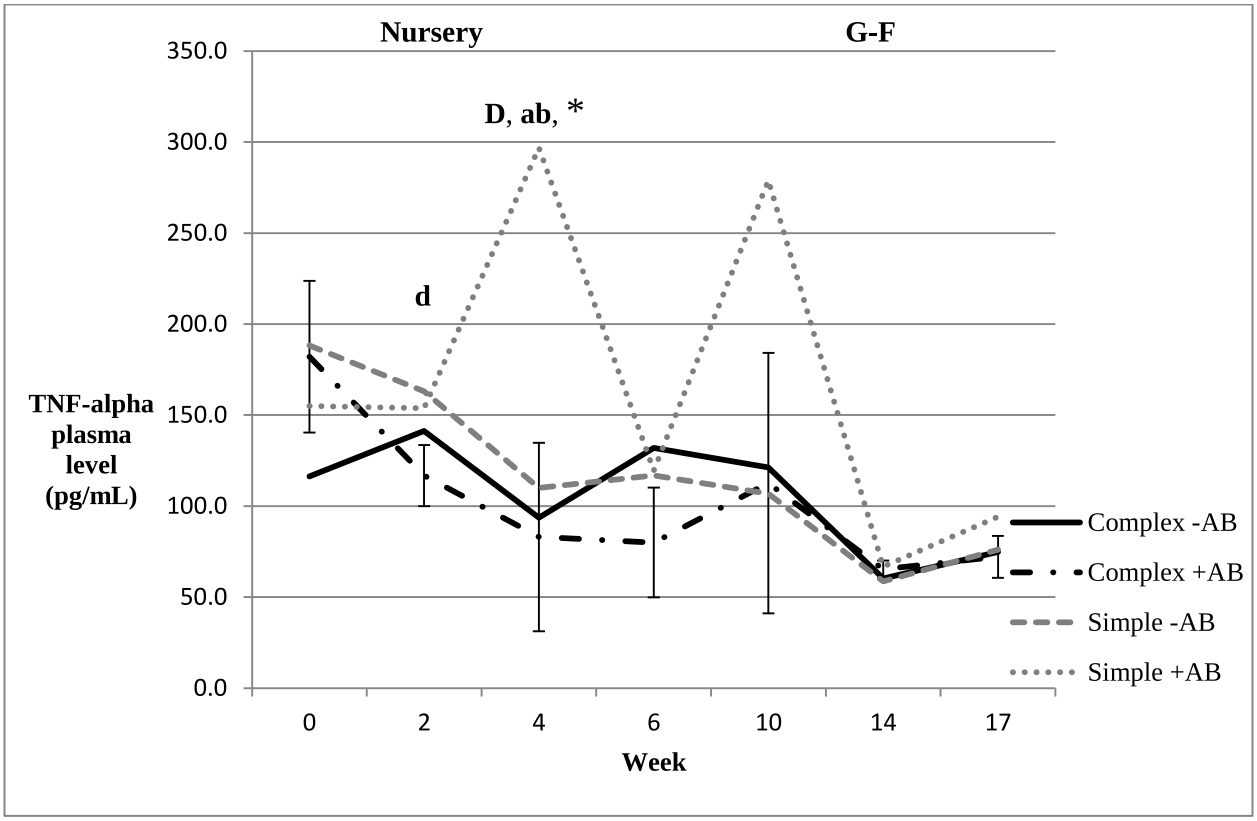
Figure 4.2. Effect of diet complexity and in-feed antibiotics on plasma level of IL-6 in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (block 2, chapter 3). Data are means and SEM (n = 3 observations [pens] per treatment).

Values did not differ between treatments (*P* > 0.10).

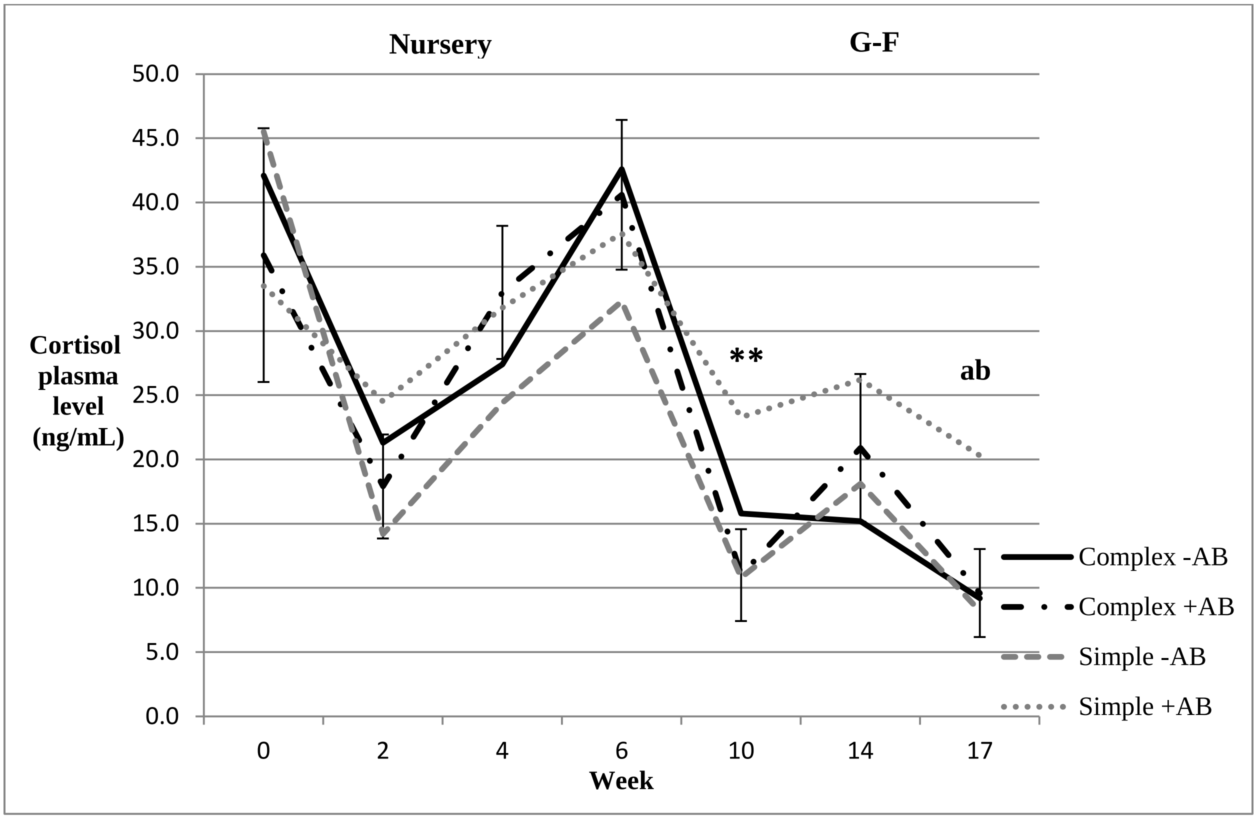
Figure 4.3. Effect of diet complexity and in-feed antibiotics on plasma level of TNF-α in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (block 2, chapter 3). Data are means and SEM (n = 3 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

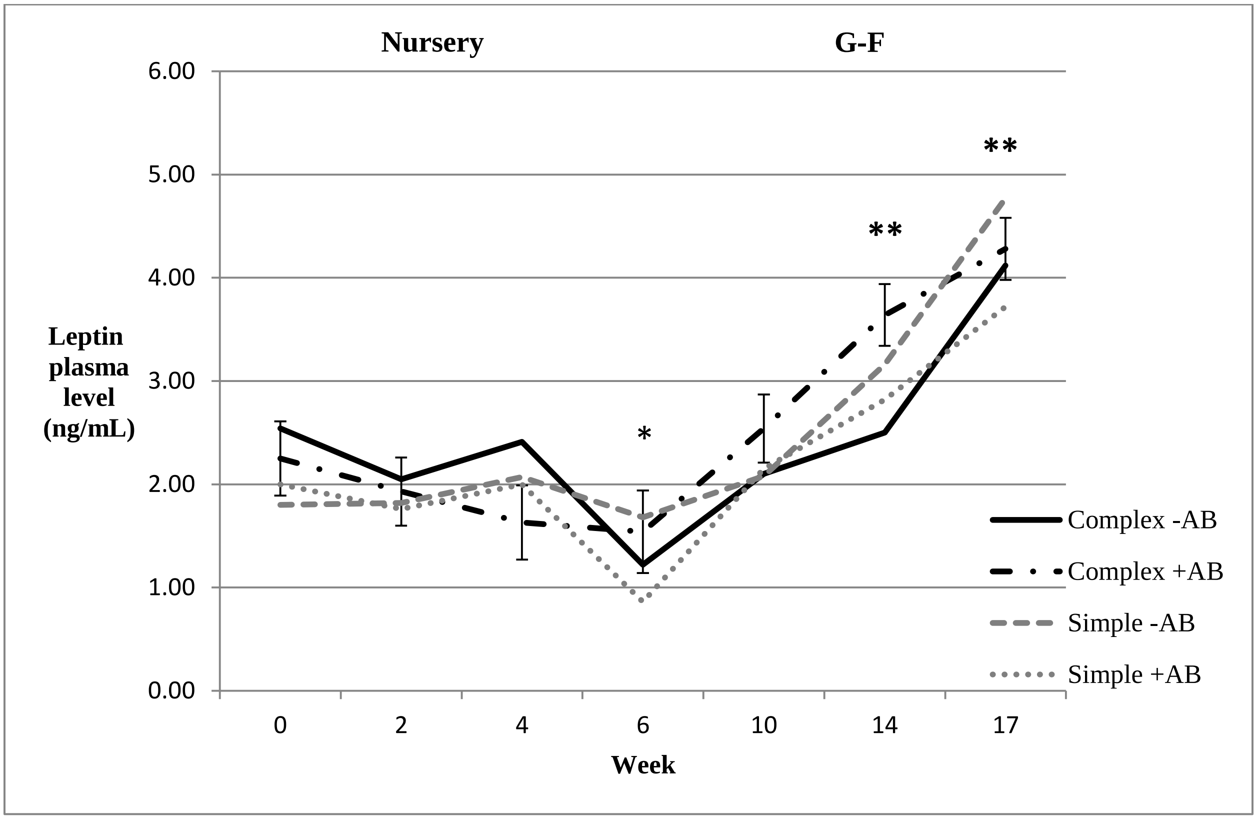
Figure 4.4. Effect of diet complexity and in-feed antibiotics on plasma level of cortisol in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (block 2, chapter 3). Data are means and SEM (n = 3 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

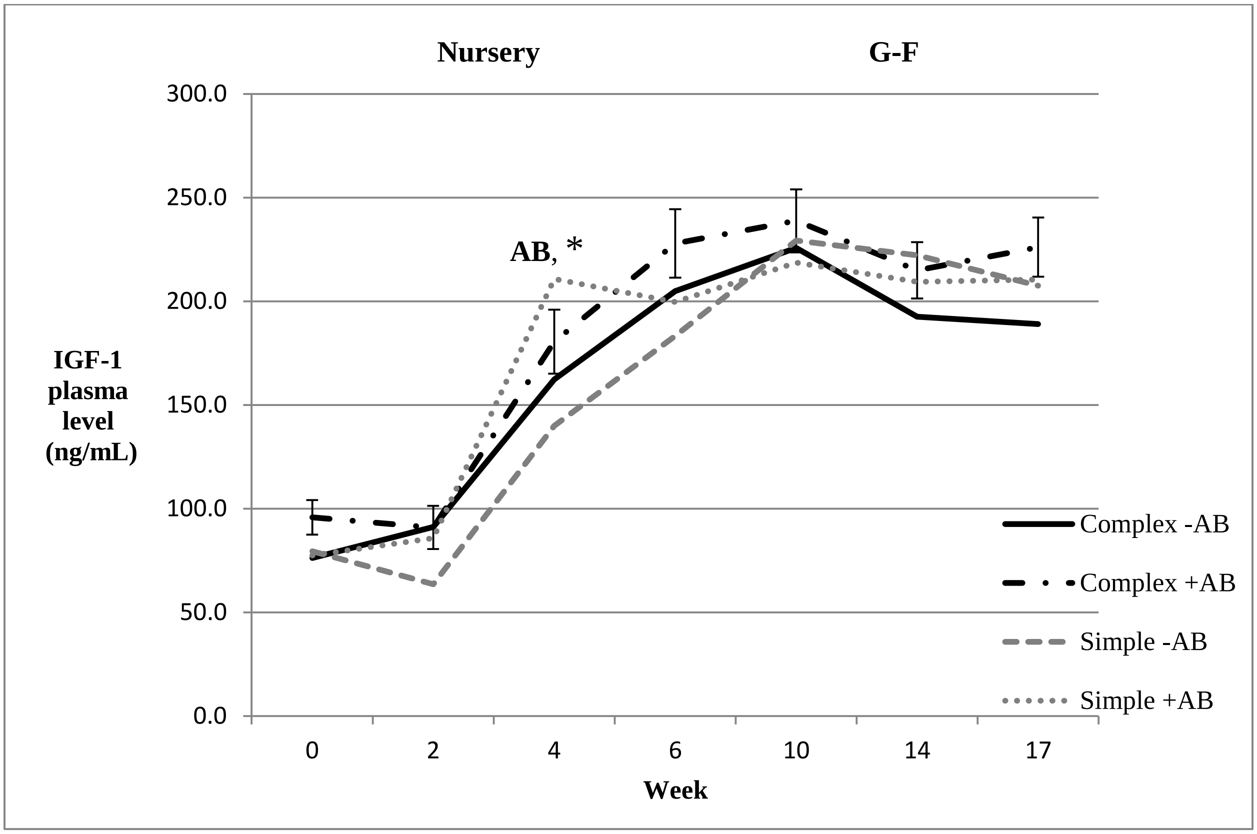
Figure 4.5. Effect of diet complexity and in-feed antibiotics on plasma level of leptin in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (block 2, chapter 3). Data are means and SEM (n = 3 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

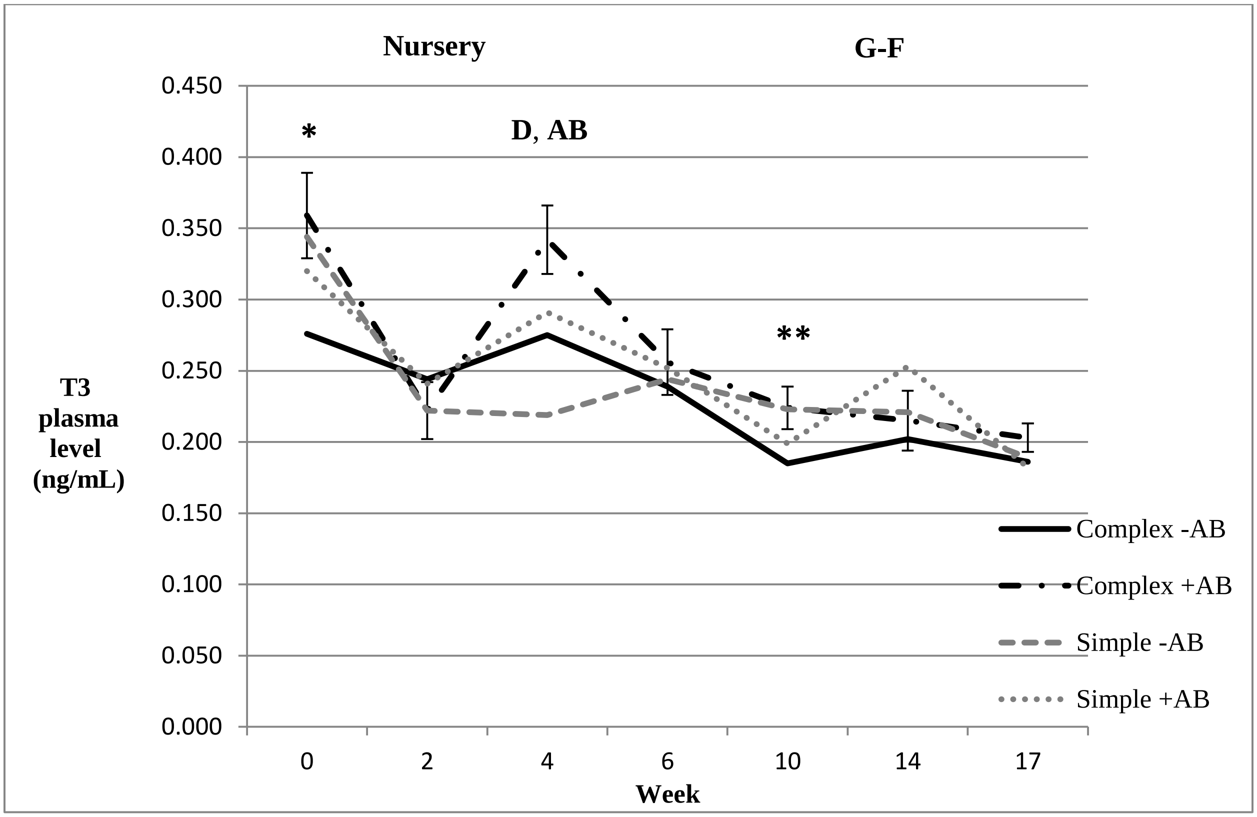
Figure 4.6. Effect of diet complexity and in-feed antibiotics on plasma level of IGF-1 in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment per block at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (blocks 2, 3 and 4; Chapter 3). Data are means and SEM (n = 9 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

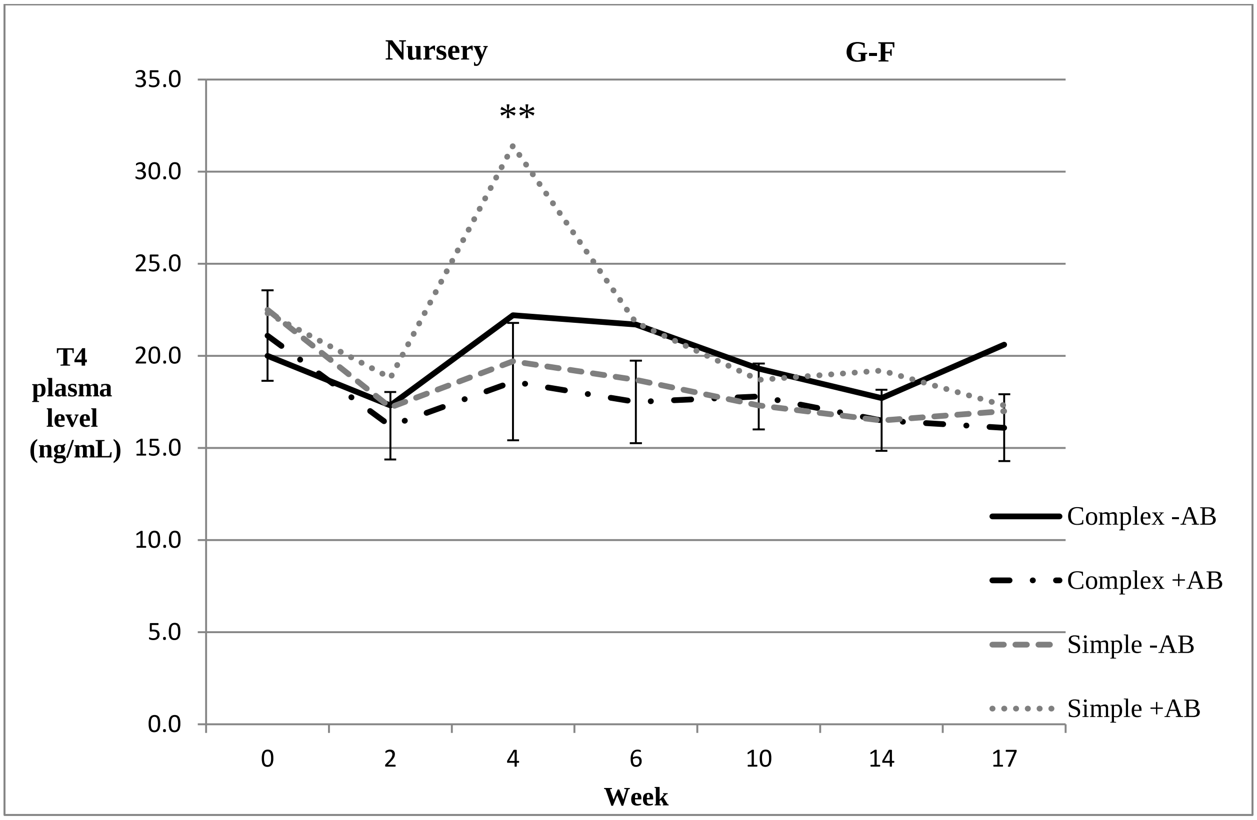
Figure 4.7. Effect of diet complexity and in-feed antibiotics on plasma level of T_3 in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment per block at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (blocks 2, 3 and 4; Chapter 3). Data are means and SEM (n = 9 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

Figure 4.8. Effect of diet complexity and in-feed antibiotics on plasma level of T_4 in growing pigs over time [1]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter. Observations were taken from 3 pens per treatment per block at wk 0 (weaning), 2, 4, 6, 10, 14 and 17 post-weaning (blocks 2, 3 and 4; Chapter 3). Data are means and SEM (n = 9 observations [pens] per treatment).

D, AB, or ** indicates a significant effect ($P < 0.05$) of diet complexity, antibiotic usage or an interaction of nursery diet complexity and antibiotic usage, respectively; d, ab, or * indicates a trend ($0.05 < P < 0.10$) towards an effect of diet complexity, antibiotic usage or an interaction between diet complexity and in-feed antibiotic usage, respectively.

5.0. Effect of nursery feeding program on body composition, carcass and meat quality at market weight, and nutrient accretion in pigs

5.1. Abstract

An experiment was conducted to examine the effect of nursery feeding programs on meat quality at market weight, the weight of primal and retail carcass cuts, body composition, as well as the rate of nutrient accretion at different times between weaning and market weight of pigs. Four dietary treatments were used in a 2 × 2 factorial design based on diet complexity (complex vs. simple) and in-feed antibiotics (600 [+AB] vs. 0 [-AB] ppm chlortetracycline). A total of 552 pigs, in 5 blocks, were weaned at 3 wk of age and an initial BW of 7.03 ± 0.07 kg. Nursery diets were fed in a 3-phase feeding program (Phase I, II, and III fed for 7, 14, and 21 d, respectively). All pigs were fed common grower-finisher (G-F) diets thereafter. Pigs had free access to feed and water. Six pigs per treatment were slaughtered for chemical body composition analysis at wk 2, 8, 12 and 17 post-weaning; an additional 11 pigs per treatment were slaughtered at wk 17 post-weaning (approximately 115 kg BW; market weight) for analysis of physical body composition and loin meat quality. Nursery feeding program had no effect on objective or subjective meat quality measures or the weight of primal and retail carcass cuts at wk 17 post-weaning, with the exception of primal belly weight. Feeding simple nursery diets tended to increase primal belly weight at wk 17 post-weaning. In general, dietary treatment did not affect chemical body composition or the rate of BW gain throughout the experiment, with the exception of protein deposition (Pd). Feeding simple nursery diets tended to have increased Pd between 70 and 115 kg BW.

Key words: nursery feeding program, meat quality, body composition, carcass composition, pigs

5.2. Introduction

Feeding programs utilized during the nursery and grower-finisher (**G-F**) periods can have substantial effects on the rate and composition of BW gain of pigs and, thus, carcass composition at market weight (Chapter 3; Lebret, 2008). If compensatory growth is achieved following a period of nutrition-induced reductions in BW gain, it may be associated with increased rates of lean tissue gain and muscle protein turnover, which may affect feed efficiency, physical and chemical body composition at market weight and meat quality (Wellock et al. 2003; Kristensen et al., 2004, Lametsch et al., 2006; Stolzenbach et al., 2009;).

Wellock et al. (2003) hypothesized that, following a period of nutrition-induced changes in the rate and composition of BW gain, when nutrient restrictions are removed the rate and composition of BW gain will be altered in order to achieve a genetically determined target body composition. This hypothesis was confirmed by Martinez-Ramirez et al. (2008) who showed that feeding amino acid deficient diets to pigs between approximately 15 and 35 kg BW caused reduced rates of body protein deposition (**Pd**) and increased rates of body lipid deposition (**Ld**) resulting in a lower body protein content (**PB**) relative to body lipid content (**LB**). When the amino acid intake restriction was removed, pigs showed compensatory gain that was largely attributed to increased Pd and reduced Ld. This resulted in a LB to PB ratio (**LB/PB**) at 115 kg BW that was not different from pigs that were not exposed to amino acid intake restrictions.

In a similar manner, feeding simple nursery diets may reduce Pd early post-weaning (Whang et al., 2000). This can have an effect on LB/PB in the nursery period and may alter the composition of BW gain during a subsequent period of compensatory gain. The objective of this study was to assess the effect of nursery feeding programs on physical and chemical body composition as well as meat quality at market BW (approximately 115 kg). Using the serial slaughter method, dynamic changes in chemical composition of BW between weaning and market BW were evaluated. These objectives were formulated to further explore the observed effects of nursery feeding programs on growth during the nursery period and subsequent G-F period (Chapter 3).

5.3. Materials and methods

5.3.1. Animals, diets and experimental design

The pigs used for meat quality and body composition analysis were taken from the population of pigs used in the growth performance study (Chapter 3). Information pertaining to animal handling, housing practices, dietary treatments and general experimental protocol can be found in section 3.3.1. of this thesis.

5.3.2. Serial slaughter procedure

Two pigs per treatment per block that were closest to the treatment median BW, in blocks 3 to 5, were removed for chemical body composition analysis at wk 2, 8 and 12 post-weaning. Pigs were weighed prior to slaughter and euthanized using an injection of pentobarbital (Euthansol, Schering Canada Inc., Pointe-Claire, QC, Canada) and exsanguination via severing of the carotid artery. Also in blocks 3 to 5, 6 pigs per treatment per block were slaughtered at wk 17 post-weaning (market weight; approximately 115 kg BW) for evaluation of physical and chemical body composition as well as loin meat quality. At market BW, pigs were transported to the meats laboratory in the Animal and Poultry Science building of the University of Guelph, rested for at least 1 h prior to slaughter, weighed and processed as outlined by Martinez-Ramirez et al. (2009). Briefly, pigs were stunned by electric shock and exsanguinated via severing of the carotid artery. Hot carcass weight was recorded as well as backfat depth and muscle depth between the 3rd and 4th last ribs at 7 cm from the midline using a Hennesy grading probe (CA and Associates, Mississauga, ON, Canada). Pig carcasses were split longitudinally. The left hand side of carcasses of pigs slaughtered at wk 17 post-weaning were stored at 4 °C and were used for carcass dissection and meat quality analysis. Also at wk 17 post-weaning, the right hand side of 2 carcasses per treatment per block, from blocks 3 to 5, were placed in plastic bags and immediately frozen at – 20 °C for chemical body composition analysis.

5.3.3. Physical body composition and meat quality analysis

The liver, kidneys, spleen, heart and lungs were removed from all slaughtered pigs and were weighed individually. The full gastro-intestinal tract (stomach, small and large intestine) was weighed, emptied and re-weighed to determine gut fill. The weight of the blood expelled during exsanguination was also recorded.

The left hand side of carcasses of pigs slaughtered at wk 17 were stored at 4 °C for 24 h. They were then weighed and dissected as per the Canadian carcass grading system (Anonymous, 1986). Primal carcass cuts were weighed and dissected into retail products, lean trim, fat trim, skin and bones. Weights of the primal cuts, retail cuts, bone and trim were expressed as proportions of the weight of the left hand side of carcasses. Subjective loin meat quality measurements (subjective colour, firmness, and marbling) were taken according to the procedures adapted from the National Pork Producers Council (1991). Loin meat colour (whiteness, redness and yellowness represented by L*, a* and b* values, respectively) was measured objectively using a Konica Minolta Chroma Meter (Model CR-400; Mississauga, ON).

Objective measurements for pH, drip loss and shear force of loin meat were also evaluated (Martinez-Ramirez et al., 2009).

5.3.4. Chemical body composition analysis

The whole carcasses of pigs euthanized at wk 2, 8 and 12 post-weaning (including head, feet, hair, nails and skin), the right hand side of carcasses of pigs slaughtered at wk 17 post-weaning and all pooled visceral tissues were stored in plastic bags at – 20 °C until chemical analysis occurred.

Homogenization of carcasses and pooled viscera was performed according to Tuitoek et al. (1997). In short, frozen carcasses were weighed prior to being cut into 1 kg pieces with a band saw; carcasses and visceral tissues were ground using a large meat grinder (model B-801, Autio Company, Astoria, OR, USA). Carcass samples were ground 3 times using a 12.5 mm die while visceral tissues were ground 2 times using a 6 mm die. After the last grinding, two homogeneous sub-samples (approximately 250 g) of carcass and pooled visceral tissues were collected and weighed. One sub-sample was stored at – 20 °C while the other was freeze dried. Prior to processing, freeze-dried samples were re-weighed to calculate water loss during freeze drying. Samples were then ground with liquid nitrogen (**N**) and a conventional coffee grinder. Duplicate samples were analyzed at Agrifood Laboratories (Guelph, ON, Canada) to determine dry matter (**DM)**, crude protein (**CP**; N x 6.25), crude fat (**CF**), ash, calcium and phosphorus content as per AOAC (1997). Carcass and viscera N content was measured with a LECO-FP 428 analyzer (LECO Instruments Ltd., Mississauga, ON, Canada) and CF contents were determined using an ANKOM XT-15 extractor (ANKOM Technology, Macedon, NY, USA). Samples were heated at 600 °C for 2 hours to determine ash content and ash was then used to determine calcium and phosphorus content using an ICP Optical Emissions Spectrometer Optima 3000 (PerkinElmer Inc., Walthom, MA, USA).

5.3.5 Calculations and statistical analysis

Chemical body compositions were expressed as a proportion of empty BW (**eBW**) and calculated at wk 2, 8, 12 and 17 post-weaning (Möhn et al., 2000; Weis et al., 2004). In addition, the contributions of carcass and viscera to PB and LB were calculated, as well as Pd, Ld and the ratio between Ld and Pd (**Ld/Pd**) across multiple time periods. Data was analyzed using the MIXED procedure of SAS (V 9.2 SAS Institute, Inc., Cary, NC, USA) with pig as the experimental unit. Diet complexity (complex vs. simple) and the use of in-feed antibiotics (+AB vs. –AB) and their interaction, time of slaughter (days post-weaning) and gender were considered main effects while block was regarded as a random effect. When appropriate, BW at weaning was used as a covariate. The Tukey-Kramer adjustment was used to assess differences among treatment means when an interaction between diet complexity and the use of in-feed antibiotics was observed. Means were considered to be significantly different when $P < 0.05$; trends were considered when $0.05 < P < 0.10$.

Regression analyses were completed using the PROC REG procedure to test the linear or quadratic relationships between PB and time, LB and time as well as body composition (LB/PB) and time. Values from the initial slaughter (wk 2) were used as the starting point for regression analyses. Linear or quadratic relationships were considered to be significant when $P < 0.05$; trends were considered when $0.05 < P < 0.10$.

5.4. Results

5.4.1. General observations

Due to logistics at the abattoir in block 5, meat quality observations were missed for 1 pig per treatment. Furthermore, chemical analyses data from 4 pigs were excluded because of non-realistic values, e.g. the sum of CP, CF and ash content deviated by more than 15% of analyzed DM content. In all other samples, the sum of CP, CF and ash was within 3% of analyzed DM content.

As mentioned in Chapter 3, a severe disease challenge occurred during block 5 of the performance study. Statistical analysis indicated no effect of block on the response variables that are reported in this Chapter, with the exception of PB as a proportion of eBW at wk 12. This will be described in section 5.4.4.

5.4.2. Meat quality analysis and carcass dissection at market weight

There was no effect of dietary treatment on any of the subjective or objective aspects of meat quality analysis that were evaluated (Table 5.1). Furthermore, with the exception of primal belly weight, dietary treatment had no effect on the weight of any primal or retail cut, total fat trim, total lean trim or bone mass (Table 5.2). There was a trend for pigs that were fed simple nursery diets to have increased (P=0.08) primal belly weight at slaughter. There was also an interactive effect of diet complexity and in-feed antibiotics (P = 0.04) on primal belly weight. Pigs that were fed complex nursery diets that included antibiotics had decreased primal belly weight relative to pigs that were simple nursery diets including antibiotics (P = 0.04).

5.4.3. Physical body composition

For several aspects of physical body composition (gut fill, organ weights) there were interactive effects of treatment and time of slaughter ($P < 0.05$). Therefore, data are presented separately for different times post-slaughter (Table 5.3). With the exception of empty gut weight and liver weight, dietary treatment had no effect on the physical composition of pigs at wk 2 post-weaning. Feeding simple nursery diets tended to increase ($P = 0.09$) the weight of empty gut at week 2. There was also an interactive effect ($P = 0.03$) of nursery diet complexity and the use of in-feed antibiotics on liver weight. Pigs fed complex nursery diets excluding antibiotics had numerically increased liver weights as compared to pigs fed simple nursery diets that excluded antibiotics; however, differences between individual treatment means were not significant.

With the exception of kidney weight at wk 8 post-weaning, there was no effect of nursery dietary treatment on physical body composition at wk 8 or 12. Feeding complex nursery diets tended to increase ($P = 0.08$) kidney weight at wk 8.

Empty gut weight at wk 17 post-weaning was increased ($P = 0.02$) in pigs fed simple nursery diets. There was also an interactive effect ($P = 0.04$) of nursery diet complexity and in-feed antibiotic usage on spleen weight at wk 17. Pigs fed simple nursery diets including antibiotics had heavier spleens as compared to pigs that were fed complex nursery diets including antibiotics ($P = 0.06$). There also tended to be an interactive effect ($P = 0.08$) of nursery diet complexity and the use of in-feed antibiotics on kidney weight at wk 17 post-weaning. Pigs that were fed simple nursery diets excluding antibiotics had numerically increased kidney weights at wk 17 as compared to pigs fed complex nursery diets excluding nursery diets, but differences between individual treatment means were not significant. Lastly, there was a trend towards an interactive effect (*P* = 0.08) of nursery diet complexity and the use of in-feed antibiotics on eBW at wk 17 post-weaning. Pigs fed simple nursery diets that excluded antibiotics had numerically lighter eBW than other treatments, but differences between individual treatment means were not significant.

5.4.4. Chemical body composition

In the results obtained from the initial kill at wk 2 post-weaning, there were no differences in chemical body composition among treatments, except in PB as a proportion of eBW and LB/PB (Table 5.4). Body protein content as a proportion of eBW was increased at wk 2 post-weaning ($P < 0.01$) in pigs fed simple nursery diets. There was also an interactive effect ($P < 0.01$) of nursery diet complexity and the use of in-feed antibiotics on PB as a proportion of eBW at wk 2. Body protein content as a proportion of eBW was decreased in pigs that were fed complex nursery diets excluding antibiotics as compared to pigs fed simple nursery diets excluding antibiotics ($P < 0.01$). Lastly, there was a trend towards an interaction (*P* = 0.052) of nursery diet complexity and the use of in-feed antibiotics on LB/PB at wk 2 post-weaning. Numerically, LB/PB was lower in pigs fed simple nursery diets excluding antibiotics as compared to pigs fed complex nursery diets excluding antibiotics, but differences between individual treatment means were not significant.

With the exception of the proportion of LB associated visceral lipid content at wk 8 and the proportion of PB associated with carcass and visceral lean tissue at wk 12, there was no effect of nursery dietary treatment on chemical body composition at wk 8 and 12 post-weaning, nor on Pd and Ld between weaning and either of wk 8 or 12 post-weaning (Tables 5.5 and 5.6). At wk 8, the proportion of LB associated with visceral lipid content was increased (*P* = 0.047) in pigs previously fed simple nursery diets. At wk 12, the proportion of PB associated with visceral lean tissue tended to be decreased (P = 0.08) when pigs were fed nursery diets that included in-feed antibiotics. Furthermore, there tended to be an interactive effect (P = 0.08) of nursery diet complexity and in-feed antibiotics on the proportion of PB associated with carcass lean tissue at wk 12 post-weaning. Numerically, pigs fed simple nursery diets excluding antibiotics had a smaller proportion of PB associated with carcass lean tissue at wk 12 than pigs that were fed simple nursery diets including antibiotics; however, differences between individual treatment means were not significant.

As mentioned previously, there was an effect of block on PB as a proportion of eBW at wk 12 post-weaning. As such, data obtained from block 5 was removed and analysis was re-run for this variable: PB/eBW was 16.6%, 16.6%, 15.6% and 17.0% for the complex –AB, complex +AB, simple –AB and simple +AB treatments, respectively; after this adjustment there were no differences among treatments.

There was a trend towards an effect (P = 0.08) of nursery diet complexity on the rate of Pd from 70 to 115 kg BW. Pigs fed simple nursery diets tended to have a greater rate of Pd in the specified BW range (Table 5.7). There was also an interactive effect (P = 0.03) of nursery diet complexity and the use of in-feed antibiotics on chemical body composition at wk 17 post-weaning. Pigs fed simple nursery diets excluding antibiotics tended to have a lower proportion of PB associated with carcass lean tissue than pigs that were fed simple nursery diets including antibiotics (P = 0.09). There tended to be an interactive effect (P = 0.096) of nursery diet complexity and in-feed antibiotic usage on eBW at wk 17 post-weaning. Pigs that were fed simple nursery diets including antibiotics had numerically decreased eBW at slaughter as compared to pigs fed simple nursery diets excluding antibiotics, but differences between individual treatment means were not significant. There was also a trend towards an interactive effect ($P = 0.09$) of nursery diet complexity and the use of in-feed antibiotics on the composition of tissue growth from 40 and 115 kg BW. Pigs fed simple nursery diets including antibiotics tended to have a numerically larger proportion of total tissue gain associated with Pd than pigs that were fed simple nursery diets excluding antibiotics, but differences between individual treatment means were not significant.

5.4.5 Changes PB, LB and LB/PB over time

Based on regression analyses, PB increased linearly ($P < 0.01$) and quadratically ($P < 0.05$) for all treatments from wk 2 to wk 17 (Figure 5.1). The quadratic regression equations for each treatment were: $y = 0.001x^2 + 0.10x + 1.29$ ($R^2 = 0.98$), $y = 0.0004x^2 + 0.11x + 1.31$ ($R^2 = 0.99$), $y = 0.001x^2 + 0.08x + 1.42$ ($R^2 = 0.96$) and $y = 0.0004x^2 + 0.12x + 1.32$ ($R^2 = 0.97$) for complex –AB, complex +AB, simple –AB and simple +AB, respectively.

Body lipid mass increased linearly ($P < 0.01$) and quadratically ($P < 0.01$) across all treatments from wk 2 to wk 17 (Figure 5.2). The quadratic regression equations for each treatment were: $y = 0.003x^2 – 0.02x + 0.84$ ($R^2 = 0.95$), $0.003x^2 – 0.06x + 1.00$ ($R^2 = 0.94$), $y = 0.003 x^2 – 0.02x + 0.78$ ($R^2 = 0.90$) and $y = 0.02 x^2 + 0.02x + 0.87$ ($R^2 = 0.94$) for complex –AB, complex +AB, simple –AB and simple +AB, respectively.

Body composition changed over time as LB/PB increased linearly ($P < 0.01$) for all treatments (Figure 5.3). While the LB/PB of pigs fed complex +AB in the nursery increased quadratically ($P = 0.01$), no other treatment showed a quadratic increase in LB/PB over time. The linear regression equations for each treatment were: $y = 0.007x + 0.66$ ($R^2 = 0.43$), $y = 0.010x + 0.43$ ($R^2 = 0.60$) and $y = 0.07x + 0.55$ ($R^2 = 0.69$) for complex –AB, simple –AB and simple +AB, respectively. The quadratic equation for pigs fed complex +AB, the regression was $y = 0.0001x^2 - 0.002x + 0.56$ ($R^2 = 0.79$).

5.5. Discussion

In this study, complex or simple nursery diets, including or excluding in-feed antibiotics, were fed to assess the effect of nursery diet complexity and in-feed antibiotic usage on growth performance up to market weight, plasma levels of growth-related hormones, meat quality, weight of primal and retail cuts, body composition, as well as Pd and Ld based on serial slaughter measurements.

The rate of growth immediately post-weaning may influence subsequent pig growth performance as well as carcass and meat quality characteristics at market BW (Wolter et al., 2003). While a number of studies have been conducted to better understand the effect of growth performance immediately post-weaning on subsequent growth performance and carcass quality, results of these studies have been variable. Wolter et al. (2003) indicated that pigs experiencing accelerated growth post-weaning had lower levels of backfat thickness and increased estimated carcass lean content at market BW. It has also been shown that reduced growth performance early post-weaning and subsequent compensatory growth may improve pork eating quality (Kristensen et al., 2004). Further studies have shown that post-weaning growth performance has no effect on carcass characteristics at market weight (Chaosap et al, 2011; Dritz et al., 1996a). In the present study, diet complexity and the use of in-feed antibiotics influenced growth performance post-weaning (Chapter 3), but had no effect on wean-to-slaughter growth performance (Chapter 3), carcass quality or subjective and objective meat quality measures.

In the present study, the weight of retail and trimmed cuts as a proportion of the left carcass was consistent with the findings of other studies (Martinez-Ramirez et al., 2009; Tuitoek et al., 1997). Martinez-Ramirez et al. (2009) showed that protein intake restriction between approximately 15 and 35 kg BW reduced growth performance but induced compensatory growth thereafter with no effect on the weight of primary carcass cuts and total carcass lean content.

In the present study, feeding simple nursery diets tended to increase the weight of the primal belly at slaughter and there was an interactive effect of nursery diet complexity and the use of in-feed antibiotics on primal belly weight. The observed effect is mainly due to an increase in the weight of the belly in pigs that were fed simple nursery diets that included antibiotics. To our knowledge, there are no other studies that have observed this effect.

Godfrey et al. (1991) indicated that when feed intake was reduced between 40 and 85 kg BW, carcasses yielded less fat and more muscle than those of pigs that were fed ad libitum. However, there were observed differences in the distribution of tissues across the carcass as pigs that were fed restrictively had increased levels of fat and lean tissue in the belly relative to fat and lean content in other primal cuts. This is consistent with the findings of this study as the average daily feed intake during the grower and finisher periods was numerically lowest in pigs that had the largest bellies, e.g. pigs that were fed simple nursery diets that included antibiotics. Furthermore, Estany et al. (2002) indicated that increased belly weight may be related to an increase in total carcass muscle content. This is consistent with the findings of the current study as the amount of PB as a proportion of eBW and the percentage of total PB attributed to carcass lean tissue was numerically greatest in pigs that had the largest bellies, e.g. pigs that were fed simple nursery diets that included antibiotics.

Previous research has shown that the weight of organs is not affected by diet complexity (Dritz et al, 1996a) or by restricting amino acid intake (Kamalakar et al., 2009; Martinez-Ramirez et al., 2008). In this study, diet complexity did not generally affect organ weight as a proportion of eBW. The weight of the kidneys at wk 8, as well as empty gut weight at wk 2 and 17 post-weaning, was affected by nursery feeding programs. Pigs fed complex nursery diets tended to have larger kidneys at wk 8 which may be related to dietary digestible protein intake in the nursery period. Feeding increased amounts of digestible protein may increase kidney weight due to the increased metabolic activity associated with urea synthesis and excretion of excess protein intake (Kerr et al., 1995). Pigs fed simple nursery diets tended to have increased empty gut weight at wk 2 and 17 post-weaning. The increase in gut weight at wk 17 may be, in part, explained by increased feed intake; pigs fed simple nursery diets that excluded antibiotics had, numerically, the highest average daily feed intake in the finisher period (Chapter 3). Pigs fed simple nursery diets also tended to have a larger empty gut as a proportion of eBW at wk 2. This may be reflective of these pigs having lighter live BW at wk 2 and the anticipated lower digestibility of the simple nursery diets as compared to the complex diets. Previous studies have shown an inverse relationship between diet digestibility and gut weight (e.g. de Lange et al., 2003).

Reducing nursery diet complexity may negatively influence immediate and subsequent growth performance and alter the dynamics of Pd and Ld (de Greef et al., 1992; Dritz et al., 1996a). Conversely, Whang et al. (2000) indicated that, although feeding simple nursery diets decreased nursery growth performance, it was followed by a compensatory growth response resulting in no overall effect of nursery feeding programs on carcass protein content at market BW or Pd from weaning to market BW.

Based on previous research conducted in our laboratory, it was hypothesized that feeding simple nursery diets would reduce dietary protein intake and increase Ld/Pd during the nursery period. Martinez-Ramirez et al (2008) indicated that restricting amino acid intake resulted in increased carcass fatness during the restriction period and subsequently induced increased Pd during the compensatory growth period. The latter was suspected to be driven by a genetically predetermined target LB/PB during the energy-dependent phase of growth. In the present study, feeding simple nursery diets did not increase LB or LB/PB at wk 2 or wk 8 post-weaning. Contrary to this, pigs fed simple nursery diets had a greater level of PB as a proportion of eBW at wk 2 post-weaning. Whang et al. (2000) indicated that protein deposition is given priority in tissue development early post-weaning as, even during short periods of BW loss, pigs may have positive Pd supported by energy mobilized from LB. In the current experiment, pigs fed simple nursery diets had decreased growth performance in the nursery period and had numerically lighter live BW at wk 2 post-weaning. However, pigs fed simple nursery diets had more PB as a proportion of eBW. This suggests preferential Pd in favour of Ld early post-weaning.

In general, nursery feeding program did not affect mean nutrient accretion rates between wk 2 and 17 post-weaning or body composition at slaughter. Nursery diet complexity and the use of in-feed antibiotics in nursery diets had no effect on Pd, Ld or Ld/Pd, with the exception of Pd in the finisher phase. Pigs fed simple nursery diets tended to have greater Pd between 70 and 115 kg BW, which is indicative of compensatory lean tissue gain during the finisher period. Due to a lack of consistency in chemical body composition or nutrient accretion results, it is difficult to speculate what may have caused pigs that were fed simple nursery diets to have a trend towards greater Pd between 70 and 115 kg BW. Martinez-Ramirez et al. (2009) indicated that dietary nutrient restriction may reduce hypertrophy of muscle fibres and that subsequent compensatory Pd may be attributed to increased hypertrophy of satellite cells in skeletal muscle tissue if the number of muscle fibre cells has not been reduced by nutrient intake restriction.

The lack of major effects of treatment on Pd, Ld and Ld/Pd is consistent with the regression analysis which indicates no major differences between treatments for gains of PB and LB over time as well as changes in LB/PB over time. However, numerically, PB increased quickest in pigs fed simple diets that did not include in-feed antibiotics and this is related to the greater Pd observed in this treatment between 70 and 115 kg BW. The lack of effect of dietary treatment on chemical body composition measures also reflects the variable nature of these body characteristics and the choice of sampling times used for serial slaughter. As discussed in Chapter 3 of this thesis, feeding simple nursery diets reduced average daily gain throughout the entire nursery period but only reduced feed efficiency in nursery Phase I and II. Pigs that experienced periods of reduced growth began to show improvements in feed efficiency during nursery Phase III and the majority of compensatory gains in pigs fed nursery diets that did not include in-feed antibiotics, in terms of BW recovery, were made during the grower period. The dates chosen for serial slaughter may not have best represented the periods of growth restriction and compensatory growth. Therefore, any treatment-induced differences in tissue development or body composition that may have been present at the end of the period of reduced growth may not have been reflected in data obtained in the current study.

5.6. Conclusions and implications

Based on the results of the current study, nursery diet complexity and in-feed antibiotic usage had no effect on meat quality, the weight of primal and retail meat cuts, with the exception of primal belly weight, rates of Pd, Ld, Ld/Pd, with the exception of mean Pd during the finisher phase, or chemical body composition at market BW. While feeding simple nursery diets reduced growth performance in the nursery period (Chapter 3), there was no effect on carcass quality or body composition at market BW.

The use of simple nursery diets may allow producers to reduce production costs without reducing lifetime growth performance or carcass value. However, further research is required to better assess the effect of diet complexity and in-feed antibiotic usage on the dynamics of tissue accretion. The lack of treatment-induced differences in mean Pd and Ld between weaning and market weight reflects the observed variability in these traits and may be due to the timing of serial slaughter observations. Further research should be conducted to more closely match body composition analysis with the periods of reduced growth and compensatory growth.

Table 5.1. Effect of nursery diet complexity and in-feed antibiotics on subjective and objective measurements associated with meat quality

	Treatment[1]					*P*-value[2]		
Measurement[3]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
Live BW (kg)	117.6	119.0	119.3	119.0	0.98	0.40	0.57	0.36
Hot carcass weight (kg)	97.3	97.2	96.9	97.6	0.38	0.95	0.42	0.27
Carcass yield (%)	81.9	81.8	81.6	82.1	0.32	0.94	0.46	0.31
Fat probe depth (mm)	19.4	19.2	20.1	20.2	0.84	0.33	0.95	0.87
Muscle probe depth (mm)	58.6	58.3	57.4	57.1	1.13	0.30	0.76	0.99
Fat ruler measure (mm)	15.2	15.4	17.0	15.5	0.99	0.35	0.51	0.38
Loin eye area (mm^2)	4998	4980	5081	5232	122	0.19	0.59	0.50
Firmness (1-3)	1.74	1.66	1.73	1.74	0.10	0.74	0.70	0.63
Wetness (1-3)	1.62	1.56	1.71	1.63	0.13	0.53	0.55	0.96
NPPC marbling (1-10)	1.52	1.35	1.68	1.44	0.13	0.35	0.14	0.81
NPPC colour (1-6)	2.42	2.37	2.20	2.30	0.15	0.34	0.86	0.63
Japanese colour (1-6)	2.26	2.27	2.19	2.32	0.11	0.91	0.55	0.58
Loin L*	51.8	51.5	51.9	52.1	0.81	0.67	0.95	0.80
Loin a*	8.71	8.41	8.40	8.57	0.31	0.79	0.83	0.45
Loin b*	3.89	3.46	3.68	3.80	0.38	0.86	0.69	0.46
Loin pH	5.43	5.41	5.46	5.42	0.02	0.44	0.28	0.68
Drip loss (%)	5.74	4.63	6.16	5.63	0.58	0.24	0.18	0.62
Shear force (kg)	4.39	4.47	4.41	4.31	0.26	0.78	0.97	0.73

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] n = 17 observations (pigs) per treatment

Table 5.2. Effect of nursery diet complexity and in-feed antibiotics on the weight of retail cuts and carcass contents as determined by carcass dissection of pigs at market weight

	Treatment[1]					*P*-value[2]		
Measurement[3]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
Left side carcass weight (kg)	43.2	43.7	43.7	44.1	0.37	0.23	0.18	0.86
Shoulder, primal (%)	20.4	20.7	20.5	20.3	0.26	0.38	0.91	0.31
Butt (%)	7.96	8.03	7.73	7.79	0.16	0.15	0.67	0.95
Picnic (%)	9.65	9.92	9.87	9.80	0.15	0.75	0.51	0.23
Belly, primal (%)	19.5	19.3	19.4	20.2	0.24	0.08	0.28	0.04
Belly, retail (%)	11.9	11.9	11.9	12.5	0.23	0.18	0.19	0.19
Loin, primal (%)	25.0	25.0	24.9	25.1	0.38	0.95	0.77	0.88
Tenderloin (%)	0.96	0.97	0.99	0.96	0.02	0.55	0.53	0.40
Boneless loins (%)	7.33	7.38	7.30	7.37	0.16	0.90	0.70	0.95
Ham, primal (%)	24.7	24.8	24.6	24.6	0.25	0.45	0.91	0.84
Ham, retail (%)	18.4	18.4	18.1	18.4	0.26	0.66	0.55	0.52
Bone (%)	8.26	8.63	8.26	8.15	0.18	0.19	0.47	0.17
Fat trim (%)	15.5	15.8	16.2	15.4	0.64	0.87	0.66	0.36
Lean trim (%)	7.86	7.60	7.75	7.89	0.20	0.65	0.77	0.32

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] Values for cuts of meat, bone tissue, fat trim and lean trim represent their weight as a proportion of the left carcass weight (n = 17 observations [pigs] per treatment).

Table 5.3. Effect of nursery diet complexity and in-feed antibiotics on the physical composition of growing pigs at different times post-weaning

	Treatment[1]					*P*-value[2]		
Measurement[3]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
Wk 2								
Live BW (kg)	9.80	9.67	9.10	9.20	0.48	0.25	0.98	0.82
Empty BW (kg)	9.14	9.04	8.41	8.59	0.46	0.22	0.94	0.76
Blood (%)	7.66	8.99	7.80	8.25	0.79	0.71	0.27	0.59
Empty gut (%)	9.68	9.61	10.1	10.3	0.32	0.09	0.90	0.72
Liver (%)	3.67	3.28	3.19	3.60	0.17	0.65	0.95	0.03
Kidneys (%)	0.60	0.56	0.59	0.61	0.03	0.55	0.77	0.35
Heart (%)	0.58	0.57	0.59	0.59	0.03	0.91	0.73	0.87
Spleen (%)	0.22	0.19	0.18	0.19	0.02	0.29	0.57	0.37
Lungs (%)	2.09	2.09	2.04	2.11	0.08	0.90	0.71	0.71
Wk 8								
Live BW (kg)	39.6	40.1	39.7	41.8	1.61	0.59	0.42	0.61
Empty BW (kg)	38.0	38.4	38.0	40.1	1.52	0.59	0.42	0.56
Blood (%)	6.69	5.98	7.56	7.17	0.81	0.22	0.51	0.84
Empty gut (%)	7.93	7.82	8.21	7.65	0.24	0.82	0.19	0.37
Liver (%)	2.86	2.84	2.84	2.81	0.12	0.80	0.83	0.96
Kidneys (%)	0.60	0.57	0.50	0.52	0.04	0.08	0.80	0.54
Heart (%)	0.55	0.57	0.59	0.53	0.04	0.91	0.56	0.30
Spleen (%)	0.22	0.21	0.21	0.18	0.02	0.37	0.41	0.55
Lungs (%)	2.13	1.96	2.05	1.89	0.10	0.42	0.11	0.95
Wk 12								
Live BW (kg)	70.1	70.5	69.3	69.6	2.07	0.71	0.87	0.98
Empty BW (kg)	67.0	67.7	66.1	66.6	1.95	0.62	0.78	0.98
Blood (%)	5.23	5.14	5.44	4.93	0.56	0.99	0.57	0.69
Empty gut (%)	7.01	6.92	7.35	7.27	0.21	0.13	0.70	> 0.99
Liver (%)	2.50	2.50	2.68	2.44	0.10	0.57	0.23	0.22
Kidneys (%)	0.45	0.49	0.49	0.47	0.02	0.67	0.78	0.18
Heart (%)	0.44	0.47	0.42	0.41	0.03	0.19	0.76	0.44

Spleen (%)	0.18	0.18	0.19	0.20	0.01	0.17	0.95	0.84
Lungs (%)	1.63	1.75	1.72	1.75	0.09	0.63	0.44	0.68
Wk 17								
Live BW (kg)	116.1	117.3	117.8	114.5	1.32	0.69	0.42	0.11
Empty BW (kg)	113.2	114.7	115.0	111.8	1.22	0.66	0.50	0.08
Blood (%)	3.30	3.29	3.59	3.35	0.14	0.21	0.38	0.39
Empty gut (%)	5.12	5.16	5.66	5.50	0.18	0.02	0.75	0.58
Liver (%)	1.71	1.68	1.77	1.71	0.06	0.43	0.40	0.78
Kidneys (%)	0.32	0.35	0.37	0.34	0.01	0.26	0.70	0.08
Heart (%)	0.40	0.37	0.38	0.39	0.02	0.93	0.47	0.33
Spleen (%)	0.16	0.14	0.16	0.17	0.01	0.12	0.63	0.04
Lungs (%)	1.12	1.24	1.19	1.27	0.08	0.54	0.24	0.80

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] Values are expressed as a % of empty BW (n = 6 [pigs] per treatment per sampling period).

Table 5.4. Effect of nursery diet complexity and in-feed antibiotics on the chemical body composition of pigs at wk 2 post-weaning

	Treatment[1]					*P*-value[2]		
Measurement[4]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
PB (kg)[3]	1.39	1.39	1.32	1.36	0.04	0.74	0.11	0.62
LB (kg)[3]	0.83	0.76	0.81	0.84	0.04	0.66	0.42	0.04
LB/PB (g/g)[3]	0.64	0.55	0.54	0.61	0.04	0.73	0.80	0.052
PB (% of empty BW)	14.4	15.1	16.0	15.7	0.15	< 0.01	0.31	< 0.01
LB (% of empty BW)	9.14	8.22	8.67	9.57	0.59	0.46	0.99	0.14
Ash (% of empty BW)	2.45	2.68	2.74	2.61	0.13	0.42	0.71	0.21
Water (% of empty BW)	71.6	72.5	71.3	71.2	0.52	0.17	0.49	0.37

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] PB: whole body protein weight; LB: whole body lipid weight; LB/PB: ratio between while body lipid weight and body protein weight.

[4] n = 6 observations (pigs) per treatment

Table 5.5. Effect of nursery diet complexity and in-feed antibiotics on the chemical body composition of pigs at wk 8 post-weaning as well as nutrient accretion rates between wk 2 and wk 8 post-weaning

	Treatment[1]					*P*-value[2]		
Measurement[4,5]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
PB (kg)[3]	6.60	6.71	6.42	6.51	0.24	0.43	0.67	0.96
Pd (g/d)	126.0	126.9	122.8	125.3	5.34	0.65	0.73	0.88
LB (kg)[3]	4.91	4.93	4.35	5.03	0.35	0.50	0.28	0.31
Ld (g/d)	99.3	99.0	86.3	103.3	8.56	0.61	0.30	0.29
LB/PB (g/g)[3]	0.75	0.74	0.68	0.77	0.05	0.70	0.34	0.27
Ld/Pd (g/g)	0.79	0.79	0.71	0.82	0.06	0.65	0.36	0.30
PB (% of empty BW)	17.0	16.9	17.3	16.7	0.33	0.86	0.37	0.45
LB (% of empty BW)	12.8	12.7	11.6	12.6	0.70	0.30	0.48	0.38
Ash (% of empty BW)	2.37	2.42	2.32	2.35	0.10	0.52	0.66	0.92
Water (% of empty BW)	65.7	63.8	65.3	64.2	1.92	0.97	0.40	0.83
Visceral protein (% of PB)	11.6	10.9	11.8	10.9	0.54	0.81	0.11	0.90
Carcass protein (% of PB)	81.7	82.9	80.3	81.3	1.14	0.20	0.29	0.89
Visceral lipid (% of LB)	6.84	6.90	9.48	8.24	0.94	0.047	0.50	0.47
Carcass lipid (% of LB)	94.8	95.5	92.4	94.9	2.14	0.47	0.44	0.65

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] PB: whole body protein weight; LB: whole body lipid weight; LB/PB: ratio between while body lipid weight and body protein weight.

[4] Pd, Ld and Ld/Pd represent the rates of whole body protein deposition, whole body lipid deposition, and the composition of deposition (n = 6 observations [pigs] per treatment).

[5] Statistical analysis of PB, Pd, LB, Ld, LB/PB, Ld/Pd, and visceral/carcass protein or lipid content as a percentage of PB or LB included individual pig BW at weaning as a covariant.

Table 5.6. Effect of nursery diet complexity and in-feed antibiotics on the chemical body composition of pigs at wk 12 post-weaning as well as nutrient accretion rates between wk 2 and wk 12 post-weaning

	Treatment[1]					*P*-value[2]		
Measurement[4,5]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
PB (kg)[3]	11.1	11.3	10.6	11.3	0.31	0.47	0.14	0.45
Pd (g/d; 40-70 kg BW)	158.0	159.2	142.4	169.5	10.6	0.80	0.20	0.22
Pd (g/d; 10-70 kg BW)	142.8	144.6	136.3	145.2	4.58	0.52	0.26	0.44
LB (kg)[3]	11.3	10.2	12.0	10.9	1.16	0.53	0.35	0.98
Ld (g/d; 40-70 kg BW)	230.3	181.2	277.6	231.3	39.6	0.23	0.25	0.97
Ld (g/d; 10-70 kg BW)	153.5	138.1	166.1	147.2	16.9	0.53	0.34	0.92
LB/PB (g/g)[3]	1.02	0.90	1.13	0.96	0.11	0.45	0.21	0.83
Ld/Pd (g/g; 40-70 kg BW)	1.49	1.20	2.09	1.37	0.34	0.26	0.16	0.52
Ld/Pd (g/g; 10-70 kg BW)	1.07	0.96	1.21	1.02	0.12	0.42	0.23	0.75
PB (% of empty BW)	16.5	16.9	16.2	17.0	0.39	0.83	0.14	0.50
LB (% of empty BW)	16.8	15.2	17.4	16.5	1.33	0.47	0.34	0.80
Ash (% of empty BW)	2.57	2.54	2.44	2.50	0.19	0.66	0.94	0.82
Water (% of empty BW)	61.8	62.9	61.6	61.6	1.13	0.52	0.63	0.65
Visceral protein (% of PB)	10.6	10.3	11.3	10.6	0.25	0.11	0.08	0.44
Carcass protein (% of PB)	83.7	83.4	82.4	84.3	0.61	0.77	0.21	0.08
Visceral lipid (% of LB)	6.38	7.09	6.94	6.92	0.39	0.62	0.40	0.35
Carcass lipid (% of LB)	93.4	92.7	92.9	92.9	0.40	0.69	0.40	0.31

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] PB: whole body protein weight; LB: whole body lipid weight; LB/PB: ratio between while body lipid weight and body protein weight.

[4] Pd, Ld and Ld/Pd represent the rates of whole body protein deposition, whole body lipid deposition, and the composition of deposition (n = 6 observations [pigs] per treatment).

[5] Statistical analysis of PB, Pd, LB, Ld, LB/PB, Ld/Pd, and visceral/carcass protein or lipid content as a percentage of PB or LB included individual pig BW at weaning as a covariant.

Table 5.7. Effect of nursery diet complexity and in-feed antibiotics on the chemical body composition of pigs at wk 17 post-weaning as well as nutrient accretion rates between wk 2 and wk 17 post-weaning

	Treatment[1]					*P*-value[2]		
Measurement[4,5]	Complex -AB	Complex +AB	Simple -AB	Simple +AB	SEM	Diet	AB	Diet × AB
PB (kg)[3]	17.4	17.5	17.6	18.3	0.46	0.25	0.39	0.40
Pd (g/d; 70-115 kg BW)	143.6	128.4	154.5	151.3	9.83	0.08	0.36	0.52
Pd (g/d; 40-115 kg BW)	156.4	143.1	175.9	150.9	11.0	0.22	0.11	0.61
Pd (g/d; 10-115 kg BW)	148.2	143.7	159.6	145.8	6.93	0.33	0.21	0.51
LB (kg)[3]	25.9	28.4	27.9	25.3	2.11	0.78	0.98	0.21
Ld (g/d; 70-115 kg BW)	345.5	420.9	387.7	319.1	49.0	0.55	0.95	0.17
Ld (g/d; 40-115 kg BW)	304.0	334.0	341.7	292.2	32.1	0.95	0.76	0.20
Ld (g/d; 10-115 kg BW)	228.9	252.4	248.4	223.8	19.3	0.80	0.98	0.20
LB/PB (g/g)[3]	1.53	1.61	1.68	1.35	0.18	0.74	0.49	0.20
Ld/Pd (g/g; 70-115 kg BW)	2.73	3.41	2.82	2.24	0.60	0.29	0.93	0.24
Ld/Pd (g/g; 40-115 kg BW)	2.12	2.21	2.39	1.53	0.28	0.43	0.19	0.09
Ld/Pd (g/g; 10-115 kg BW)	1.63	1.69	1.82	1.29	0.18	0.52	0.21	0.11
PB (% of empty BW)	15.8	15.6	15.7	16.7	0.44	0.26	0.32	0.15
LB (% of empty BW)	23.7	25.0	24.8	22.6	1.75	0.71	0.78	0.29
Ash (% of empty BW)	3.01	2.47	2.57	2.80	0.25	0.83	0.52	0.15
Water (% of empty BW)	54.9	54.5	54.6	56.4	1.36	0.53	0.57	0.40
Visceral protein (% of PB)	7.98	8.19	8.67	7.61	0.43	0.90	0.34	0.13
Carcass protein (% of PB)	88.2	87.9	87.0	88.8	0.47	0.67	0.16	0.03
Visceral lipid (% of LB)	5.28	5.58	6.06	6.04	0.55	0.24	0.77	0.79
Carcass lipid (% of LB)	94.6	94.3	93.9	93.9	0.56	0.25	0.81	0.80

[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

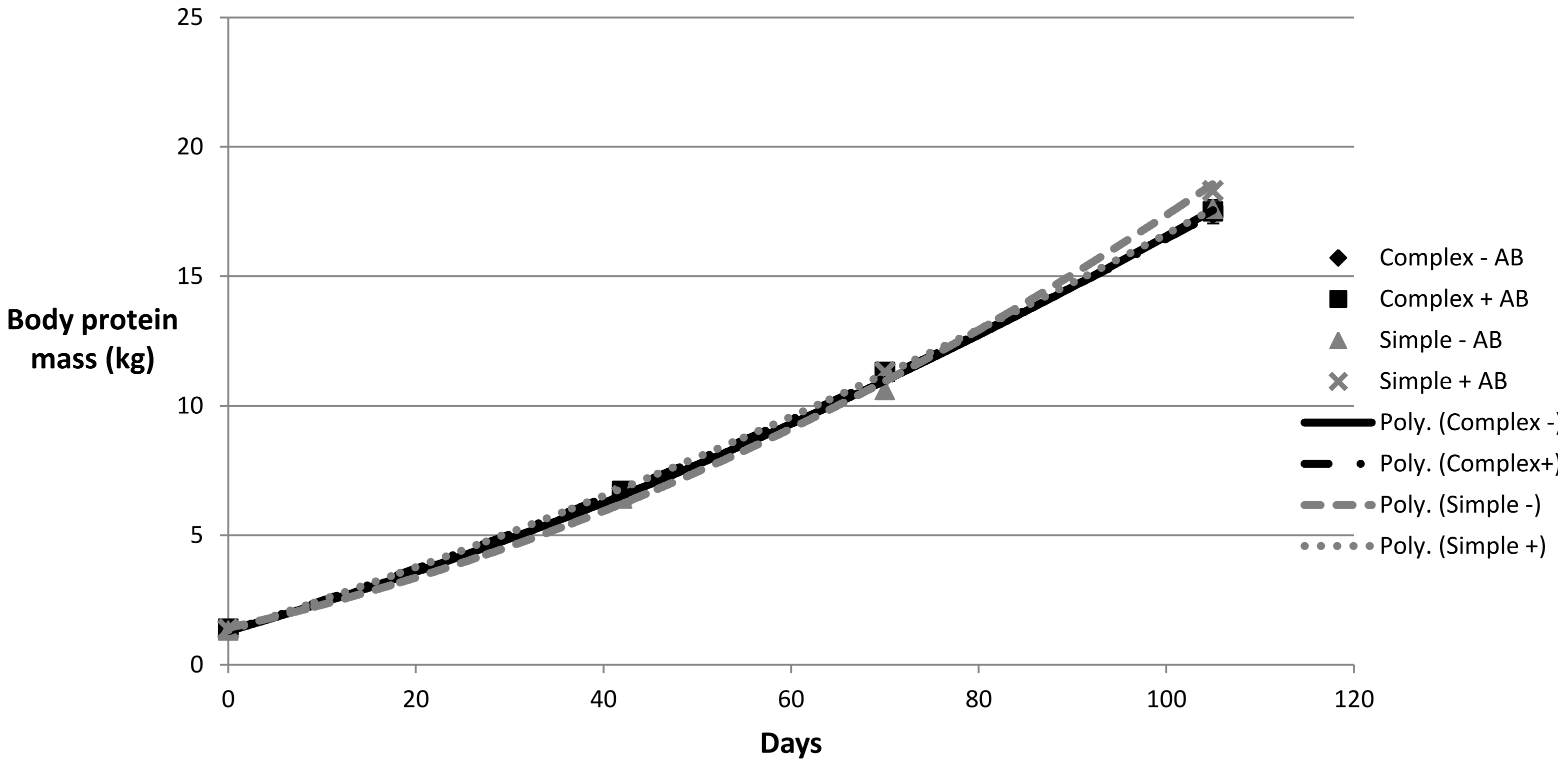
[2] Probabilities of effects. Diet: effect of diet complexity; AB: effect of in-feed antibiotic inclusion; Diet × AB: interactive effect of in-feed antibiotic inclusion and diet complexity.

[3] PB: whole body protein weight; LB: whole body lipid weight; LB/PB: ratio between whole body lipid weight and body protein weight.

[4] Pd, Ld and Ld/Pd represent the rates of whole body protein deposition, whole body lipid deposition, and the composition of deposition (n = 6 observations [pigs] per treatment).

[5] Statistical analysis of PB, Pd, LB, Ld, LB/PB, Ld/Pd, and visceral/carcass protein or lipid content as a percentage of PB or LB included individual pig BW at weaning as a covariant.

Figure 5.1. Effect of dietary treatment on the relationship between whole body protein (PB) and time (days since weaning) [1, 2]

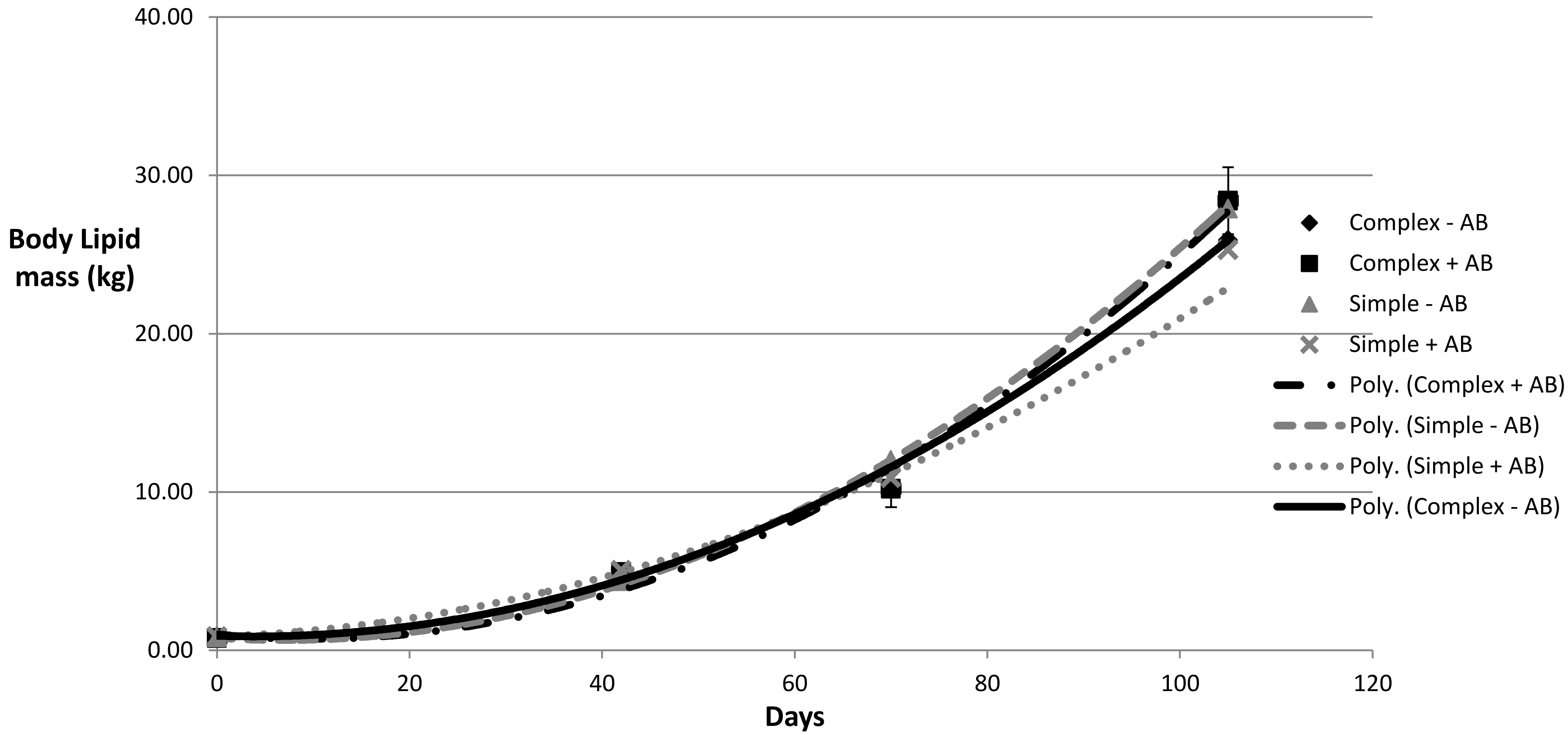


[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Observations were taken from 6 pigs per treatment of wk 2, 8, 12 and 17 post-weaning. Data are means and SEM from blocks 3-5.

Regression equations representing all treatments are $y = 0.001x^2 + 0.10x + 1.29$ ($R^2 = 0.98$), $y = 0.0004x^2 + 0.11x + 1.31$ ($R^2 = 0.99$), $y = 0.001x^2 + 0.08x + 1.42$ ($R^2 = 0.96$) and $y = 0.0004x^2 + 0.12x + 1.32$ ($R^2 = 0.97$) for complex –AB, complex +AB, simple –Ab and simple +AB, respectively. $P < 0.05$ for all parameter estimates.

Figure 5.2. Effect of dietary treatment on the relationship between whole body lipid (LB) and time (days since weaning) [1, 2]

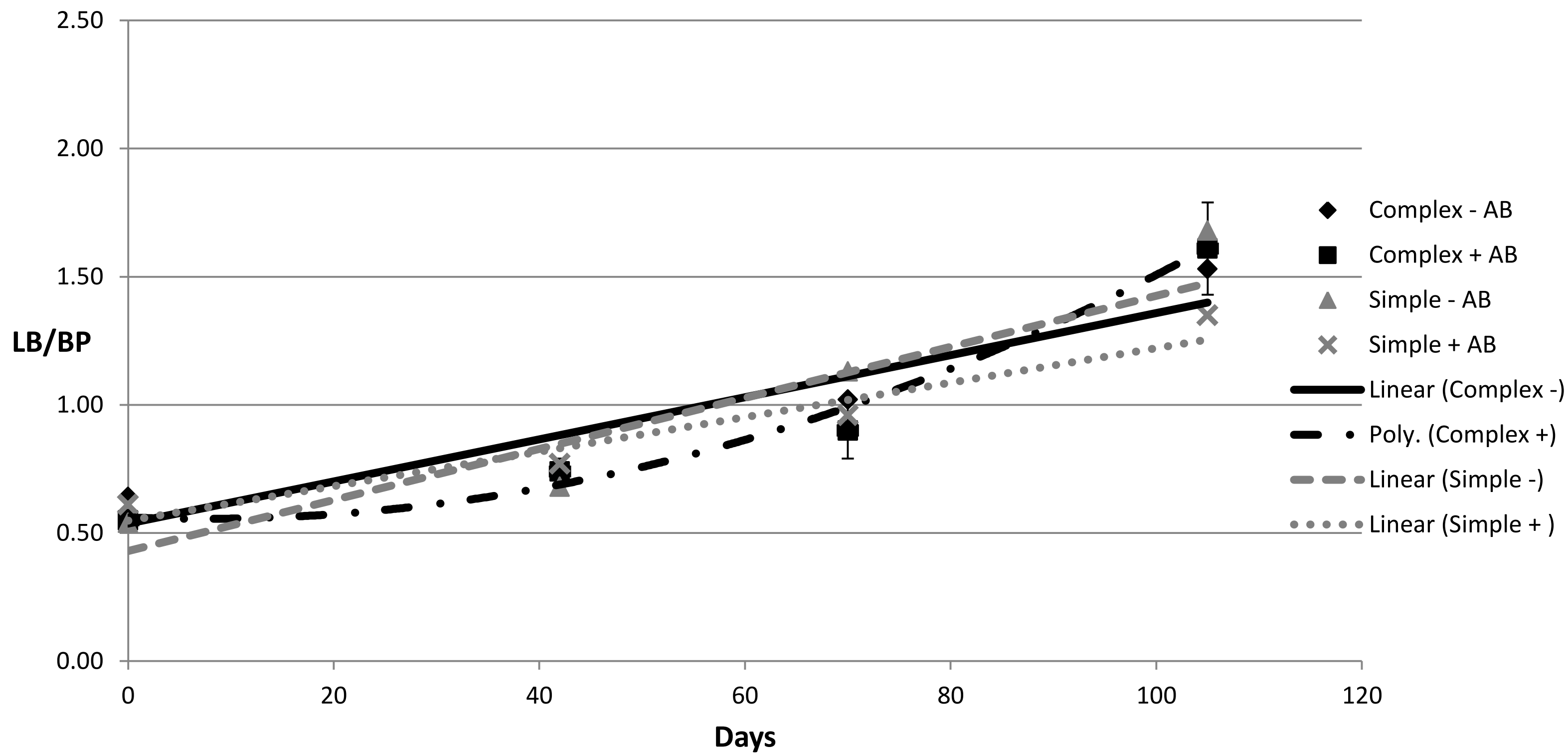


[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Observations were taken from 2 pigs per treatment at wk 2, 8, 12 and 17 post-weaning. Data are means and SEM from blocks 3-5.

Regression equations representing all treatments are $y = 0.003x^2 – 0.02x + 0.84$ ($R^2 = 0.95$), $0.003x^2 – 0.06x + 1.00$ ($R^2 = 0.94$), $y = 0.003 x^2 – 0.02x + 0.78$ ($R^2 = 0.90$) and $y = 0.02 x^2 + 0.02x + 0.87$ ($R^2 = 0.94$) for complex –AB, complex +AB, simple –Ab and simple +AB, respectively.

Figure 5.3. Effect of dietary treatment on the relationship between body chemical composition (LB/PB) and time (days since weaning) [1, 2]



[1]Dietary treatments were based on diet complexity (Complex and Simple), with or without antibiotic inclusion (Chlortetracycline, 600 ppm [added in the form of Aureomycin 220 G] in complete feed; added at the expense of corn) fed from weaning to 63 d of age (i.e. nursery). All pigs received common grower and finisher diets thereafter.

[2] Observations were taken from 2 pigs per treatment at wk 2, 8, 12 and 17 post-weaning. Data are means and SEM from blocks 3-5.

Regression equations representing all treatments are $y = 0.007x + 0.66$ ($r^2 = 0.43$), $y = 0.0001x^2 - 0.002x + 0.56$ ($R^2 = 0.79$), $y = 0.010x + 0.43$ ($r^2 = 0.60$) and $y = 0.07x + 0.55$ ($r^2 = 0.69$) for complex –AB, complex +AB, simple –Ab and simple +AB, respectively.

6.0. General discussion, implications and future considerations

Feed costs represent the largest proportion of total costs in commercial pork production. Nursery feeding programs include highly digestible, processed ingredients that are designed to help a young pig transition from sow's milk to a solid diet (Mahan and Lepine, 1991); these ingredients are expensive, increase diet complexity and increase nursery feed costs. The use of nursery feeding programs that include highly digestible ingredients, such as blood plasma or whey, have been shown to improve nursery pig growth performance (Dritz et al., 1996a,b; Mavromichalis et al., 2001). However, there is evidence that reducing nursery diet complexity by removing some of these expensive, highly digestible ingredients from the diet may reduce post-weaning growth performance without compromising long-term growth performance or carcass quality (Whang et al., 2000; Wolter et al., 2003). Furthermore, reducing nursery diet complexity may cause physiological changes in piglets post-weaning (Shen et al., 2012), including changes in the endogenous synthesis of growth-related hormones and animal sensitivity to these hormones (Morovat and Dauncey, 1998). This may also alter the animal's immune response and thereby influence nutrient utilization, animal growth performance and, ultimately, carcass quality (Hornick et al., 2000; Lebret, 2008). Including antibiotics in nursery pig diets generally improves growth performance post-weaning (Coffey and Cromwell, 1995) and may also permanently affect pig physiology.

The objectives of the studies reported in this thesis were to assess the effect of nursery diet complexity and in-feed antibiotic usage on growth performance up to market BW (approximately 115 kg), carcass quality at market BW and dynamic changes in blood plasma levels of various immune and growth-related hormones. These hormones were also evaluated to identify potential bio-markers that may be used to predict the effect of external stressors on growth performance. Furthermore, the effect of nursery diet complexity and in-feed antibiotic usage on meat quality, the size of primal and retail meat cuts at market BW, dynamic changes in body composition over time and the rate of nutrient accretion at various stages of growth were also examined.

Feeding simple diets to newly weaned pigs decreased growth performance early post-weaning (Chapter 3). The latter is consistent with a number of studies that have shown improved nursery performance when expensive animal protein sources are included in nursery diets (Dritz et al., 1996a,b; Mavromichalis et al., 2001; Sulabo et al., 2010). Furthermore, the inclusion of antibiotics in nursery diets improved average daily gain during Phase II and III of the nursery period. This is also consistent with the findings of other studies (Coffey and Cromwell, 1995; Dritz et al, 2002; Ragland et al., 2008).

The results of this study indicate that feeding simple nursery diets or nursery diets that do not include antibiotics compromises growth performance during the nursery period but does not affect growth performance between weaning and market BW or carcass value (Chapter 3). Furthermore, based on the results of calculating the compensatory growth index (**CG%**), feeding nursery diets that do not include antibiotics induces compensatory growth following a period of reduced growth. It is important to note that the reference group chosen for CG% calculations (complex, +AB) had the slowest rate of gain during the G-F period. As such, the use of CG% values to identify compensatory growth incidences may have led to overestimating the overall extent of compensatory growth. Moreover, it is also important to note that the current study only examined the use of chlortetracycline at one dosage level and the inclusion rate used was at a level that is considered a therapeutic dosage. As such, the observed responses may have varied if other antibiotics or other dosage levels were used.

Along with the absence of any effect of nursery feeding programs on wean-to-finish growth performance and carcass quality at market BW, feeding simple nursery diets reduced feeding costs (Chapter 3). However, a disease challenge that was present in greatest severity in block 5 of this performance study indicated that the use of simple nursery diets may compromise the pig's ability to achieve compensatory growth and recuperate from earlier reductions in performance during a disease challenge. The findings of this study indicate that there may be a link between nursery feeding programs and a pig's ability to cope with environmental stressors.

Based on the results of this study, there did not appear to be a relationship between dietary treatment and plasma concentrations of IL-1β, IL-6, TNF-α, cortisol or leptin (Chapter 4). However, plasma IGF-1 levels at wk 4 tended to be lower for pigs fed nursery diets that did not include antibiotics and this corresponded to decreased nursery growth performance. Animals that experienced previous reductions in IGF-1 plasma levels and growth performance, followed by superior subsequent growth performance may have recovered levels of IGF-1 following realimentation (Therkildsen et al., 2004; Ishida et al., 2011). The plasma levels of IGF-1 in pigs fed nursery diets that did not include antibiotics recovered during the grower phase when compensatory growth occurred, but they did not exceed levels observed in the pigs on treatments that did not show compensatory growth. These findings suggest that plasma IGF-1 levels are closely associated with pig growth performance, but that there are factors that may affect the sensitivity of the pig's response to plasma IGF-1 levels during periods of compensatory growth. Moreover, based on the results of this study, there was an apparent correlation between IGF-1 plasma levels at weaning and subsequent growth performance. This may indicate that IGF-1 can be used as a bio-marker to predict future pig growth performance.

Triiodothyronine levels were reduced in pigs fed simple nursery diets at wk 4 but returned to the same level as pigs fed complex nursery diets from wk 6 to the end of the grower-finisher period. There may have been a delay from the end of the period of restricted nutrient intake to when T_3 levels were normalized and this may be an indication of a mechanism involved with compensatory growth. When basal metabolic rates decrease, along with plasma levels of T_3, the amount of dietary energy partitioned towards maintenance is reduced. Consequently, if the basal metabolic rate and the plasma level of T_3 remain reduced when pigs no longer experience compromised growth or nutrient intake, a greater proportion of nutrients may be available to support growth (Hornick et al., 2000). This may explain the improvement in feed efficiency observed in pigs fed simple diets during the final nursery phase and may be an indication of compensatory growth.

In the present study, diet complexity and the use of in-feed antibiotics influenced growth performance post-weaning but had no effect on carcass yield or subjective and objective meat quality measures (Chapter 5). With the exception of a trend towards pigs that were previously fed simple nursery diets having a larger primal belly size, there were no effects of nursery diet complexity on primal or retail meat cut size. In general, nursery dietary treatment did not influence tissue accretion rates or body composition at slaughter. Nursery diet had no effect on Pd, Ld or Ld/Pd through the grower-finisher phases, with the exception of Pd in the finisher phase as pigs fed simple nursery diets tended to have greater Pd rates from 70 to 115 kg BW. The lack of effect of diet treatment on chemical composition measures may be due to the sampling protocol that was used to evaluate changes in body composition over time. The sampling times chosen for serial slaughter observations may not have been the time points that best represented the period of reduced growth performance or the period of recovered growth performance. In future research, it may be more appropriate to remove pigs for body composition analysis at weaning, in order to determine proper baseline composition at the beginning of the nutrient intake restriction period, as well as at wk 4 post-weaning, as this time marked the apparent beginning of the period of recovered growth performance. Additional pigs could then be analyzed at wk 12 and 17 post-weaning to assess the dynamic changes in body composition up to market BW.

The use of simple nursery diets may reduce total feed costs by as much as $5/pig (Chapter 3) with no meaningful effects on wean-to-finish growth performance, carcass composition or meat quality. These findings need to be further explored as they represent an excellent opportunity for Canadian hog producers to reduce production costs and increase profits.

There are several research opportunities that should be explored to better understand the findings reported in this thesis. Further research should be conducted to evaluate the cost-benefit of feeding low complexity nursery diets and the effect this has on the pig's ability to deal with environmental stressors. Research relating growth performance during the nursery period and subsequent animal performance should be conducted under varying conditions to better represent commercial pork production practices. Specifically, the effect of in-feed antibiotic inclusion on subsequent growth performance should also be assessed. In addition, research should be completed to better understand the relationship between T_3 and basal metabolic rate during periods of reduced growth performance and subsequent periods of compensatory growth. Supplementary research should also be conducted to assess the possibility of using IGF-1 plasma levels at weaning to predict the future growth performance of growing pigs of varying genotypes and under varying environmental conditions. Lastly, further research is required to better assess the effect of diet complexity on the dynamics of nutrient accretion as this represents the composition of growth and is an important determinant of nutrient requirements.

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