THE IMPACT OF DIETARY INCLUSION OF CITRUS PULP ON THE GROWTH, FEED EFFICIENCY, CARCASS MERIT, AND LEAN QUALITY OF FINISHING PIGS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2012

To my Mom, Sister, and Papa for always pushing me to strive for excellence

ACKNOWLEDGMENTS

I would like to thank Dr. Chad Carr, for his endless dedication and guidance during my graduate education at the University of Florida. Chad has continually helped me, not only with my masters program, but also through my transition to Florida. His guidance has helped me a tremendous amount, and his friendship I have gained is priceless. It has been a tremendous joy to get to know Chad and his wife, Cathy. I greatly appreciate all that Dr. Carr has done for me and will continue to call on him for advice in the future.

I would also like to thank the members of my committee, Dr. Adegbola Adesogan and Dr. Joel Brendemuhl. I have called on each of them continuously throughout my research, and each and every time they gave me assistance on the current problem, while inticing me to think about unforeseen situations. Their wisdom has helped my education to become more well-rounded than I could have expected.

I must thank all of the graduate and undergraduate students at the University of Florida. Without their help I would never been able to accomplish what I have. Brett Denney, Parker Capparelli, and Christy Odom were a treamendous help in the care and well being of my hogs while on trial.

I am deeply thankful to Nick Myers, Mellissa Schook, and Mr. Larry Eubanks. Without their help in mixing, weighing, and feeding my pigs this trial would not have even started. Those early mornings and sticky nights of feeding and cleaning feeders could not have been fun. Nick and Mellissa have both been the greatest of friends to me while I have been in the sunshine state. I will stay in touch with Nick and Mr. Larry, and both will be great contacts.

Lastly, my most important thank you must be extended to my family. They are always there for me, and without pushing, continue to encourage me to do my best and strive for

excellence. My parents and my sister have always been a constant throughout my education and particularly, my Master's program. I owe my success up to, and beyond, this point to them.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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August 2012

Chair: Chad Carr
Major: Animal Sciences

The objective of this research was to study the impact of dietary inclusion of citrus pulp on the growth performance, carcass merit, and lean quality of finishing pigs. During the 39 d trial, pigs (n = 40) were fed one of four diets, consisting of a corn-soybean meal control diet (CON), the CON diet supplemented with 15% ensiled whole pulp (WP), ensiled pressed pulp (PP), or dried pulp (DP) on a dry matter (DM) basis. Dietary treatment did not affect overall average daily gain (ADG), pork carcass composition, or any measurement of loin color or pH at fabrication. Pigs fed the WP and PP diets had a greater ($P = 0.01$) overall gain to feed ratio than pigs from the DP and CON treatments. Gilts fed the CON diet had greater ($P = 0.01$) dressing percentages than pigs fed DP, WP, or PP. During retail display loin chops from pigs fed the PP diet had greater ($P = 0.03$) subjective lean color scores than chops from the other treatments. Dietary treatment did not affect trained sensory evaluation of pork chops for connective tissue or off-flavor, and chops from pigs fed either DP, WP, or PP did not differ or had greater values for juiciness and tenderness than pork chops from CON pigs. Replacing 15% of the diet DM with either DP, WP, or PP had marginal effects on growth performance, carcass traits, lean quality, or sensory characteristics.

CHAPTER 1
INTRODUCTION

Feed and other input costs have reached such critical levels that fibrous feedstuffs such as citrus pulp, previously determined to be of marginal quality for monogastrics (Cunha et al. 1950) are now being re-evaluated for use in swine diets (Watanabe et al., 2010). Citrus pulp is often included as an energy supplement in the diets of dairy and beef cattle in Florida due to its availability and low cost (Arthington et al., 2002). Whole citrus pulp (pulp residue, rind, and seed) contains approximately 10% dry matter (DM), immediately after the juice is removed. Whole citrus pulp (WP) is then pressed to extract citrus liquor and 0.05% calcium carbonate is added during grinding to make pressed pulp which contains approximately 20% DM. Pressed pulp (PP) is heated to make dried pulp (DP) which contains approximately 90% DM (Kale and Adsule, 1995) and typically has by high concentrations of pectin (22 to 40%); a high Ca:P ratio (3.5 ± 1.7% Ca to 0.34 ± 0.07% P), and relatively low concentrations of CP (7.2 ± 0.2%), fat (3 ± 1.0%), NDF (19.3 ± 1.3%), and ADF (16.9 ± 2%; DM basis; Arthington et al., 2002; Bampidis and Robinson, 2006).

Dried citrus pulp has been documented to have corn replacement values of 95 and 78% when fed to growing pigs at 10 and 20% DM, respectively, and replacing 20% of the ration with DP did not affect the feed:gain ratio (Baird et al., 1974; Watanabe et al., 2010). The WP and PP products are generally offered to livestock producers at little to no cost, but only producers very close to citrus processing facilities use such products due to the expense of transporting a low percentage DM feedstuff. However, many citrus processors would like to increase the number of markets for fresh pulp, due to the energy expended in the thermal process to dry and pellet citrus pulp. Recent work in South America shows including 10.0% ensiled WP had little impact on lean growth efficiency compared to control diets (Cerisuelo et al., 2010). It has been shown that

anaerobic ensiling of citrus peels maintains the quality and nutritional value and can increase the crude protein (CP) content (Megias et al. 1993). Theobjective of this research was to study the impact of dietary inclusion of citrus pulp on the growth, feed efficiency, carcass merit, and lean quality of finishing pigs.

CHAPTER 2
REVIEW OF LITERATURE

Feed costs have historically been, and will continue to be, the single largest cost of pork production (Hofstrand, 2009). Feed costs have been trending upward for the past six years, largely due to the competition faced by the livestock industry for corn from ethanol processors. This has driven all facets of U.S. animal agriculture being driven to try and reduce feed costs. Pork producers near ethanol refineries have the opportunity to utilize the ethanol byproducts as feedstuffs to reduce their feed costs, but this is currently not a viable option for Florida producers.

Feed costs are greater in Florida due to the cost of additional transportation from where the grain was produced, resulting in corn being approximately $1.25 per bushel more expensive on average than in the Midwest (Personal communication). A pig consumes approximately 295 kg of complete feed from birth until slaughter, and approximately 70% of the diet is corn, thus it costs over $10 more to raise a pig in Florida than the Midwest, due to the cost of corn alone. The combination of increased feed costs and decreased slaughter capacity has dramatically decreased pork production throughout the southeastern U.S., except for North Carolina. However, the few Florida pork producers which exist today can generally obtain prices above market value for their pigs via niche pork marketing or selling pigs to youth for exhibition. There has been an increase in the number of small U.S.D.A. inspected pork processors in Florida over the past five years. If Florida pork producers could significantly decrease their production costs, they could possibly become more profitable.

Byproduct Feedstuffs

Byproducts have been utilized in livestock diets for many years and will continue to be a research area in the future (Cromwell, 2008). The growth of the U. S. corn ethanol industry has

dramatically increased the use of byproduct feedstuffs. Corn ethanol is made in two ways either the dry grind or wet mill process, resulting in two different byproducts, distillers grains or corn gluten feed, respectively (Bothast and Schlicher, 2005). A diagram depicting both processes is shown in Figure 2-1. The byproduct of the dry grinding process after fermenting, release of carbon dioxide, and removal of the ethanol, is known as distillers dry grains. The distillers dyr grains are concentrated by evaporation and mixed with the residual solids that are a produced during fermentation to produce wet distillers grains with solubles (WDGS) (Bothast and Schlicher, 2005). This product initially contains 10-12% DM but then most is dried to approximately 88-90 % DM and is referred to as dried distillers grains with soluble (DDGS) (Bothast and Schlicher, 2005). The co-products from wet-milling production of ethanol include corn germ meal, corn gluten meal, and corn gluten feed (Stein et al, 2008). Also, a wet milling technology that fractionates corn prior to fermentation produces a product called glutenol (Shurson and Alghamdi, 2008).

An estimated 33.4 million t of DDGS was produced in the United States in 2009/2010, and an estimated 8,439 t was fed to pigs in 2010/2011 making DDGS the most utilized byproduct feedstuff in the swine industry (Baker and Hoffman, 2011). The energy content of DDGS makes it an attractive option as a byproduct feed for swine. When compared to corn it has approximately 20% more gross energy than corn (Stein and Shurson, 2008) but the dietary fiber fraction of the DDGS is approximately three times that of corn (Stein et al., 2008). Of this fiber, 20% is digestible in the small intestine but only 50% in the total tract. Therefore, the fiber contributes little to the energy value of these products (Stein et al., 2008). This negates the gross energy advantage of DDGS and leaves it with approximately the same metabolizable energy value as corn (Stein and Shurson, 2008). The added fiber in DDGS may also affect other

nutrient digestibilities. The amino acid (AA) digestibility of DDGS has been shown to be 10 units lower than that of corn and this decrease in AA digestibility may be attributed to the effect increased dietary fiber has on digestibility of AA (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008; Stein et al., 2008). The low digestibility of AA, particularly lysine, is of concern, because DDGS has higher crude protein (CP) than corn (27.5% and 8%, respectively) (Stein et al., 2008).

Marginal inclusion of DDGS does not seem to affect the performance of pigs in the finishing stages. An inclusion rate of up to 15% DDGS in the diets of pigs from 50 to 76 kg body weight resulted in no differences in average daily gain (ADG) or gain to feed ratio (G:F), when compared to pigs fed a corn-soybean meal control diet (Linneen et al., 2008). These findings are supported by studies showing up to 20% DDGS can be used in diets fed throughout the finishing period without reducing ADG and G:F, provided that diets are adequate in AA (McEwen, 2006, 2008; Augspurger et al., 2008; Drescher et al., 2008; Duttlinger et al., 2008; Widmer et al., 2008). However, higher inclusion rates such as 30% DDGS or greater, had inconsistent results on G:F (Gaines et al., 2007 a, b.; Xu et al., 2007). The inconsistency of these findings at greater inclusion levels is thought to be from differences in energy source between experiments (Stein et al., 2008). Though data has shown contradicting results on ADG and G:F for pigs fed DDGS, in 18 out of 25 studies feeding DDGS at less than 25% of the ration during the finishing stage had no effect on ADG, and 16 out of 25 studies found no effect on G:F (Stein and Shurson, 2008). Also, in 13 out of 14 studies with levels of less than 25%, DDGS had no effect on percent lean meat. Due to a greater amount of fiber in DDGS diets, 8 out of 18 studies showed a decrease in dressing percentage (Stein and Shurson, 2008). Feeding DDGS will continue to be a widely used feedstuff in swine diets and yet it needs to be used in moderation

Levels of 20% or lower in finisher diets have be shown to have no effect on pig performance when compared to conventional corn-soybean meal diets (Cromwell et al., 1983).

Canola meal (CM), has been used as a protein supplement in swine diets. The CP of CM is approximately 67% (Salo, 1980). However, it is also high in fiber and because of this it has lower AA digestibility than soybean meal (Sauer et al., 1982). Finisher diets containing up to 22.5 % CM negatively affect ADG, but do not affect G:F (Seneviratne et al., 2009). This contradicts previous work that observed no difference in ADG or G:F when finishing pigs were fed up to 50% CM as a replacement for soybean meal in the diet (Baidoo et al., 1987). These findings are more than 20 years apart and a better understanding of nutrient utilization in the swine industry could have impacted this difference.

The Midwest has seen an increase in availability of field peas for livestock diets (Stein et al., 2006). Field peas have a nutritive value similar to soybean meal with regards to fiber, yet contain approximately half the CP of soybean meal but more than double the CP of corn (Stein et al., 2006). Pigs fed up to 36% field peas in their diets had no difference in ADG or G:F when compared to pigs fed a conventional corn-soybean meal diet (Stein et al., 2006). Further work shows that pigs fed a diet containing 46% field peas during the finishing stage had similar ADG to pigs fed a conventional corn-soybean meal base diet (Hawkins et al., 2006). Field peas also had no effect on carcass traits such as backfat thickness (BF), longissimus muscle (LM) area, or objective color and firmness scores of the LM (Hawkins et al., 2006). However, the cost of gain for pigs on the peas and extruded bean diets was less than half the cost of the commercial diet (Hawkins et al., 2006). This shows the importance of utilizing field peas and other by-products in swine diets.

Even more exotic feed stuffs have been evaluated in swine diets. Pigs fed 2% fermented apples in the finisher diet had increased ADG and G:F when compared to a control diet or a diet with 4 or 6% fermented apples. Pigs fed 2% fermented apples also had higher sensory overall acceptability scores than pigs fed a conventional diet (Lee et al., 2009a). However, pigs fed *Eucommia ulmoides* leaves at 3 or 5% of finishing diets had decreased ADG than pigs fed a conventional diet, but *Eucommia ulmoides* increased sensory overall acceptability scores (Lee et al., 2009b). The inclusion of scallop viscera silage had no effect on ADG or ADFI (Myer et al., 1990). Although, pigs fed the scallop viscera silage had a blander overall flavor than CON pigs (Myer et al., 1990). Fermented oyster mushrooms in the finishing diet at less than 3% of the diet had no effect on ADG or G:F, but greater than 5% decreased both ADG and G:F (Song et al., 2007). Including another type of mushroom, *Flammulina velutipes*, at 10% or greater in the diet decreased ADG and 50% or greater decreased dressing percent when compared to a basal control diet (Chu et al., 2012).

Citrus Byproduct Feedstuffs

Citrus is one of the most abundant crops in the world (Marin et al., 2007). The byproduct of the citrus juicing industry is pulp which can be utilized in livestock diets. Citrus pulp is often included as an energy supplement in the diets of dairy and beef cattle in Florida due to its availability and low cost (Arthington et al., 2002). A diagram depicting the citrus byproduct processing is on Figure 2-2. Fresh citrus fruit residue, from here forward referred to as whole pulp (WP), consists of rind and seed and contains approximately 10% DM (a, Figure 2-2). A kg of oranges after juicing will produce 492 to 692 g of WP. Of this, 60 to 65 % is peel and 35 to 40 % is pulp and seeds (Bampidis and Robinson, 2006). This product is then pressed to extract citrus liquor and 0.05% calcium carbonate is added during grinding to make pressed pulp (PP) which contains approximately 20% DM (b, Figure 2-2). The PP is dehydrated to make dried

citrus pulp (DP) which contains approximately 90% DM (c, Figure 2-2). Products produced in the intermediate phases of making DP from WP can all be utilized as livestock feed, though only the three described were utilized in this trial. The average chemical composition of WP and DP is included in Table 2-1. Citrus byproducts can vary in nutritive value. Three samples of pulp from different varities of citrus varied for ADF between 13.76 to 21.60 % (Arosemena et al.,1995). The same three samples had similar CP and NDF, which closely followed those of NRC (1989) values. However, Ca varied as much as 1.75% between the samples of different citrus varities (Arosemena et al.,1995). This shows the importance of using feeds from consistent supplies.

The earliest work with citrus pulp at levels of 10 and 25% resulted in pigs appearing to be unthrifty and exhibit rough hair coats (Glasscok et al., 1950). This led to work at ower levels, 0.5, 2.0, and 5.0% which showed no ill effects of feeding citrus pulp to swine (Wallace et al., 1953). Additional work was done replacing corn with citrus molasses and it was shown that replacing 10% of the corn with citrus molasses had no effect on finishing swine from 40 to 100 kg (Cunha et al., 1950). Later work showed that at 5 and 10% citrus pulp in the diet of finishing pigs had decreased daily gain, however the same study showed 15% inclusion of citrus pulp had no effect on carcass cutability or quality (Hollis et al., 1969).

Dried citrus pulp has been documented to have corn replacement values of 95 and 78% when fed to growing pigs at 10 and 20% DM, respectively and replacing 20% of the ration with DCP did not affect feed to gain ratio (Baird et al., 1974; Watanabe et al., 2010). The WP and PP products are generally offered to livestock producers at little to no cost, but only producers very close to citrus processing facilities use such products due to the expense of transporting a low

percentage DM feedstuff. However, many citrus processors would like to increase the market for fresh pulp due to the energy expended to dry and pellet citrus pulp.

Recent work in South America shows including 10% ensiled fresh citrus pulp residue had little impact on lean growth efficiency compared to conventional corn-soybean meal diets (Cerisuelo et al., 2010). No known research has evaluated silage from citrus pulp with different levels of oil and water on the growth performance, efficiency, carcass merit, and lean quality of finishing pigs.

Ensiling High-Moisture Feedstuffs

Ensiling refers to the changes in which take place when a forage or feed with high moisture contents is stored in the absence of air.Ensiling is the most economical and satisfactory way to preserve byproduct feeds (Ensminger et al., 1990). Feeds that contain more than 20% water are often referred to as high-moisturefeeds (Ensminger et al., 1990). These feedstuffs are often inexpensive if easily accessible and are generally highly palatable (Ensminger et al., 1990). However, to livestock having trouble consuming enough high-moisture feed to meet their nutritional requirements, and such feedstuffs cannot be exposed to the air for long periods, as they will start to produce molds and spoil (Ensminger et al., 1990).

Ensiling occurs in three phases, the respiration phase, anaerobic phase, and stable phase. First, any remaining oxygen is utilized by the living plant cells and aerobic bacteria producing heat, water, and carbon dioxide. This constitutes the repiration phase. Once the oxygen is depleted, the anaerobic phase begins with acid forming and proteolytic bacteria using the carbohydrates and sugars to survive and grow and producing primarily lactic and acetic acid, along with alcohol (Ensminger et al., 1990). Finally, when the silage reaches a pH below 4.2 it is stable and can be kept for years if air is excluded (Ensminger et al., 1990). Feedstuffs are ensiled to optimize the quality and productivity of harvest crops (Pahlow et al., 2003). Crops

such as corn have 30 to 50% higher feeding values when fed as silage as compared to a grain or stover (Ensminger et al., 1990). Ensiling has also been shown to be a better protein source than dried forage in non-ruminant diets (Ensminger et al., 1990). The main disadvantages to ensiling feedstuffs are the amount of storage space needed and because of the moisture content an increased quantity needs to be stored in order to match the nutrient amount of dried forage (Ensminger et al., 1990).

Ensiling triticale, wheat, and barley for as little as 10 days sufficiently decreased the pH to a sufficient level to allow for successful preservation (Pieper et al., 2010). The same effect has been shown for apple pomace and maize (Pirmohammadi et al., 2006). Ensiling orange peel can effectively preserve the feedstuff by obtaining an optimal level of lactic acid, between 3 and 13 percent of the dry matter (Megia et al., 1993). Ensiling orange peels increased the CP of the feedstuff after as little as 2 d of ensiling (Megia et al., 1993). Although DM content will continue to vary, ensiling for 2 days also increased the percent ADF in orange peel silage (Megias et al., 1993).

High-Fiber Diets for Swine

Fibrous feedstuffs have traditionally not been utilized for swine diets due to their documented depression of diet digestibility (Johnston et al., 2003). However, fibrous feedstuffs traditionally used for ruminant diets have been re-evaluated for use in non-ruminant diets due to the social and economic climate of developed countries where livestock systems are competing with humans for cheap feed products (Cast, 1999). The most accepted definition of fiber is the sum of lignin and non-starch polysaccharides that are not digested by endogenous enzymes secreted in the digestive tract (Trowell et al., 1976). Starch, fat, and protein are almost entirely digested in the gastro-intestinal tract, thus the parts of a feedstuff that are not starch is often referred to as fiber. It is thought that total dietary fiber, which consists of soluble dietary fiber

(SDF) and insoluble dietary fiber, is the more appropriate way to clasify fiber for swine diets. SDF more appropriately includes the water-soluble polysaccharides such as pectins and fructans (Johnston et al., 2003).

The most important factor in examining the fiber component of a feedstuff is the amount of lignin. Lignin is not digested by pigs and is not fermented by resident microbes in the gut (Graham et al., 1986; Shi and Noblet, 1993). In addition, lignin affects the indigestibility of other fibrous parts of the diet. As cellulose becomes cross-linked with lignin its accessibility by the microbes decreases drastically (Johnston et al., 2003). Pectins and fructans increase viscosity of digesta which causes swelling of feed components thus increasing the surface area for microbial attachment in the hindgut (Mosenthin et al., 2001; Noblet and LeGoff, 2001). Fiber is digested primarily in the hindgut as a result of fermentation, and can negatively affect total tract digestibility of nitrogen and ether extract (Noblet and Shi, 1993; Shi and Noblet, 1993; LeGoff and Noblet, 2001). Pigs fed high fiber diets tend to have a slight increase in maintenance energy requirements which can be attributed to the pigs having proportionally heavier gastro-intestinal tracts than pigs fed low fiber diets (Rijnen et al., 2001; Yen et al., 2001). Pigs attempting to maintain higher maintenance requirements are thought to increase feed intake to maintain digestible energy intake (Dierick et al., 1989). This causes an increase in consumption without an increase in gain. The end-products of hind gut fermentation, short chain fatty acids and lactic acid, can supply up to 24 to 30% of the energy needs for growing-finishing pigs (Rerat et al., 1987; Yen et al., 1991). Dietary fiber improves in digestibility normally increases with the age of the pig due in part to a more voluminous large intestine and cecum (Kass et al., 1980; Pekas, 1991) that contain a more extensive microbial population and hence fermenting feeds to a greater extent (Yen, 2001).

The lower nutritive value of high fiber diets combined with the decrease in metabolizable energy from substrates derived from hindgut fermentation would suggest that high fiber feedstuffs decrease the gain of finishing pigs if diets are not formulated with adequate amounts of net energy (NE) (Just, 1984). However, adding 10% soybean hulls to a low-protein, amino acid-supplemented diet to pigs from 27 to 114 kg body weight did not affect the performance of pigs (Shriver et al. 2003). Additionally, soybean hulls actually improved carcass leanness due most likely to lower net energy content of the soybean hulls compared to the other components of the diet. Similarly reports show that feeding up to 15% soybean hulls had no effect on performance of pigs weighing between 22 and 84 kg (Kornegay, 1981). The same effect has been shown when feeding alfalfa, corn cobs, peanut hulls and sugar beets (Dierick et al., 1989).

As stated previously fiber digestibility increases with pig body weight. This would indicate that fibrous feedstuffs would be more effective in finishing swine diets. Pigs fed diets containing 24% wheat bran or 16% sugar beet pulp had increased digestibility as the pigs increased in age and weight, regardless of which fiber source (Galassi et al., 2003). Pigs fed wheat bran or sugar beet pulp had similar retained energy, protein accretion, and fat accretion as pigs fed a control diet (Galassi et al., 2003). Similarly, feeding 70% oats had no effect on growth performance or carcass traits for finishing pigs weighing between 52 and 109 kg (Fortin et al., 2003).

Managing High Fiber/High Moisture Feedsuffs

Another important issue to consider when using byproduct feeds is how to properly manage the use of those feeds. Relatively high concentrations of DDGS may increase the fat content of the diet and consequently cause problems with feed bridging in bins and feeders (Stein and Lange, 2007). This may cause a modification in the storage and (or) delivery system of high moisture or high fat byproduct feeds. Also preliminary studies done at the University of Florida

show that increasing amounts of high moisture ensiled citrus pulp can cause bridging in feeders. The increased moisture in the WP and PP feed also lead to spoilage if the feed was not consumed.

Increasing the amount of fiber in swine diets can also have effects on manure management. The decreased digestibility of fiber in DDGS results in increased quantities of manure (Pedersen et al., 2007). Also, as the percentage of DDGS in the diet increased bad odors increased (Gralapp et al., 2002). In addition, the composition of the manure may also influence the microbial environment of manure in storage altering generation of gases and thus potential for odors (Johnston et al., 2003).

Pork Quality

Lean Quality

Pork lean quality has become an increasingly important determinant of carcass value. The two most important factors determining pork quality are lean color and water-holding capacity. Consumer appeal is driven primarily by lean color (Brewer and McKeith, 1999). The lean color which consumers tend to prefer is more reddish-pink with a lower light reflectance (L * value) than pork that is pale gray to white with greater light reflectance (Norman et al., 2002). According to the Pig Improvement Company (PIC, 2003), pork loins must exhibit an L* value lower than 50 (suggesting a relatively dark lean color) to be eligible for the premiums associated with Japanese export market. For further processors, water-holding capacity is of the utmost concern, because cooking and processing yields are directly impacted by the ability of fresh pork to retain water. This value is emphasized when considering that 75% of the pork produced in the U. S. is further processed (Cannon et al., 1995). Table 2-2 describes the parameters for evaluating pork lean quality (NPB, 1999).

The metabolism of intramuscular glycogen is the primary factor in the conversion of muscle to meat and the quality attributes of fresh pork (Berg, 1999). Glycogen is a polymer of glucose units linked with α 1-4 and α 1-6 bonds around the protein P-glycogenin and is the primary energy substrate in muscle. Two lactate molecules are produced per glucose molecule during postmortem anaerobic glycolysis. In living muscle, lactate is transported in the blood to the liver where it ultimately returns to the muscle as glucose vie the cori cycle. In postmortem muscle metabolism, lactate accumulates in the muscle as lactic acidand this results in the natural pH decline of muscle tissue and the conversion of muscle to meat (Brooks et al., 1996).

The initial rate of pH decline is primarily determined by the rate of glucose metabolism immediately before, during, and immediately after slaughter (Warriss, 1987). Any pre-harvest stress could cause changes in ante-mortem muscle metabolism and consequently affect postmortem muscle glycolysis and lean quality. Many factors can ncrease muscle metabolism ante-mortem including genetic predisposition, pig excitability, pre-slaughter stress on the farm, during transport and at the plant and (or) interactions of all of the aforementioned factors (Meisinger, 2002). The ultimate condition of pork muscle is influenced by skeletal muscle pH drop as a function of time, in vivo temperature patterns, carcass chilling rate, and the conditions at the onset of rigor mortis (Figure 2-3) (Pearson, 1987).

A rapid decline in pH while muscle temperature is still high can result in pale, soft, and exudative (PSE) pork. Pork classified as PSE is characterized by rapid acidification of the postmortem muscle with a pH less than 6.0 within 1 h (Briskey, 1964). Rapid pH fall, combined with high postmortem muscle temperatures, denatures the myofibrillar integrity of the muscle structure which can lead to a dramatic loss of water-binding capacity and extensive light fragmentation. Generally, acute, short-term stress immediately before harvest can lead to the

production of PSE pork (Bennett et al., 1973; Boles et al., 1991; Person et al., 2005). Animals exposed to prolonged chronic stress, will deplete muscle glycogen, resulting in insufficient lactic acid production and elevated pH values (> 5.8; Hedrick et al., 1959). Pork with elevated pH will have increased water holding capacity, and a dark lean color due to increased light absorbency (Hedrick et al., 1959). Extreme cases of glycogen depletion cause dry, firm and dark (DFD) pork.

Fat Quality

Ideal pork fat quality can be defined as firm and white, while poor quality fat is said to be soft, oily, wet, grey, and floppy (Wood, 1984). Meat products containing low quality, soft fat, show defects, such as insufficient drying, an oily appearance, become rancid more quickly, and have a lack of cohesiveness between muscle and adipose tissue all upon fabrication. These factors lead to a reduction in consumer appeal (Gandemer, 2002; Maw et al., 2003; Carr et al. 2005). It is well established that pork fatty acid composition can be influenced by the fat composition of swine diets (Seerly et al., 1978; Miller et al., 1990; Madsen et al., 1992). More importantly, the quality of pork fat is determined by the composition of the dietary fatty acids (Kühne, 1983). Apple et al. (2008) reported that the fatty acid profile of fat sources consumed in the diets of swine is reflected in the pork carcasses and that diets high in unsaturated fats may result in pork carcasses with soft fat. This has economic impact because soft pork bellies produce bacon with decreased yields and poor sliceability (Nordstrom et al., 1972; Shackelford et al., 1990; Correa et al., 2008).

The most widely accepted measurement of fat quality is iodine value (IV), a numerical value for halogen combined to the double bond which gives an overall estimate of the percentage of unsaturated fatty acids (Hugo and Roodt, 2007). A range of 60 to 70 for IV of pork fat is considered the maximum level for acceptable pork (Hugo and Roodt, 2007). Products with IV in

excess of this will likely have reduced processing value. Fat quality is a major consideration when feeding byproduct feedstuffs. Feeding DDGS to growing and finishing pigs increases IV value and this was shown in 7 out of 8 studies (Stein and Shurson, 2008). Pigs fed more than 20% dietary DDGS had significantly increased unsaturated fatty acids to change the IV to over 70which is likely to produce pork bellies with unacceptable processing value.

Table 2-1. A summary of the chemical composition (mean ± S.E.M.) of several orange by-products summarized by Bampidis and Robinson, 2006

Variable	WP[a]	DP[b]
DM, %	19.2 ± 0.4	89.7 ± 5.0
CP, %	6.4 ± 0.5	6.9 ± 0.14
NDF, %	20.0 ± 7.1	22.0 ± 1.1
ADF, %	15.0 ± 1.5	19.7 ± 1.0
Ca, %	0.7 ± 0.2	1.6 ± 0.2
P, %	0.2 ± 0.0	0.1 ± 0.0

[a]WP = Whole pulp

[b]DP = Dried pulp

Table 2-2. Targets for fresh pork loin quality, adapted from NPB (1999)

Variable	Target range
Subjective color score [a]	3.0 to 5.0
Lightness (L*)[b]	49 to 37
Subjective marbling score[c]	2.0 to 4.0
Ultimate pH[d]	5.6 to 5.9
Drip loss, %	≤ 2.5%

[a]1 = white to pale pinkish gray to 6 = dark purplish red (NPPC, 2000).

[b]L* = measure of darkness to lightness (larger value indicates a lighter color); a* = a measure of redness (larger value indicates a redder color)

[c]1 = 1% intramuscular fat to 10 = 10% i.m. fat (NPPC, 2000).

[d]Measured ≥ 24 h postmortem.

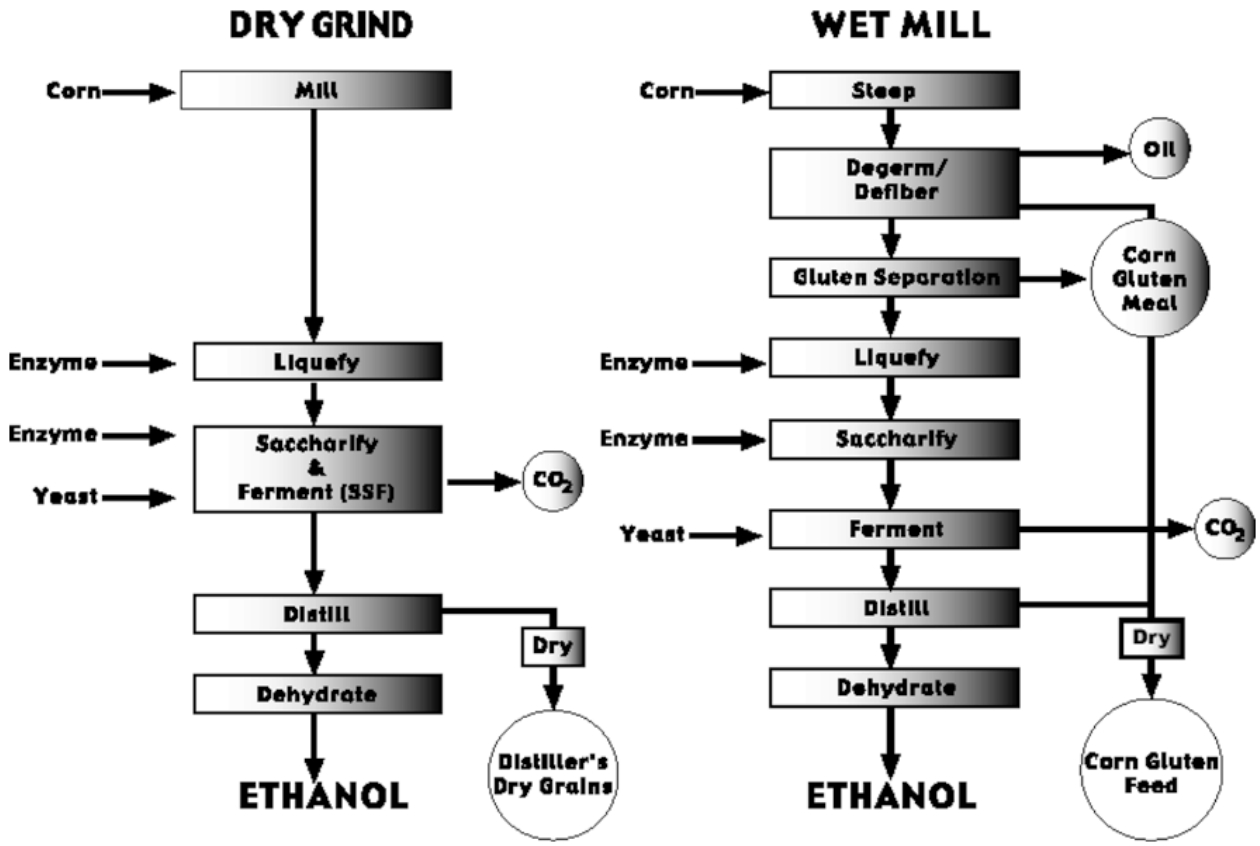

Figure 2-1. Process of dry grin and wet mill ethanol production

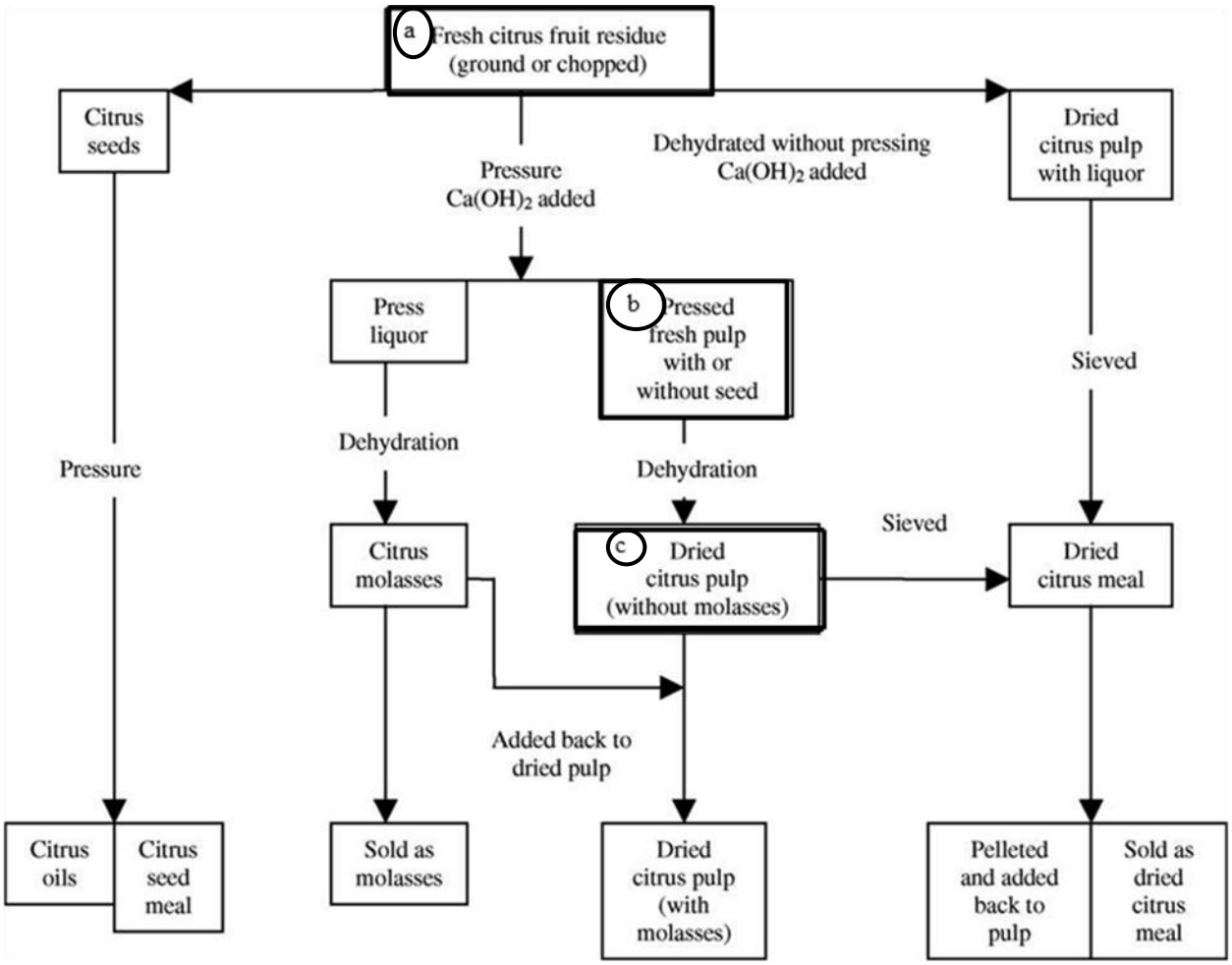

Figure 2-2. Diagram of citrus by-product processing. (Bampidis and Robinson, 2006)

[a] = Whole pulp

[b] = Pressed Pulp

[c] = Dried pulp

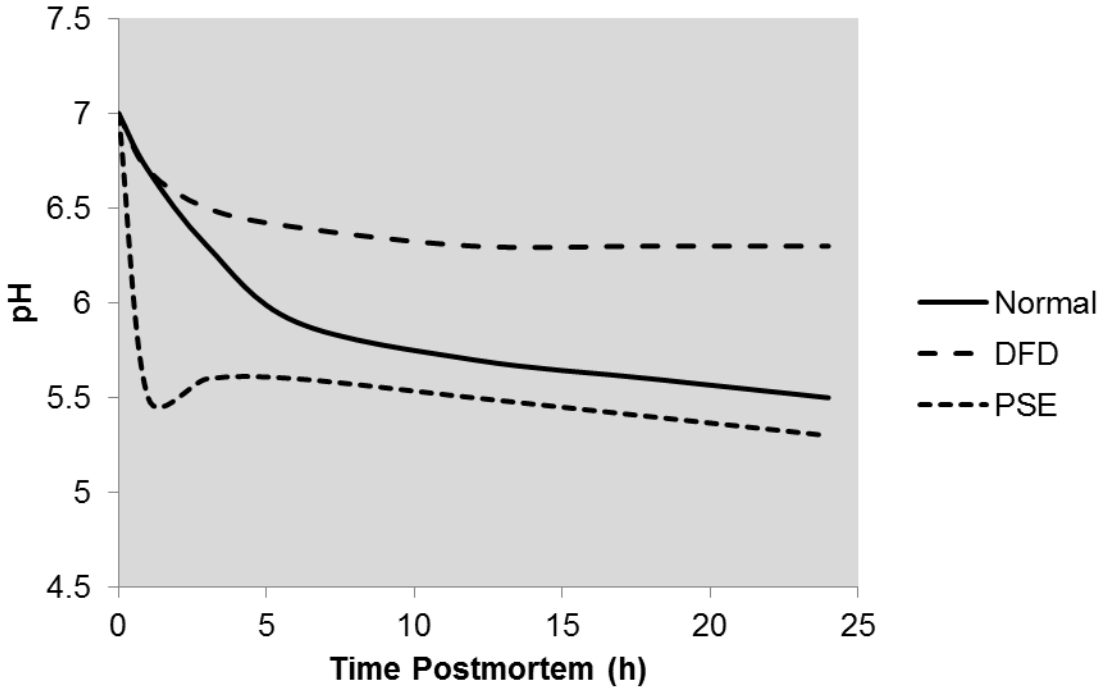

Figure 2-3. The relationship of postmortem pH decline with characteristics of pork muscle, adapted from Sellier and Monin (1994). DFD = Dark firm and dry pork PSE = Pale soft and exudative pork

CHAPTER 3
THE IMPACT OF DIETARY INCLUSION OF CITRUS PULP ON THE GROWTH, FEED EFFICIENCY, CARCASS MERIT AND LEAN QUALITY OF FINISHING PIGS

Feed and other input costs have reached such critical levels that fibrous feedstuffs such as citrus pulp, previously determined to be of marginal quality for monogastrics (Cunha et al. 1950) are now being re-evaluated for use in swine diets (Watanabe et al., 2010). Citrus pulp is often included as an energy supplement in the diets of dairy and beef cattle in Florida due to its availability and low cost (Arthington et al., 2002). Whole citrus pulp (pulp residue, rind, and seed) contains approximately 10% dry matter (DM), immediately after the juice is removed. Whole citrus pulp (WP) is then pressed to extract citrus liquor and 0.05% calcium carbonate is added during grinding to make pressed pulp which contains approximately 20% DM. Pressed pulp (PP) is heated to make dried pulp (DP) which contains approximately 90% DM (Kale and Adsule, 1995). No known work has been done evaluating citus pulp at different oil and moisture levels in finishing swine diets. The objective of this research was to study the impact of dietary inclusion of citrus pulp on the growth, feed efficiency, carcass merit, and lean quality of finishing pigs.

Materials and Methods

Ensiling

All citrus pulp products were obtained on the same production day from a commercial vertically integrated citrus processing facility (Cutrale Citrus Juices USA, Auburndale, FL) which only process a single variety of oranges, and transported 350 km to the University of Florida swine facility. The distance was used as a cost variable for fuel in the economic analysis. The WP and PP products were placed in 208 l, plastic anaerobic containers the following day and anerobically sealed. The WP and PP were stored at 972 kg/m^3. A 1400 g composite sample taken on day 37 of ensilement from the top, middle, and bottom portions of a representative

container of PP and WP were analyzed (Table 3-1) to determine the value of the corrections needed for the base diets. Nutritional information for DP was attained from NRC (2001). The WP and PP products were fed after a minimum of 40 d of ensiling. Ensiled pulp was removed from the ensiling containers weekly, blended with the corrected basal diet and fed to pigs within 7 d to minimize mold growth. Ensliled pulp with visible mold growth at blending was excluded from feeding.

Animals

Experimental procedures and animal handling methods were approved by the University of Florida Institute of Food and Agricultural Sciences Animal Research Committee. Forty whiteline crossbred barrows and gilts weighing 85.3 ± 11.2 kg were blocked by weight and gender. Pigs were then randomly allocated in to 20 pens which were randomized to the four experimental diets. There were five replicates per treatment and two pigs per pen. Pens were gender specific. Pigs were housed in a partially slatted concrete-floored pens (3 m^2 per pig) in an open-sided building and offered feed and water ad libitum. Pigs were allowed a 7 d acclimation period to the experimental diets. During the subsequent 39 d trial, pigs (n = 10) were either fed a conventional corn-soybean meal finisher ration containing 0.78 % lysine (CON) or a base diet replaced with either 15 % DP, WP, or PP on a dry matter (DM) basis. Diets were isolysinic. Dietary energy contents were 3653, 3530, 3503 and 3534 Kcal ME/kg, respectively, for CON, DP, WP, or PP (Table 3-1). Pigs and feeders were weighed every 13 d and feed disappearance was recorded to determine average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F). One gilt from the DP treatment was eliminated from the trial due to a rectal prolapse. Her penmate was removed from the growth analysis, but was included in the carcass data and all subsequent analysis. Cost/kg of live gain/pen of pigs was calculated by using

current wholesale prices for each ingredient. Transport costs and labor for mixing the diets were also included for the WP and PP products. The following equation was then used.

$$\text{Cost of gain} = \frac{(\text{Total Intake} * \text{Price of Diet}) + \text{Labor}}{\text{Total Gain}}$$

Carcass Fabrication and Lean Quality Data

Pigs were comingled and transported 5 km to the University of Florida Meat Laboratory Abattoir at the conclusion of the trial and provided ad libitum access to water during a 12 h lairage. Pigs were humanely slaughtered using electronic stunning. Hot carcass weights were recorded prior to storing carcasses in the cooler. The pH of the longissimus muscle (**LM**) was measured 45-min postmortem between the 10th and 11th ribs with a temperature-compensating pH meter (model 99163, Hanna Instruments USA., Woonsocket, RI) and pH was also measured within the semimembranosus muscle (SM). Right carcass sides were fabricated at 24-h postmortem into primal cuts according to the National Association of Meat Purveyors (NAMP) guidelines (NAMP, 2007). After a 15 min bloom period, 10th rib fat depth, LM area, subjective marbling scores, lean color (NPPC, 2000), and lean firmness scores (NPPC, 1991) were taken at the 10th rib. Also, LM pH and objective lean color analysis were measured using a Hunter Miniscan XE Plus (Hunter Laboratory, Reston, VA) with an illuminant setting of D65/10 with a 2.54 cm aperture at the 10th and 11th rib interface and face of the gluteus medius (GM) (L*, a*, b*). Hunter L*, a* and b* values were used to calculate hue angle, representing a change from the true red axis = ($\tan^{-1}$ {b*/a*}); chroma, representing the total color or vividness of color = $((a^{*2} + b^{*2})^{1/2}$ according to standard equations (Minolta, 1998).

After deboning, one 2.54 cm LM chop was fabricated from the initial $10^{th}/11^{th}$ rib separation and used to determine 24-h drip loss according to procedures by Honikel et al. (1987) with some modifications. In brief, samples were initially weighed and recorded and then placed

in a Whirl-Pak bag (Nasco, Fort Atkinson, WI). Samples were suspended for 24-h at 4°C, samples were then reweighed and drip loss was calculated by taking the difference in weights as a percentage of the initial weight.

After storage, six 2.54 cm LM chops were fabricated from the 10th rib interface of each loin section. Starting from the most anterior end of the loin, chops were cut and vacuum packaged for objective tenderness measurement (n = 2) and trained sensory panel evaluation (n = 2) or used for retail evaluation (n = 2). Retail evaluation LM chops were placed on 17S Styrofoam trays (Genpack, Glens Falls, NY) and overwrapped with polyvinylchloride film (23,250 mL of O_2/m^2/24 h°C/% relative humidity) and placed within a Hill (Hill Refrigeration Div., Trenton, NJ) coffin-style retail case at 2 ± 3°C for 5 d. Cases were illuminated with GE T8 Linear Fluorescent lamps (2,800 lm, 4,100 K; General Electric Company, Fairfield, CT) that emitted a case average of 1,148 lx. LM chops were rotated daily to balance for uneven temperature and light distribution within the case.

Subjective and Objective Retail Color Analysis

Using a whole number scale (AMSA, 1995), a 6- to 8-member trained panel evaluated LM chops for lean color (1 = white to pale pinkish gray to 6 = dark purplish red; NPPC, 2000), fat color (1 = White; 2 = Creamy white; 3 = Slightly tan; 4 = Moderately tan; 5 = Tan; 6 = Brown), and percentage surface discoloration (1 = No discoloration = 0%; 2 = Slight discoloration ≈ 1 to 10%; 3 = Small discoloration ≈ 11 to 25%; 4 = Modest discoloration ≈ 26 to 51%; 5 = Moderate discoloration ≈ 51 to 75%; 6 = Extensive discoloration ≈ 76 to 99%; 7 = Total discoloration =100%) daily for 5 d. Objective color measurements of these LM chops were also taken as well as using a Hunter-Lab MiniScan XE. Illuminance with the aperture settings and calibration procedures described previously. The change in total color (ΔE) from d 0 of retail display = $((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2}$ was calculated according to standard equations (Minolta, 1998).

Shear Force and Sensory Evaluation

LM chops for Warner-Bratzler shear force analysis were thawed for 24-h at 4°C, then cooked on an open hearth, variable heat grill (Model 31605 AH, Hamilton Beach/Proctor-Silex Inc., Southern Pines, NC) to an internal temperature of 71°C (AMSA, 1995). Temperature was monitored using copper-constantan thermocouples and a recording thermometer (Omega Engineering Inc., Stamford, CT). LM Chops were weighed before and after cooking. LM Chops were allowed to cool for 24 h at 4°C. Six 1.3-cm diameter cores were removed parallel with the muscle fibers. Each core was sheared once perpendicular to the muscle fiber orientation using a Warner-Bratzler shear head attached to an Instron Universal Testing machine (Model 1011; Instron Corporation, Canton, MA) with a cross-head speed of 200 mm/min.

LM chops for sensory evaluation were prepared and cooked using the same procedures as for shear force. Ten panelists were trained according to the procedures for sensory evaluation described by the AMSA (1995). A taste panel consisting of seven to ten trained panelists evaluated tenderness, juiciness, pork flavor intensity, tenderness, and off-flavor, with the first three traits being evaluated on an eight point scale (1 = extremely tough, dry, bland, or an abundant amount of connective tissue; 8 = extremely tender, juicy, intense, or no connective tissue detected) and off-flavor was evaluated on a six point scale (1 = extreme off-flavor; 6 = no off-flavor). Water and unsalted crackers were provided to panelists between samples to cleanse the palate.

Statistical Analysis

All performance, carcass composition, lean quality, retail scoring, sensory, and shear force data were analyzed using the mixed model procedure of SAS (SAS Inst., Inc., Cary, NC). Pen was the experimental unit for all performance data and individual pig was the experimental unit for carcass, lean quality, retail, trained sensory, and shear force analysis. A randomized block

design was used with gender being a block. The CON and PP treatments included three pens of gilts and two pens of barrows and the DP and WP treatments included three pens of barrows and two pens of gilts. Boar and boar nested within litter was utilized as a random variable and initial pig weight was used as a covariate in all analyses. Display day was included in the repeated measures analysis of objective and subjective retail evaluation of LM chops. Least square means were calculated for main and interactive effects and separated statistically using pair-wise *t*-tests (P-DIFF option of SAS) when a significant ($P < 0.05$) F-test was detected. Additionally, the standard error (SE) for each main effect was reported.

Results

Growth

Initial weights were similar ($P = 0.14$) across treatments at the start of the 39 d feeding period (Table 3-3). No differences ($P \geq 0.25$) in pen ADG were observed across treatments for the first and last 13 d of feeding, which resulted in no difference ($P = 0.26$) in ADG over the entire feeding period (Table 3-3). These findings agree with those of Watanabe et al. (2010) who replaced 15% of a control diet with ensiled citrus byproducts. However, although treatments did not differ statistically for ADG in this trial, the numerically lower ADG of pigs fed WP is of practical economic significance.

Pens of barrows fed the PP diet had greater ADG and G:F ($P < 0.05$) than pens of barrows fed the CON or WP diets during the second 13 d of feeding (citrus pulp inclusion × gender, $P = 0.02$; Figure 3-1). Additionally, pens of gilts did not differ ($P \geq 0.05$) for ADG or G:F during the second 13 d of feeding (Figure 3-1). Our results for gender effects on growth performance (Table 3-3) were consistent with previous findings (Chen et al., 1999; Wiseman et al., 2007; Xu et al., 2007), which have shown that barrows have greater feed intake and ADG than gilts.

Pens of pigs fed WP and PP had greater G:F ($P \leq 0.05$) than pens fed CON and DP diets during the first 13 d of feeding and for the overall feeding period. This is most likely attributed to these pigs having markedly lower DMI ($P \leq 0.05$) during the initial period (Table 3-3). This contradicts the findings from Baird et al. (1974) who reported no difference in feed efficiency when replacing up to 40% of the diet with dry citrus pulp. In this study, the increased NDF in the WP and PP diets likely increased hind gut growth during the first period of feeding. This added gut mass combined with the additional gut fill of the high moisture diets could have explained the increase in G:F for the WP and PP diets (Pluske et al., 1998; Rijnen et al., 2001; Yen, 2001). The findings for pigs fed the two low moisture diets to have elevated DMI during the first 13 d of feeding compared to the rest of the period are not understood. However, the increased acidity of the two ensiled products could have lead to a decrease in the palatability of the WP and PP diets, potentially decreasing feed intake.

The cost of gain was more similar for all treatments for the second and third feeding periods, but during the first 13 d of feeding the WP and PP had numerically lower cost of gain at 1.12 and 1.08 dollars per kg than pigs fed the CON or DP diets which were 1.81 and 1.62 dollars per kg, respectively (Table 3-4). The cost of the WP and PP diets were lower than the CON and DP diets and this combined with the increased gain per kg of DMI for the two high moisture diets explains the overall lower cost of gain compared with the CON diet. However, it is important to note that the additional labor of ensiling, weekly feed blending, and preventing feed bridging within the feeders for pigs fed WP and PP diets increased the cost of gain when compared to pigs fed the CON and DP diets.

Carcass traits

Dietary citrus pulp inclusion did not affect ($P \geq 0.11$) live weight, HCW, 10th-rib fat depth, LM area, or lean muscle percentage (Table 3-5). The lack of dietary treatment differences for

back fat depth in this study contradicts the findings of Cerisuelo et al. (2010) who reported pigs fed citrus pulp had less fat thickness. This difference in findings could be due to the variation in data collection methods whereas Cerisuelo et al. (2010) measured back fat depth at the last rib, compared with 10th-rib fat thickness in the current study. Findings for LM area across dietary treatment are consistent with previous findings by Cerisuelo et al. (2010) and Baird et al. (1974).

Gilts fed the CON diet had greater dressing percentages ($P < 0.01$) than all other gender-treatment combinations, which did not differ (citrus pulp inclusion × gender, $P = 0.02$; Figure 3--2). The decreased dressing percentage of gilts fed citrus pulp is likely caused by an increase in hindgut fermentation. Previous work shows that an increase of fiber in swine diets can increase the weights of the stomach, caecum and colon and the length of the colon, thus decreasing dressing percentage (Jorgenson et al., 1996; Rijnen et al., 2001; Yen, 2001). Our data for dressing percent are consistent with the findings of Cerisuelo et al. (2010) and Baird et al. (1974) who fed pigs diets containing up to 40% of citrus pulp in their diets. The findings for gilts to have greater dressing percentages than barrows is supported by Ellis et al. (1996) and Latorre et al. (2004), but differs from other authors (Fortin, 1980; Hamilton et al., 2000; Latorre et al., 2003); who reported gender did not affect dressing percentage. These conflicting reports collectively support our findings. However, the findings in our study for gilts to produce leaner, lighter carcasses (Table 3-5) are well supported (Latorre et al., 2003; See et al., 2004; Carr et al., 2005).

Lean Quality

Dietary treatment did not affect ($P \geq 0.25$) any measurement of LM or SM subjective quality, pH, or objective lean color during chilling or at fabrication (Table 3-6). These findings for firmness and marbling were consistent with those of Baird et al. (1974) for hogs fed up to 20 % citrus pulp. These findings agree with the reports of authors who fed other ensiled high fiber,

high moisture diets at similar inclusion levels such as apples (Lee et al., 2009a) and mushrooms (Song et al., 2007; Chu et al., 2012). LM chops from pigs fed WP had greater ($P < 0.03$) 24-h drip loss values than LM chops from pigs fed the DP diet, and LM chops from the PP treatment had greater ($P < 0.03$) drip loss values than chops from the DP treatment (Table 3-6). However, LM roasts stored for 7 d did not differ in purge loss ($P = 0.59$) across treatments (Table 3-6). The lack of agreement between the two assessments of moisture loss may be explained by the different methodology and conditions used to calculate the percentages.

Citrus pulp inclusion did not affect ($P \geq 0.10$) any pH measurement, Hunter L*, a*, b*, or chroma values of the GM (Table 3-7). The GM from pigs fed DP was less truly red (greater hue angle values; $P < 0.03$) than the GM from pigs fed CON or PP diets (Table 3-7). The statistical differences between genders for GM redness, chroma, and hue are likely of little practical significance because all numbers fall into the acceptable ranges shown in Table 2-2 for pork quality (Table 3-7).

Retail Evaluation

Dietary citrus pulp inclusion did not affect ($P \geq 0.83$) trained retail panel evaluation of LM chops for fat color or percentage discoloration over 5 d of retail display (Table 3-8). There were also no differences between dietary treatments ($P \geq 0.64$) for Hunter b*, chroma, hue angle values or total color change (Δ E values) of LM chops over the 5 d display period. LM chops from pigs fed PP were subjectively darker (greater lean color scores, $P < 0.03$) than LM chops from pigs fed CON, DP, or WP diets (Table 3-8). Diets with 17 to 18 % fat and low carbohydrate digestability have shown to decrease the glycogen storage in the LM (Rosenvold et al., 2001). A decrease in muscle clycogen could increase water holding capacity and color being the reason for LM chops from PP pigs having darker lean color than LM chops from CON pigs (Rosenvold & Andersen, 2003). Across display, LM chops from barrows fed the WP diet and

gilts fed the PP diet were darker (lower L* values; $P < 0.04$) than LM chops from barrows fed the CON, DP, or PP diets, as well as gilts fed the CON or WP diets (citrus pulp inclusion × gender, $P < 0.03$; Figure 3-3). LM chops from barrows fed the WP diet were more red (higher a* values; $P < 0.04$) than pigs fed CON diet, gilts fed the PP and WP diets, and barrows fed the DP diet, over 5 d of display (Figure 3-3). Though these statistical differences were observed, all lean quality measurements for all treatments fell into acceptable ranges listed in Table 2-2. Collectively dietary citrus pulp inclusion had little impact on lean quality during retail display.

Regardless of dietary treatment, LM chops displayed a linear decrease ($P < 0.01$) in subjective lean color score and chroma values and a linear increase ($P < 0.01$) in fat color and percentage discoloration scores and hue angle values, across 5 d of retail display (data not shown). The findings for pork lean color to become less vivid and less truly red during retail display are supported by previous authors (Milligan et al., 1998; Apple et al., 2007). LM chops from barrows were more discolored ($P = 0.02$) on d 5 of retail display than gilts on the same day (gender × days of retail display, $P = 0.01$; Figure 3-4).

Sensory Evaluation

Dietary citrus pulp inclusion did not affect ($P \geq 0.44$) trained sensory panelist values of LM chops for connective tissue or off-flavor, LM cooking loss percentage, or WBSF values of chops from the LM or GM (Table 3-9). Chops of LM from gilts fed the WP diet were more tender (greater tenderness values, $P < 0.05$) than LM chops from barrows fed the same diet and gilts fed the CON or PP diets and all pigs fed the DP diet (citrus pulp inclusion × gender, $P < 0.04$; Figure 3-5). LM chops from gilts fed the DP or WP diets and barrows fed the PP diet were more juicy ($P < 0.05$) than all pigs fed the CON diet or gilts fed the PP diet (Figure 3-5). Gilts fed PP had LM chops with more bland pork flavor ($P < 0.05$) than gilts fed the WP diet and barrows fed the CON or PP diets (Figure 3-5). The findings for dietary citrus pulp inclusion to

either not affect or even slightly improve palatability is similar to the findings from pigs fed diets containing up to 7% ensiled red clover (Jonsall et al., 2000), persimmon shells (Kim et al., 2006) or apples (Lee et al., 2009a).

Implications

Citrus pulp is a viable byproduct for utilization in finishing swine diets at 15%. of the diet DM. Pigs fed the PP diet displayed a 20% improvement in G:F across the feeding period. Replacing 15% of the diet DM with citrus pulp had marginal effect on carcass traits, shelf life, or sensory characteristics. Replacing 15% of the diet DM with ensiled citrus pulp, can decrease the cost of gain if those feedstuffs are accessible within a close range of swine operations. However, anagement will be very important when feeding an ensiled high moisture feedstuff to pigs. These feedstuffs should be utilized within 7 d of removing from the ensilement container to prevent spoilage and mycotoxin development from mold. Additionally, these diets will require additional labor to ensile the high moisture pulp, to mix and blend feed more frequently to maintain feed quality and palatability, and to prevent feed bridging, clumping, and waste within the feeders. Feeding ensiled citrus pulp has improved application for gestating sows because feed is generally offered once daily on the floor, minimizing problems with feeders, and sows have improved hindgut fermentation compared to finishing pigs, suggesting the citrus pulp could be fed at an increased rate.

Table 3-1. Composition of the experimental diets (dry matter basis)

	Diet[1]			
Ingredients	CON	DP	WP	PP
Citrus pulp	0.00	15.00	15.00	15.00
Corn	79.45	64.90	65.00	64.55
Soybean meal	16.00	16.25	16.25	16.25
Vegetable Oil	1.75	1.75	1.75	1.75
Limestone	1.30	0.55	0.45	0.90
Monocalcium phosphate	1.00	1.05	1.05	1.05
Salt	0.30	0.30	0.30	0.30
Vitamin-trace mineral premix[1]	0.20	0.20	0.20	0.20

[1]Supplied per kilogram of premix:5,500 IU vitamin A; 680 IU vitamin D_3; 5.5 mg vitamin K activity; 7 mg riboflavin; 23 mg d-pantothenic acid; 34 mg niacin; 140 mg choline chloride; 27 mg vitamin B_{12}; 100 mg zinc (ZnO); 50 mg iron ($FeSO_4$); 27 mg manganese (MnO); 5 mg copper ($CuSo_4$); 0.8 mg iodine (CaI_2) and 0.15 mg selenium ($NaSeO_3$).

Table 3-2. Chemical composition of the experimental diets (dry matter basis)

	Diet[1]			
Nutrient composition	CON	DP	WP	PP
DM, %	88.8	89.1	57.7	66.9
ME, Kcal/kg	3657	3530	3534	3503
CP, %	16.9	16.53	16.69	16.69
NDF, %	8.43	10.59	10.51	10.95
Crude fat, %	21.14	18.28	16.31	18.66
Lysine, %	0.78	0.78	0.78	0.78
Calcium, %	0.73	0.73	0.72	0.73
Phosphorus, %	0.57	0.56	0.56	0.56

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp.

Table 3-3. Effect of dietary citrus pulp inclusion and gender on growth and feed efficiency of pens

	Diet[1]				Gender		*P*-values		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	8	10	10	18	20			
No. of pens	5	4	5	5	9	10			
Initial pig wt, kg	89.7 ± 5.14	86.20 ± 5.16	84.4 ± 5.02	87.8 ± 5.04	83.8 ± 4.98	90.3 ± 4.98	0.14	< 0.01	0.82
1st 13 d									
DMI, kg	101.0[a] ± 3.6	97.0[a] ± 4.6	62.9[b] ± 3.7	63.8[b] ± 3.6	75.3 ± 3.0	87.1 ± 2.6	< 0.01	0.02	0.66
ADG, kg/d	2.02 ± 0.19	1.92 ± 0.24	1.95 ± 0.19	2.02 ± 0.19	1.75 ± 0.15	2.20 ± 0.14	0.98	0.06	0.79
Gain:feed, kg	0.25[b] ± 0.04	0.26[b] ± 0.05	0.41[a] ± 0.04	0.41[a] ± 0.04	0.33 ± 0.03	0.34 ± 0.03	0.03	0.90	0.81
2nd 13 d									
DMI, kg	73.6 ± 2.8	74.3 ± 3.5	71.3 ± 2.8	74.2 ± 2.8	69.5 ± 2.29	77.2 ± 2.00	0.87	0.03	0.68
ADG, kg/d	2.04 ± 0.10	2.15 ± 0.13	1.79 ± 0.10	2.18 ± 0.10	2.02 ± 0.09	2.05 ± 0.07	0.26	0.13	0.02
Gain:feed, kg	0.36 ± 0.02	0.37 ± 0.02	0.33 ± 0.02	0.37 ± 0.02	0.38 ± 0.02	0.38 ± 0.02	0.26	0.13	0.02
3rd 13 d									
DMI, kg	75.2 ± 3.5	75.7 ± 4.2	63.0 ± 3.5	64.1 ± 4.3	66.8 ± 4.2	72.1 ± 3.5	0.52	0.96	0.95
ADG, kg/d	1.74 ± 0.14	1.69 ± 0.18	1.36 ± 0.15	1.44 ± 0.14	1.48 ± 0.12	1.63 ± 0.10	0.25	0.38	0.95
Gain:feed, kg	0.30 ± 0.02	0.29 ± 0.03	0.28 ± 0.02	0.29 ± 0.02	0.29 ± 0.02	0.29 ± 0.03	0.94	0.81	0.32
Overall									
DMI, kg	249.8[a] ± 7.5	247.0[a] ± 9.5	197.2[b] ± 7.6	202.1[b] ± 7.5	211.6 ± 6.2	236.5 ± 5.4	< 0.01	0.01	0.44
ADG, kg/d	1.94 ± 0.09	1.91 ± 0.11	1.69 ± 0.09	1.88 ± 0.09	1.71 ± 0.07	1.99 ± 0.06	0.26	0.02	0.31
Gain:feed, kg	0.30[b] ± 0.01	0.30[b] ± 0.01	0.34[a] ± 0.01	0.36[a] ± 0.01	0.32 ± 0.01	0.33 ± 0.01	0.01	0.33	0.17

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

[a, b]For diet effects, values lacking a common superscript letter differ ($P \leq 0.05$).

Table 3-4. Effect of dietary citrus pulp inclusion on cost of gain per pen ($/kg gained)

	Diet[1]				Diet + Labor[2]			
Feeding period	CON	DP	WP	PP	CON	DP	WP	PP
1st 13 d	4.01	3.57	2.50	2.42	4.01	3.57	3.67	3.67
2nd 13 d	2.74	2.55	3.24	2.60	2.74	2.55	4.58	3.73
3rd 13 d	3.57	3.14	3.43	3.29	3.57	3.14	5.07	4.96
Overall	3.32	3.06	2.96	2.70	3.32	3.06	4.30	4.03

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

[2]Labor calculated using 1.5 h per day * minimum wage for WP and PP treatments.

Table 3-5. Effect of dietary citrus pulp inclusion and gender on carcass traits

	Diet[1]				Gender		*P*-values		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	9	10	10	19	20			
Live weight, kg	123.2 ± 1.61	121.4 ± 1.76	118.3 ± 1.62	122.1 ± 1.61	118.2 ± 1.22	124.3 ± 1.16	0.19	< 0.01	0.24
HCW, kg	94.7 ± 1.45	91.78 ± 1.59	89.46 ± 1.40	92.0 ± 1.41	90.0 ± 1.18	94.0 ± 1.16	0.11	0.02	0.24
10th-rib fat depth, cm	2.59 ± 0.31	2.26 ± 0.30	2.20 ± 0.29	2.22 ± 0.29	2.08 ± 0.28	2.57 ± 0.28	0.23	0.02	0.28
LM area, cm^2	46.56 ± 1.68	46.62 ± 1.76	46.24 ± 1.60	46.01 ± 1.61	49.90 ± 1.35	45.81 ± 1.42	0.99	0.53	0.26
Lean %[2]	51.03 ± 0.92	52.28 ± 0.95	52.61 ± 0.87	52.23 ± 0.87	53.18 ± 0.77	50.90 ± 0.80	0.51	0.03	0.27

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.
[2]Lean percentage calculated using the NPPC (2000) formula.

Table 3-6. Effect of dietary citrus pulp inclusion and gender on lean quality traits of the semimembranosus (SM) and longissimus muscle (LM) during chilling, at fabrication, and during storage

	Diet[1]				Gender		*P*-value		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	9	10	10	19	20			
SM									
45-min pH	6.56 ± 0.07	6.50 ± 0.08	6.51 ± 0.07	6.54 ± 0.07	6.53 ± 0.05	6.52 ± 0.05	0.95	0.94	0.35
24-h pH	5.73 ± 0.03	5.71 ± 0.03	5.73 ± 0.03	5.74 ± 0.03	5.73 ± 0.03	5.72 ± 0.03	0.88	0.67	0.21
LM									
45-min pH	6.33 ± 0.04	6.41 ± 0.04	6.30 ± 0.04	6.32 ± 0.04	6.35 ± 0.03	6.34 ± 0.03	0.25	0.83	0.66
24-h pH	5.66 ± 0.03	5.69 ± 0.03	5.67 ± 0.03	5.69 ± 0.02	5.68 ± 0.03	5.67 ± 0.02	0.45	0.35	0.79
Lightness (L*)[2]	46.61 ± 1.38	46.11 ± 1.39	44.74 ± 1.29	45.21 ± 1.28	44.81 ± 1.28	46.52 ± 1.12	0.48	0.13	0.26
Redness (a*)[2]	7.08 ± 0.64	7.46 ± 0.62	7.38 ± 0.60	7.01 ± 0.60	7.30 ± 0.59	7.17 ± 0.61	0.55	0.73	0.89
Yellowness (b*)[2]	11.08 ± 0.22	10.96 ± 0.24	10.70 ± 0.22	10.57 ± 0.22	10.57 ± 0.17	11.08 ± 0.16	0.35	0.04	0.36
Chroma[3]	13.20 ± 0.41	13.24 ± 0.42	12.92 ± 0.39	12.70 ± 0.38	12.82 ± 0.41	13.21 ± 0.31	0.48	0.25	0.40
Hue[4]	56.81 ± 2.39	55.63 ± 2.31	55.38 ± 2.21	56.27 ± 2.24	55.50 ± 2.20	56.55 ± 2.26	0.77	0.46	0.97
Color score[5]	2.6 ± 0.37	2.9 ± 0.36	2.7 ± 0.33	3.1 ± 0.34	2.8 ± 0.33	2.8 ± 0.33	0.33	0.88	0.41
Firmness score[6]	2.9 ± 0.24	2.4 ± 0.27	2.5 ± 0.25	2.9 ± 0.24	2.5 ± 0.19	2.9 ± 0.18	0.47	0.13	0.23
Marbling score[7]	2.0 ± 0.56	2.7 ± 0.54	2.2 ± 0.52	2.4 ± 0.52	2.1 ± 0.51	2.6 ± 0.52	0.28	0.15	0.06
Chop 24-h drip loss, %	4.17[ab] ± 1.17	3.28[b] ± 1.15	6.06[a] ± 1.06	5.34[a] ± 1.08	4.76 ± 1.06	4.67 ± 1.05	0.03	0.91	0.37
Roast 7-d purge loss, %	7.14 ± 1.42	7.37 ± 1.44	5.72 ± 1.34	7.24 ± 1.32	7.11 ± 1.34	6.62 ± 1.14	0.59	0.67	0.49

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

[2]L* = measure of darkness to lightness (larger value indicates a lighter color); a* = a measure of redness (larger value indicates a redder color); b* = a measure of yellowness (larger value indicates a more yellow color).

[3]Chroma is a measure of total color (a larger number indicates a more vivid color).

[4]Hue angle represents the change from the true red axis (a larger number indicates shift from red to yellow).

[5]1 = white to pale pinkish gray to 6 = dark purplish red (NPPC, 2000).

[6]1 = very soft and watery to 5 = very firm and dry (NPPC, 1991).

[7]1 = 1% i.m. fat to 10 = 10% i.m. fat (NPPC, 2000).

[a,b]For diet effects, values lacking a common superscript letter differ ($P < 0.03$).

Table 3-7. Effect of dietary citrus pulp inclusion and gender on lean quality traits of the gluteus medius (GM) at fabrication

	Diet[1]				Gender		*P*-value		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	9	10	10	19	20			
24-h pH	5.75 ± 0.03	5.71 ± 0.03	5.71 ± 0.03	5.71 ± 0.03	5.71 ± 0.02	5.73 ± 0.02	0.57	0.54	0.21
Lightness (L*)[2]	41.80 ± 1.17	44.15 ± 1.26	42.45 ± 1.14	41.19 ± 1.14	42.90 ± 0.93	41.90 ± 0.92	0.32	0.44	0.08
Redness (a*)[2]	9.16 ± 0.32	8.03 ± 0.34	8.51 ± 0.30	8.82 ± 0.30	8.07 ± 0.25	9.19 ± 0.25	0.10	0.01	0.68
Yellowness (b*)[2]	10.79 ± 0.22	10.64 ± 0.24	10.42 ± 0.22	10.11 ± 0.22	10.29 ± 0.16	10.70 ± 0.16	0.16	0.09	0.36
Chroma[3]	14.17 ± 0.34	13.34 ± 0.37	13.48 ± 0.33	13.42 ± 0.33	13.09 ± 0.28	14.11 ± 0.27	0.28	0.02	0.48
Hue[4]	49.71[b] ± 0.81	53.02[a] ± 0.89	50.87[ab] ± 0.81	49.02[b] ± 0.81	51.91 ± 0.62	49.40 ± 0.58	0.02	0.01	0.78

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

[2]L* = measure of darkness to lightness (larger value indicates a lighter color); a* = a measure of redness (larger value indicates a redder color); b* = a measure of yellowness (larger value indicates a more yellow color).

[3]Chroma is a measure of total color (a larger number indicates a more vivid color).

[4]Hue angle represents the change from the true red axis (a larger number indicates shift from red to yellow).

[a,b] For diet effects, values lacking a common superscript letter differ ($P < 0.01$).

Table 3-8. Effect of dietary citrus pulp inclusion and gender on subjective and objective lean quality traits of longissmus muscle chops across 5 d of retail display

	Diet[1]				Gender		*P*-value		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	9	10	10	19	20			
Lean color score[2]	$2.93^{b} \pm 0.10$	$2.95^{b} \pm 0.10$	$2.95^{b} \pm 0.10$	$3.14^{a} \pm 0.10$	2.98 ± 0.10	3.01 ± 0.10	0.03	0.05	0.06
Fat color score[3]	2.08 ± 0.10	2.12 ± 0.11	2.16 ± 0.11	2.09 ± 0.11	2.09 ± 0.11	2.09 ± 0.11	0.99	0.73	0.48
Discoloration, %[4]	1.69 ± 0.16	1.78 ± 0.16	1.83 ± 0.15	1.66 ± 0.15	1.72 ± 0.15	1.76 ± 0.15	0.83	0.18	0.66
Yellowness (b*)[5]	12.35 ± 0.31	12.27 ± 0.30	12.24 ± 0.29	12.12 ± 0.30	12.12 ± 0.29	12.37 ± 0.30	0.64	0.18	0.08
Chroma[6]	15.02 ± 0.41	14.93 ± 0.41	15.00 ± 0.40	14.84 ± 0.40	14.74 ± 0.40	15.15 ± 0.40	0.85	0.02	0.15
Hue[7]	56.20 ± 1.21	56.25 ± 1.18	55.59 ± 1.13	55.68 ± 1.15	55.92 ± 1.13	55.94 ± 1.15	0.76	0.72	0.21
Δ E[8]	6.77 ± 0.40	6.83 ± 0.44	6.97 ± 0.40	6.48 ± 0.40	6.53 ± 0.31	6.99 ± 0.29	0.86	0.29	0.89

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.
[2]1 = white to pale pinkish gray to 6 = dark purplish red (NPPC, 2000).
[3]1 = White; 2 = Creamy white; 3 = Slightly tan; 4 = Moderately tan; 5 = Tan; 6 = Brown.
[4]1 = No discoloration (0%); 2 = Slight discoloration (1 to 10%); 3 = Small discoloration (11 to 25%); 4 = Modest discoloration (26 to 51%); 5 = Moderate discoloration (51 to 75%); 6 = Extensive discoloration (76 to 99%); 7 = Total discoloration (100%).
[5]b* = a measure of yellowness (larger value indicates a more yellow color).
[6]Chroma is a measure of total color (a larger number indicates a more vivid color).
[7]Hue angle represents the change from the true red axis (a larger number indicates shift from red to yellow).
[8]Δ E represents the change in total color from day 0 (larger number indicates a greater change in total color from day 0).
[a,b] For diet effects, values lacking a common superscript letter differ ($P < 0.01$).

Table 3-9. Effect of dietary citrus pulp inclusion and gender on trained sensory panel values and cooking loss of longissmus muscle (LM) chops and Warner-Bratzler Shear Force (WBSF) values of LM and gluteus medius (GM) chops

	Diet[1]				Gender		*P*-value		
Item	CON	DP	WP	PP	Gilt	Barrow	Diet	Gender	Diet × Gender
No. of pigs	10	9	10	10	19	20			
Connective Tissue[2]	6.6 ± 0.18	6.6 ± 0.17	6.7 ± 0.16	6.8 ± 0.16	6.5 ± 0.13	6.8 ± 0.13	0.79	0.08	0.55
Off-flavor[3]	5.8 ± 0.09	5.7 ± 0.08	5.8 ± 0.08	5.7 ± 0.08	5.7 ± 0.07	5.8 ± 0.09	0.75	0.55	0.59
Cook loss, %[4]	20.67 ± 1.52	19.08 ± 1.66	17.70 ± 1.52	19.40 ± 1.51	19.83 ± 1.05	18.60 ± 1.10	0.61	0.46	0.25
LM WBSF, kg	3.49 ± 0.49	3.47 ± 0.47	3.42 ± 0.45	3.45 ± 0.46	3.47 ± 0.48	3.44 ± 0.45	0.99	0.85	0.43
GM WBSF, kg	3.66 ± 0.20	3.50 ± 0.22	3.27 ± 0.19	3.32 ± 0.19	3.58 ± 0.16	3.29 ± 0.16	0.44	0.21	0.24

[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

[2]1 = abundant amount of connective tissue; 8 = none detected.

[3]1 = extreme off-flavor; 6 = no off-flavor.

[4]Cook loss percentage calculated by dividing cooked weight by thawed weight × 100 %

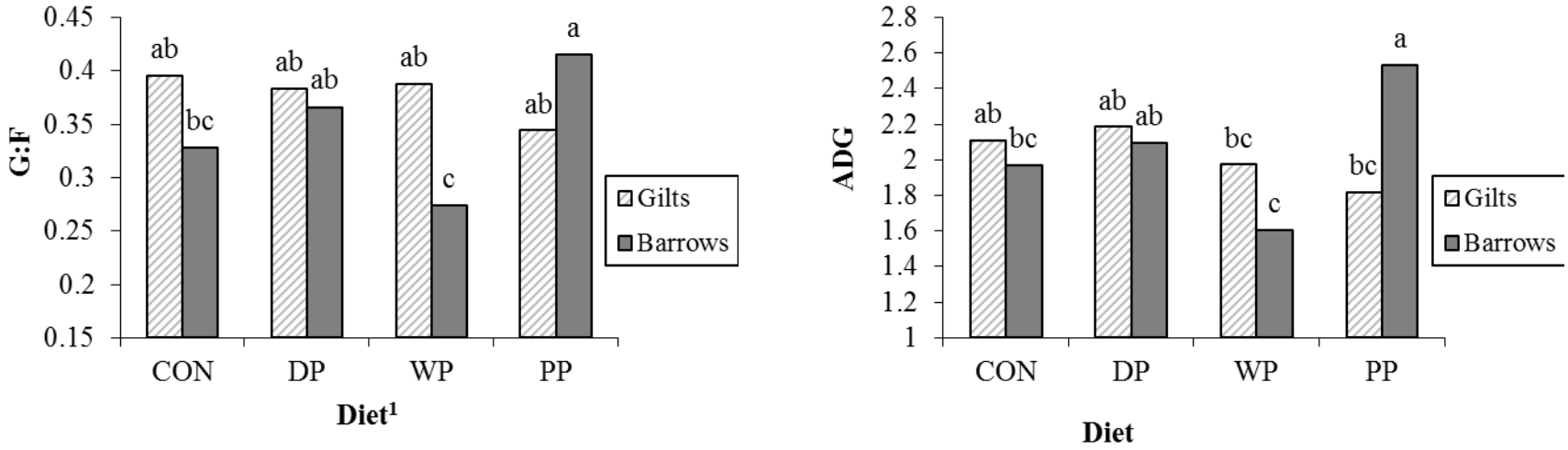

Figure 3-1. Interactive effect of dietary citrus pulp inclusion and gender on G:F and ADG of pens of pigs during the second 13 d feeding period ($P = 0.02$). Bars lacking a common letter differ ($P < 0.05$).[1]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

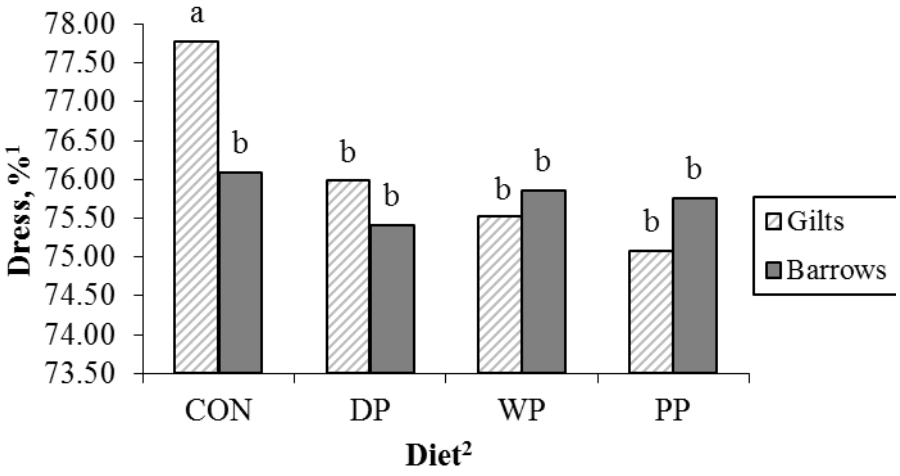

Figure 3-2. Interactive effect of dietary citrus pulp inclusion and gender on dressing percentage ($P = 0.02$). Bars lacking a common letter differ ($P < 0.01$). [1]Dressing percentage calculated by dividing hot carcass weight by full live weight × 100 %. [2]CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

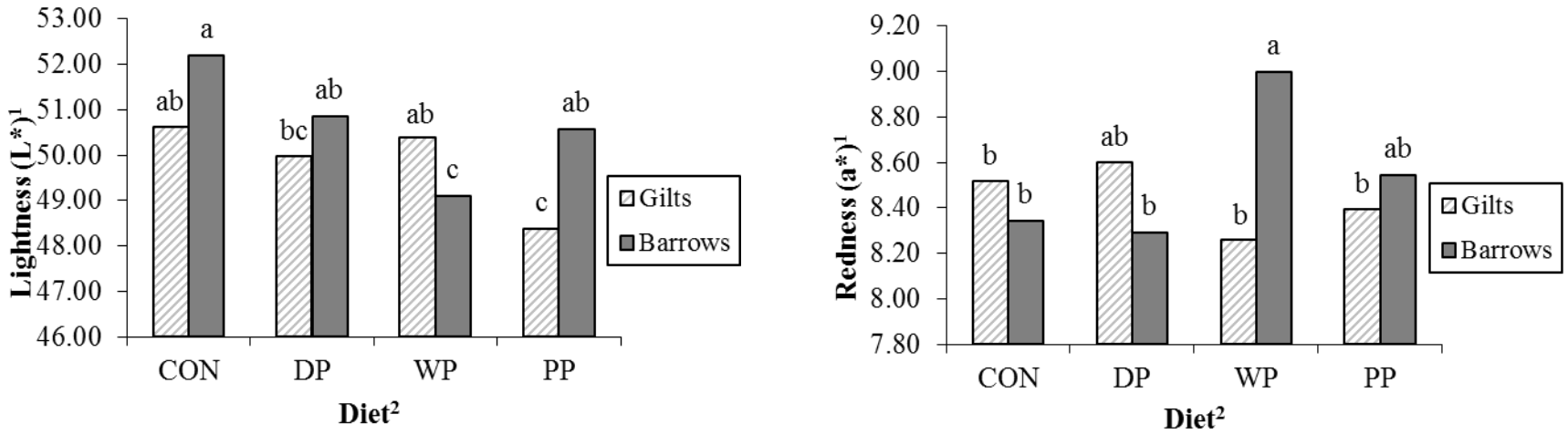

Figure 3-3. Interactive effect of dietary citrus pulp inclusion and gender on lightness and redness values of longissimus muscle chops over 5 d of retail display ($P < 0.03$). Bars lacking a common letter differ ($P < 0.04$). L* = measure of darkness to lightness (larger value indicates a lighter color); a* = a measure of redness (larger value indicates a redder color). CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

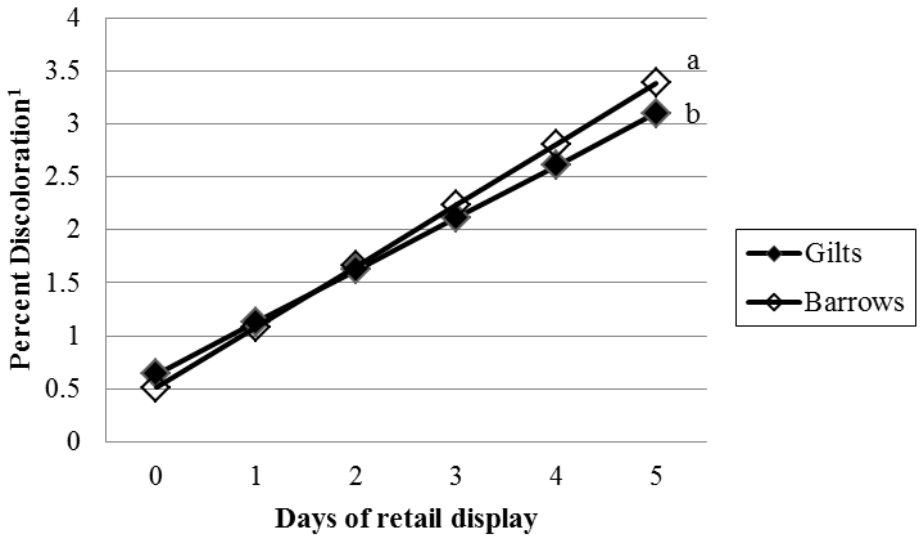

Figure 3-4. Interactive effect of gender and days of retail display on percent discoloration (P = 0.01). Means with a different letters differ ($P < 0.02$) within a given day of retail display.

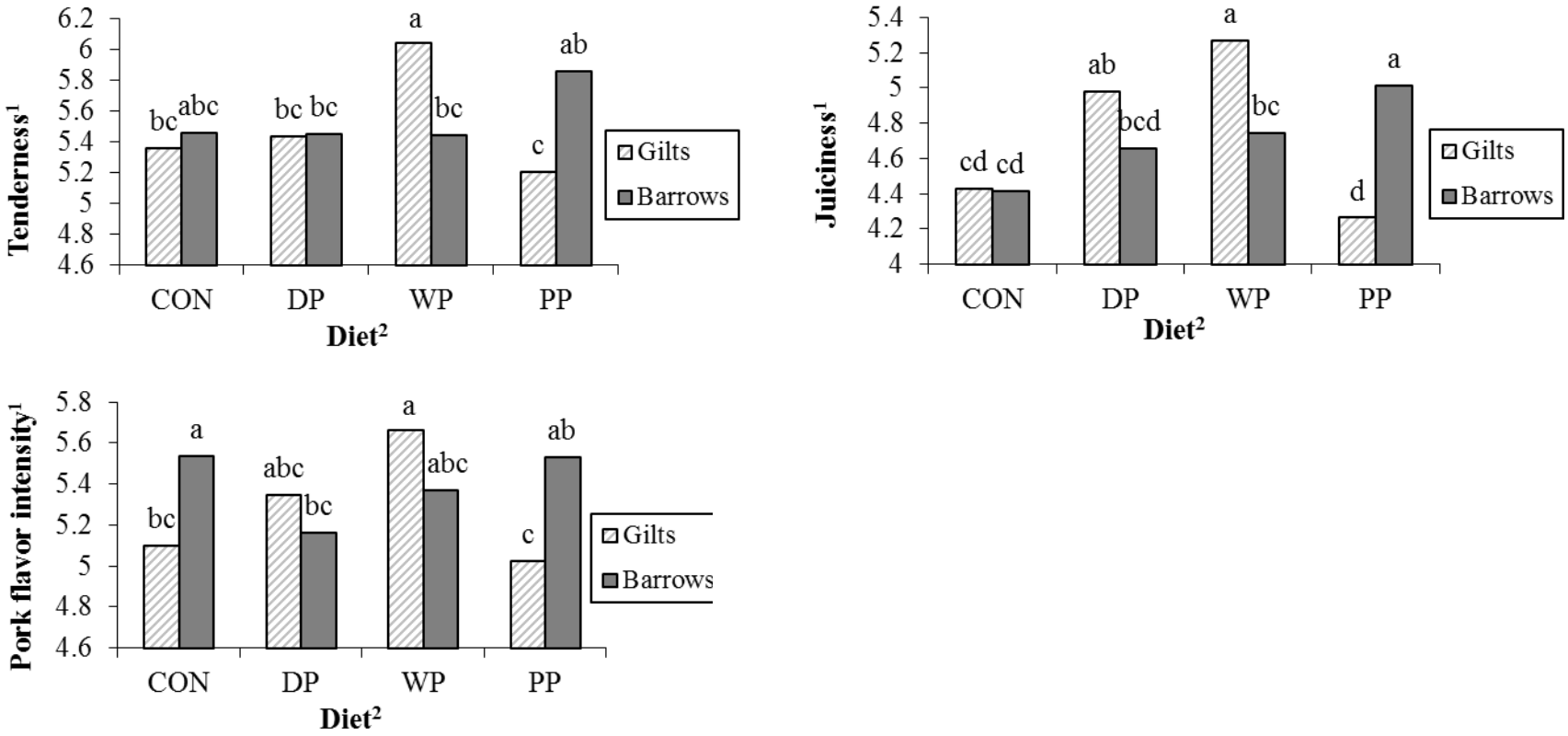

Figure 3-5. Interactive effect of dietary citrus pulp inclusion and gender on trained sensory panel tenderness, juiciness and pork flavor intensity values of longissimus muscle chops ($P < 0.04$). Bars lacking a common letter differ ($P < 0.05$). 1 = extremely tough, dry, or bland; 8 = extremely tender, juicy or intense. CON = corn-soybean meal control diet; DP = diet containing 15% dried citrus pulp; WP = diet containing 15% ensiled, whole citrus pulp, PP = diet containing 15% ensiled, pressed citrus pulp, on a DM basis.

APPENDIX A
CHEMICAL COMPOSITION OF ENSILED WHOLE PULP AND PRESSED PULP

Table A-1. Chemical analysis of whole pulp (WP) and pressed pulp (PP) from Dairy One, Ithica, NY (dry matter basis)

	Citrus byproduct	
Nutrient Composition	WP	PP
Dry matter, %	19.6	27.9
Crude protein, %	8.0	7.7
Acid detergent fiber, %	19.3	14.0
Nuetral detergent fiber, %	23.2	25.3
Fat, %	2.6	5.9
Ash, %	4.6	7.4
Calcium, %	1.0	2.0
Phosphorus, %	0.1	0.1

APPENDIX B
AEROBIC STABILITY OF WHOLE PULP AND PRESSED PULP WITH OR WITHOUT FEED

Table B-1. Aerobic stability of whole pulp (WP) and (PP) with or without feed

	Citrus pulp byproduct			
	WP	PP	WP + Feed	PP + Feed
Aerobic stability	40.67	75.75	58.00	80.25

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BIOGRAPHICAL SKETCH

Justin Crosswhite was born in Joplin, Missouri in 1988, the son of Glenn and Karen Crosswhite. He was raised alongside his sister, Lyndsey Crosswhite, in Wyandotte, Oklahoma. Justin grew up raising and showing purebred and crossbred pigs. He graduated from Wyandotte High School, Wyandotte, Oklahoma in 2006. Justin attended junior college at Connors State College where he participated on the livestock judging team and achieved an Associates of Science. He then went on to Oklahoma State University. He attained his Bachelor of Science degree in Animal Sciences in 2012. He is currently a graduate assistant finishing a Master of Science degree in Animal Sciences at the University of Florida.