

PORK CARCASS COMPOSITION, MEAT AND BELLY QUALITIES AS INFLUENCED BY
FEED EFFICIENCY SELECTION IN SIRE AND DAM LINES

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ABSTRACT

With the increased demand for lean meat and the high feed cost, the ideal animal with low input costs and excellent output quality is desired. Therefore, the selection of desired animals is crucial and could be made through estimated breeding values for feed conversion ratio (EBV-FCR), which is the genetic value of an animal and an estimation of the animal's potential for specific traits. Thus, feed efficiency (FE) can be maximized as well as growth performance and carcass composition can be enhanced by using EBV. Although improving the pig's efficiency would be profitable, concerns have been expressed about pigs selected for HFE because they may produce pork of inferior quality; however, contradictory results have been shown to date. In the current study, one hundred boars slaughtered at approximately 115 kg of body weight were used to study the influence of genetic lines (dam line vs. sire line) and EBV-FCR (low-, intermediate- and high-efficient groups) within the Large White breed on carcass attributes, meat, and belly qualities. At 96 h post-mortem, left carcass sides were evaluated for backfat depth and thickness (on first rib, last rib, and last lumbar), loin depth and area, subjective muscle colour and marbling, then fabricated into primals, and finally dissected into fat, bone, and lean. Boneless loins and skin-on boneless bellies were obtained from the right carcass sides. Loin pork chops (2.5 cm thick) were used for Warner Bratzler shear force (WBSF), cooking traits, drip loss, pH, and objective colour evaluation. Belly dimension (length, width and thick) and belly firmness (subjective belly firmness score and belly-flop angle) were measured. Slaughter weight was included as a covariate in the model due to the slaughter weight difference among genetic lines. No difference in carcass weight was detected among genetic lines ($P > 0.05$); however, the sire line had a greater loin area and loin depth and thinner fat depth than the dam line ($P < 0.05$), which favoured higher lean and lower trimmed fat proportions in the sire line ($P < 0.01$). For quality, genetic lines expressed

minimal colour changes and drip losses ($P < 0.05$), with no differences in pH, marbling level and cooking traits ($P > 0.05$). On the other hand, regardless of genetic line, high-efficient animals presented the greatest loin area, the deepest loin, the thinnest back fat on the last rib and lumbar level ($P < 0.05$), the highest lean yield and the lowest proportion of trimmed fat ($P < 0.01$) compared with other efficient groups. For meat quality, efficient groups did not differ in pH, marbling level, drip loss, objective, subjective colour score, cooking traits and WBSF ($P > 0.05$). Based on the advantageous performance observed in most carcass yield traits, high-efficient animals offer a favourable response in greater loin and leaner animals without decreased meat and belly quality traits.

Keywords: carcass composition, Estimated Breeding Value, feed efficiency, meat quality, belly quality

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ABBREVIATIONS

AAFC = Agriculture and Agri-Food Canada

ACTH=Adrenocorticotrophic hormone

ADG = average daily gain

AMSA = American Meat Science Association

BW = body weight

°C = degree Celsius

CCAC = Canadian Council of Animal Care

CM=Castrated male

cm = centimeter

CMC = Canadian Meat Council

CS=Carcass score

CSA=Cross sectional area

DFD=Dark firm dry

EBV = Estimated Breeding Value

EBV-FCR=Estimated breeding value for feed conversion ratio

FCR = Feed Conversion Ratio

FE = Feed Efficiency

FI=Feed intake

g = gram

GEBV=Genomic breeding value

h = hours

HFE=High feed efficiency

hd = head

HCW = hot carcass weight

HRFI=High residual feed intake

IMC=Immunocastrated

IF=Intact female

Kg = kilogram

LFE=Low feed efficiency

LMC=Lean meat content

LRFI=Low residual feed intake

LW=Large White

MB = Manitoba

PSE=Pale soft exudative

RFI=residual feed intake

VFI=Voluntary feed intake

WBSF = Warner-Bratzler shear force

CHAPTER 1: GENERAL INTRODUCTION

Over the last 25 years, pork producers have radically changed their production processes. by implementing more cost-effective and efficient feeding methods, breeding techniques, and management procedures to improve animal performance and carcass quality, resulting in a constant increase in revenue (Patience et al., 2015).

Feed prices and the pig's capacity to use feed for growth have a significant impact on the profitability of operations in the production of pork. The cost of feed makes up between 60 and 70 percent of the entire cost of production (McCormack et al., 2017; Yang et al., 2017) hence increasing the pig's efficiency would be profitable. The capacity of the pig to convert feed into an edible product is known as feed efficiency (FE). Improvements in FE have been made through genetics and nutrition over the years. For the last 35 years, feed conversion rate (FCR) has decreased from 3.0-3.6 to 2.6-2.2 due to selection breeding for lean carcasses (Knap & Wang, 2012; Gaillard et al., 2020) and producers have clearly understood the economic significance of choosing for FE given its potential to significantly lower costs and increase the profitability of the swine business.

In pig breeding, one method to genetically improve FE is by using estimated breeding values (EBV) for FCR to maximize FE and improve growth performance and carcass composition (Patience et al., 2015). The capacity of a producer to choose breeding stock with an acceptable combination of excellent breeding values for all economic traits is a prerequisite for genetic progress in a seed stock herd. Producers consider EBV-FCR when selecting a boar to be utilized as a terminal sire (Cassidy, 2019). Several researchers have observed that high efficiency pigs (i.e., lower EBV-FCR values) produce a leaner carcass (i.e., less back fat) with less feed (Arkfeld et al.,

2015; Beens, 2022; Cai et al., 2008; Hewitt, 2020; Hoque et al., 2007; Lefaucheur et al., 2011; Smith et al., 2011). Thus, higher efficiency pigs would cost less to produce the same amount of product, making them valuable commercially. However, negative side effects of genetic selection for high-efficiency production have emerged. Concerns have been expressed on pigs selected for high FE because they may produce pork with inferior quality (e.g., lower pH, excessive drip loss, and colour changes) which is a drawback for the producers (Cai et al., 2008; Lefaucheur et al., 2011). Nonetheless, contradictory results have been shown to date; so, it is not clear how selection programs to increase FE affect meat quality (Patience et al., 2015). For example, Cai et al. (2008) found that selecting for lower RFI (high efficiency) did not compromise loin pH, color, or marbling in Yorkshire pigs. In contrast, Gilbert et al. (2007) reported that high efficiency group presented lower pH, lighter coloured meat in the gluteus medius than low feed efficiency (LFE) group and it may be caused by a decrease in the oxidative capability of skeletal muscle (i.e., high proportions of glycolytic myofibers type). Nevertheless, that decreased lipid content and postmortem protein breakdown may result in less tender pork loins from pigs with lower RFI levels (Smith et al., 2011). It is currently uncertain how selecting for FE in pigs affects the quality of pork, and more research is needed to address this issue. This underscores the need to assess the impact of growth and carcass leanness selection on pork quality, given the increasing consumer demand for better quality pork.

Therefore, the purpose of this study is to analyze the influence of genetic lines (dam line vs sire line) and EBV-FCR (low-, intermediate and high-efficient groups) within the Large White (LW) breed on carcass traits, carcass composition, meat, and belly qualities.

CHAPTER 2: LITERATURE REVIEW

2.1. Feed efficiency

FE, which may be defined in grow-finish pigs as the efficiency with which an animal uses dietary nutrients and energy for maintenance and tissue accretion which trait has been a production aim of interest since the early 1970s (Patience et al., 2015). The simplest definition of FE is the pig's capacity to convert feed into pork product. FE is calculated as body weight (BW) increase (Kg) per kilogram of consumed feed (Patience et al., 2015). Although the term appears straightforward, it can be challenging and confusing to express and measure FE. The terms FCR and RFI are frequently used to quantify FE. According to Hoque et al. (2007), FCR is determined as feed intake (FI) divided by BW gain, and RFI is calculated as the difference between the animal's actual FI and its anticipated nutrient needs (Koch et al., 1963). Although both terms express FE, their applications vary depending on the information searched after and the way it will be used to make decisions (Patience et al., 2015). Although, FCR is the primary indicator of FE on swine farms, numerous selection studies have employed RFI instead (Gilbert et al., 2017). It has been demonstrated that animal traits related to energy cost are selected for on RFI (Shirali, 2014). Pigs selected low in RFI had lower maintenance energy needs, which resulted in less physical activity and, consequently, less heat output. This has been found to significantly contribute to the increase in energy efficiency (Gilbert et al., 2017). Therefore, low RFI pigs are preferred because to the benefits of using less energy for feeding, associating with others, producing heat, and maintenance requirement.

2.2. Importance of feed efficiency

Businesses utilize efficiency metrics to set financial and production benchmarks and targets, which may lead to decisions that boost productivity without raising production costs. For example, in other species such as cattle, a 5% improvement in FE could have an economic impact four times greater than a 5% increase in average daily weight gain (Basarab et al., 2002). In addition, feedlot studies have demonstrated that a 10% improvement in average daily gain (ADG) improved profitability by 18%; whereas a 10% improvement in FE returned a 43% increase in profits (Fox et al., 2001). Cai et al. (2008) observed that selecting pigs with lower RFI resulted in a 13.2% reduction in FI, a 6.1% decrease in growth rate, a 14% reduction in backfat, and an approximately 8% improvement in FE. The study provides evidence that selecting pigs for lower RFI can lead to improvements in FE without compromising growth performance, while also reducing backfat. Therefore, efforts aimed at improving the efficiency will have a large impact on reducing input costs associated with swine production.

In modern capital-intensive methods, feed accounts for 60 to 70% of the overall cost of hog production and FE has a significant impact on financial returns, because of the close relationship between feed costs and FE as increase FE will decrease feed cost. Sometimes FE is hard to understand therefore, activities attempted to improve FE may mistakenly result in financial losses rather than profits. This is because efforts made just to enhance FE may have a positive or negative impact on other elements of the business, not least the cost of feed (Patience et al., 2015). Therefore, understanding the factors related to FE is equally important. For instance, genetic selection alone for greater FE, may reduce growth rate because in the case of selecting for FE, some genetic lines or individuals may have a naturally higher capacity to convert feed efficiently, but they may also have a lower growth rate compared to other individuals. Increased dietary

energy concentration is another example; while this simple measure almost always improves FE, it can also increase feed cost per pig, lowering net income (Patience et al., 2015).

FE serves various purposes, such as evaluating economics, performance, and environmental impact monitoring. In general, it's better for the environment and the wallets of farmers and ranchers when less inputs are required for the same or higher productivity. The cost of feeding animals and poultry is frequently the highest. Enhancing FE can benefit both animal agriculture and the environment by lowering the main environmental effect, manure excretion and emissions during pig farming (Opio et al., 2013). Thus, a tailored diet with high feed efficiency (HFE) is an important aspect for the environmental optimisation of pig production (Hauschild et al., 2012). The FE is a reliable sign of how farmers and ranchers can protect the environment and their business line (Dotterweich, 2020).

2.3. Biological and physiological aspects of feed efficiency

From a reproductive performance perspective, Young et al. (2016) investigated how in the grow-finish stage, FE selection had an impact on subsequent reproductive performance. They discovered sows from the more productive low residual feed intake (LRFI) line had equal piglet weights at birth and weaning and had 1.3 more piglets born alive and 1.6 more piglets weaned. Thus, during gestation and lactation, LRFI sows on average gave their piglets more energy. During lactation, LRFI sows consumed 18% less feed but sows mobilized much more body reserves to deliver this extra energy to their piglets and make up for their lower FI. They lost approximately 22 pounds more BW during lactation, including nearly 0.8 inch more backfat compared to high residual feed intake (HRFI) sows (Young et al., 2016). However, there could be a question if the greater negative energy balance, loss of BW in efficient sows during lactation affects rebreeding performance and evaluation indicated no difference in rebreeding performance between their high-

and low-RFI lines (Young et al., 2016). Consequently, based on RFI, genetic selection for greater FE during the grow-finish period has no effect on reproductive success. Sows that were bred for greater efficiency, produced larger litters and were greater mothers.

From animal behaviour point of view, less fearful behaviours are observed in pigs as a result of genetic selection for FE. More feed-efficient barrows would be less upset by having a producer in the pen (Colpoys et al., 2014). Sadler et al. (2011) assessed how RFI selection affects behaviour and the presence of lesions. There were no variations between the two lines in terms of posture, behaviour, or general activity on the day they were placed in their grow-finish pens. Nonetheless, behaviour changes were observed in later rounds, with LRFI gilts becoming less active. On the day following placement, lesion scores were lower in gilts from the LRFI line as well. Therefore, a superior lesion score in gilts on the day of placement was the outcome of genetic selection for increased FE.

Improved FE in pigs can provide additional benefits, such as increased tolerance to stress as Grubbs et al., (2013) reported that LRFI pigs showed a rise in antioxidant proteins and possible changes to the metabolic pathways related to oxidative stress, metabolism, and cellular repair in comparison to their HRFI counterparts. According to the findings, pigs chosen for LRFI may be less prone to muscle oxidative stress and may have livers with greater metabolic capability. Therefore, the metabolic inefficiencies in the mitochondria may result in greater tissue stress, which inhibits the accretion of lean tissue. Also, Colpoys et al. (2015) assessed the two RFI lines' gilts' physiological stress response. The findings demonstrated that, in comparison to HRFI gilts, gilts from the more productive LRFI line tended to have lower cortisol levels both at rest and in response to ACTH(Adrenocorticotropic) stimulation as it gets the body ready for a fight or flight reaction, cortisol is crucial for responding to a stressor.

Digestibility is also related to FE. The ability of an animal to digest food depends on two factors: its digestive capacities (species, age, sex, and physiological state) and the "potential" for digestibility that is determined by the properties of the feed (Bastianelli, 2013). However, selecting for FE can enhance nutrient digestibility as well. Beens, (2022) evaluated the effect of selecting for FE using EBV for FCR on digestibility, where HFE (lower EBV-FCR values) pigs had a significantly higher apparent total tract digestibility (ATTD) of calcium ($P=0.05$) and a tendency for a higher ATTD for crude protein ($P = 0.06$), and phosphorous ($P = 0.10$) compared to LFE pigs. In addition, HFE animals consumed less feed and produced leaner carcass without affecting growth performance (ADG).

2.4. Factors affecting FE

2.4.1. Feed Form and nutrient density

The overall component quality, diet composition, nutritional availability, and feed processing type of the diet can all have an impact on FE (Tokach et al., 2012). The management of feed processing can substantially influence FE. The type of foodstuff (pelleted versus mash) and particle size (particularly for maize) can both influence the rate of growth in the pig. Compared to mash diets, pelleted feed increases feed conversion (Medel et al., 2004) as the process of pelleting breaks the chemical bond in feed making it more digestible. But for pellet feeding, it is difficult to achieve constant pellet quality (Myers et al., 2013). About 40% of final pellet quality is influenced by diet formulation, followed by conditioning, particle size, 20%, 15% die specification, and 5% cooling (Stark,1994). Pelleting induces intensive grinding of particles, and a finer particle size directly increases FE in a healthy herd due to increased specific surface of feed particles allowing better contact with digestive enzymes (Vukmirović et al., 2017). However, one must balance the expenses of the additional processing, any potential problems with diet

flowability, and any potential consequences on animal health, particularly gastrointestinal ulcers, against the desire to boost FE through a finer-ground feed (Healy et al., 1994). Optimal particle size of pig diet should be in between 500 and 1600 μm (Vukmirović et al., 2017).

Increasing the nutritional density of the diets is another technique to improve FE. In order to do this, either more energy must be provided (tallow or vegetable oils), or indigestible portions (i.e., high fibre) of the food must be broken down with the addition of enzymes such phytase, xylanases, and β -glucanases which cause the amino acid availability and digestion of energy and carbohydrates (9300.USA.09.38 Purdue University, West Lafayette, USA).

The use of precision feeding techniques, such as tracking individual FI and utilizing electronic feeding systems, has significantly contributed to improving animal efficiency (Gaillard et al., 2020). Automatic precision feeders are used with relation to precise feeding used to give individual pigs the proper amount and composition of the meal at a certain period. In addition, by improving individual nutrient efficiency, precision feeding enables real-time off-farm monitoring and intelligent management of feeds and animals for enhanced economic efficiency and much lower production costs (>8%) (Pomar & Remus, 2019). One of the most promising ways to promote high-quality, safe pork with the least negative environmental impact (60 percent reduced nutrient excretion) is through precision feeding, a significant advancement in pig nutrition. Using cutting-edge computerized systems to manage feeds and animals enables early disease detection and accurate individual treatment application to enhance herd performance and lower antibiotic use (Pomar & Remus, 2019).

2.4.2. Gender

Gender differences have been observed in FE, growth performance, and carcass traits. It is commonly known that whole males are more productive because of superior production

characteristics, grow more efficiently and improved meat quality due to leaner carcasses and higher protein content, as compared to castrated males (CM) or females (Lundstöröm et al., 2009; Patience et al., 2015). However, boar taint is a problem in case of intact male. Castration of male piglets is a traditional practice in pig production used worldwide with the main goal to prevent boar taint of pig meat. However, it has a detrimental impact on productivity due to reduced testosterone production, which negatively affect the formation of lean tissue and FE (Čandek-Potokar et al., 2017). Immunological castration has shown promise in this regard which blocks testosterone by disrupting normal function of testis which have been successfully applied in international and local pork industries (Needham et al., 2017). Different studies (D'Souza & Mullan, 2002; Gispert et al., 2010) have assessed the carcass and meat quality of intact females (IF), immunocastrated males (IMC), and CM. In comparison to whole male pigs, barrows are fatter and have inferior feed conversion compared to entire male pigs (Wood & Enser, 1982). In Large White lines, Morales et al. 2011, examined the growth rates and carcass composition of IMC, CM, and IF. IMC was the most efficient, and CM and IMC grew more quickly than IF. In comparison to CM, IMC had a lower backfat depth and a higher lean percentage. Males will exhibit greater FE because testosterone promotes growth in the animal, and males have higher levels of testosterone than females.

2.4.3. Disease

It is widely acknowledged that disease causes animals to consume less food (Kyriazakis & Doeschl-Wilson, 2009). However, the slowed rate of growth is also a result of the reduced FI. According to Patience, (2012), a 70 kg pig's entire nutritional energy intake is around one third of maintenance expenditures, which is a significant amount. Again, immune system is often considered as part of maintenance requirement and when disease occurs, host-pathogen

interactions cause the animal to expend a large amount of energy as a result of a complex immune response to infection (Patience et al., 2015). When an infectious virus challenges the host, important nutrients that would have supported production are easily shifted to support the host's immune systems. Thus, effective pathogenic environment management is crucial for optimum pig production and increased FE (Johnson, 2012).

Williams et al. (1997) studies on pigs weighing 6 to 27 kg discovered that those exposed to high levels of pathogens tended to eat less, grow more slowly, and be less productive than those exposed to low levels. When pigs are exposed to infections, metabolic pathways change their focus in order to trigger an immunological response (Johnson, 2012) that is linked to inflammation (Li & Patience, 2017). Under pathogenic challenge, pigs require nutrients for functions that enable them to defend and operate the normal functions of a healthy pig such as maintenance and growth. As many elements of the immune response are protein-rich, protein becomes the first limiting resource in immuno-challenged pigs, which is an important feature to take into account (Kyriazakis & Sandberg, 2006). In addition, there is also evidence of energy becoming limiting in pathogen-challenged pigs because of an activation of the immune response and increase in heat production(fever) (Kyriazakis & Sandberg, 2006). Therefore, avoiding disease condition to minimize immunological stress is very necessary while rearing pigs to maximize FE.

2.4.4. Genetics

Genetics also plays a significant role in selection for FE. Increase whole-herd production efficiency depends on the presence of FE genetic variation and how it interacts with other traits genetically. Consequently, it is crucial to identify and select animals with superior FE within the herd which show genetic variation. Again, in case of interaction with other genetic traits, animals have multiple genetic traits that can influence FE, such as growth rate, body composition etc. It's

important to consider these interactions when selecting animals for FE to avoid negative effects on other desirable traits (Hoque et al., 2007). The scientific literature indicates that the FE feature is heritable ($h^2=0.30$); therefore, there appears to be a way to reduce costs through genetic means (Hoque et al., 2006; Mrode & Kennedy, 1993). As genetics influences an animal's maintenance requirements, feed consumption, and nutrient utilization (Gaillard et al., 2020), pigs that have undergone genetic selection for HFE are better than their counterparts at converting feed into BW (Boddicker et al., 2011).

The selection by FE individually or interacting with other desirable traits has been studied. Fahmy & Bernard (1970) determined the rates of change in feed utilization and carcass score (i.e., leanness) in three Canadian Yorkshire lines over ten generations. Line 1 was selected based FE, line 2 on carcass score (CS; a proxy for leanness based on carcass length, backfat depth, loin muscle area, and belly grade), and line 3 a combination of these two traits. The researcher reported combined traits was more effective in improving FE and CS, respectively, than selection for these traits individually. This led to the widespread adoption of selecting for leanness as a cost-effective method to improve FE in pig breeding programs.

A genetic improvement for FE can be obtained by RFI. Cai et al. (2008) found that selection based on EBV for RFI can significantly decrease the feed required for a given rate of growth and backfat. According to Gilbert et al. (2007), their study showed that selecting growing pigs with low RFI and providing them with ad libitum access to feed resulted in improved FE without negatively affecting growth rate. Despite the reduction in voluntary feed consumption, the pigs selected for low RFI were still able to maintain a satisfactory growth rate. Thus, genetics plays a very important part in FE selection.

2.4.5. Management practices

The FE of swine is greatly influenced by management practices. Barn management such as inadequate sanitation, problems with stocking densities, poor ventilation, unsuitable temperature, low water quality, unfavorable flooring conditions, and excessive feed waste, feeder design and inadequate quantity, all of these factors can lead to lower FE in pigs (Gaines et al., 2012; Tokach et al., 2012).

For the majority of modern, integrated swine production systems, housing represents the second largest cost centre after feed, hence maximizing floor and feeder stocking rates is essential to increase FE as well profitability (Gaines et al., 2012). Decreasing floor space to the animals for instance causes reduction in ADG during the weaning to finish (Wolter et al., 2003) and finishing production period (Gonyou et al., 2006). Due to reduced pigs' access to feeder space as well as reduced their floor space to rest. According to numerous studies have indicated this fall in growth rate to be a result of lower daily FI and some researchers have reported a reduction in FE (Hyun et al., 1998). Again, it has been demonstrated that Typically, as the number of pigs per feeder space increases, the ADG and FI decrease (Wolter et al., 2002). Feed outages, or out-of-feed events can have negative effect on FE due to increased incidence of gastric ulcers, ileitis, and hemorrhagic bowel syndrome etc. (Brumm et al., 2005). In addition to this, an unclean environment may result in a decrease in FI and ADG (Renaudeau, 2009). Due to a systemic inflammatory responses and large amount of energy is destined to complex immune response to infection (Patience et al., 2015).

The temperature of the barn is a significant element of the pigs' surroundings. The optimum temperature range for manufacture is between 15 and 23 °C. FI will rise by 1.5% per °C if the temperature falls below the pigs' lower critical temperature (13 to 14°C), FI will increase by 1.5 % per °C (NRC, 1999) and FE will decline (Renaudeau et al., 2012). The amount of energy used

for growth might vary depending on temperature. Thermoregulation, or the maintenance of the body's essential processes at thermally neutral temperatures, demands energy. When the body's temperature falls below the lower essential levels (13 to 14°C), more energy is needed to sustain thermoregulation by increasing heat production. As a result, the animal will eat more food, but its increased energy will be directed toward producing heat rather than growing (Tokach et al., 2012). In contrast, pigs decrease FI when temperatures increase to decrease heat production. Pigs housed at 4 or 11 °C respectively, below their lower critical temperature, had FE 14% and 35% lower than pigs housed in their thermoneutral zone, according to research by Nienaber et al. (1990) (2.75 vs. 3.14 vs. 3.72 F:G). Therefore, keeping the environmental barn temperatures in optimal zones (15 and 23 °C) is ideal to limit energy allocated toward thermoregulation (Tokach et al., 2012) . Although it can be challenging to avoid excessive temperatures in some climates, seasonal variation still exists. To reduce the negative effects of high ambient temperatures on pig performance, it is crucial to maintain fans, sprinklers, cool cells, and any other heat dissipation equipment. Before summer temperatures rise, sprinklers must be examined, cleaned, and, if necessary, replaced to ensure they are functional. Additionally, fan controllers, stir fans, and maximum ventilation fans need to be examined. To make sure that motors and the electrical system are capable of handling demands before high temperatures put them to the test, it might be useful to run all equipment in a facility simultaneously in all rooms (Tokach et al., 2012). Furthermore, compared to pigs fed a diet with an appropriate dietary protein level (16% CP), those fed a diet with a low dietary protein level (12% CP) and supplemented with crystalline AA (lysine, tryptophan, and threonine) perform better and produce less heat (Kerr et al., 2003).

Under management system, during placement, another common practice in many production systems is to stock pens and handling which also related to FE as it will also cause

stress. Stocking pens at a greater density than normal, in order to leave one or two pens ('pull' or 'hospital' pens) to allow for sick or unthrifty pigs to be sorted at a later time. If not done properly, this approach can be problematic from a performance aspect even while it can help guarantee that sick pigs receive the right access to feed and water as well as safety from pen mates (Tokach et al., 2012). In case of handling, Boyce et al. (2001) showed that pigs exposed to negative handling for 10 seconds per day (shocking the animal with an electric prod if it approached the person) had lower FE (3.19 vs. 2.75) than pigs that received positive treatment (stroking the animal), with pigs that experienced no handling intermediate (2.89).

2.4.6. Feed intake

Pigs' ability to quickly absorb feed is crucial since it controls the amount of nutrients and energy available for the pigs' optimum growth. Given that it is closely tied to growth performance and production efficiency, FI significantly affects FE (Nyachoti et al., 2004). FI is essential for creating diet guidelines, achieving desired growth rates, and significantly affecting production efficiency and energy is the critical dietary constituent that supports maintenance, as well as tissue accretion (Patience et al., 2015). Growing pigs require nutrients for maintenance and growth and voluntary FI is driven by the need to meet these nutrient demands (Nyachoti et al., 2004). Voluntary FI is regulated by many factors including breed, sex, stage of growth, dietary energy concentration, AA balance, feed processing and form, housing conditions and climatic factors (Li & Patience, 2017; Renaudeau et al., 2006) it is highly variable (Albin et al., 2001). Again, dietary factors such as bulkiness, nutrient density, additives, contaminants, ingredient type, availability of good quality drinking water are known variables to affect FI (Nyachoti et al., 2004; Renaudeau et al., 2006). The breed and sex of the pig, as previously mentioned, do affect the voluntary FI. For the growth stage, the pig's daily FI increases along with their maintenance needs and stomach's physical

capability as they get older (in terms of BW). For instance, Bigelow & Houpt, (1988) and Quiniou et al. (1999) studied the effect of stage of growth on feeding behaviour in LW females and Piétrain boars, eight LW boars, Meishan barrows respectively over the same BW range. The number of meals decreased with increased BW (-3.8 and -3.0 meals per day) but the meal size increased (+126 and +126 g/meal) when BW increased from 20 to 60 kg. The differences observed in composition of BW gain between types of pigs are associated with differences in VFI but also with differences in feeding behaviour. The lean Piétrain pigs were characterised by a high number of small meals per day while the fat Meishan pigs had a small number of large meals per day; the conventional LW pigs were intermediate which may be caused by the increased physical capacity of the gastrointestinal tract (Quiniou et al., 1999). Given their different body compositions they had similar voluntary FI however different feed strategies. Meishan and Creole are considered a fatter breed compared to the leaner breeds Piétrain and LW (Quiniou et al., 1999; Renaudeau et al., 2006). Meishan pigs consumed half the amount of feed per day (7.3 vs 14.4 meals/day) but meal size was double the size (250 vs 125 g/meal) compared to Piétrain pigs (Quiniou et al., 1999) whereas Creole pigs consumed less meals per day (5.9 vs. 8.8 meals/d) but meal size was greater (431 vs 279 g/meal) compared to LW pigs (Renaudeau et al., 2006).

Voluntary feed intake(VFI) in pigs can be influenced by dietary crude protein content and the balance of dietary amino acids (Robinson et al., 1974). However, feeding pigs with amino acid supplemented low protein diets in an equal energy intake situation (Le Bellego et al., 2002) will not affect VFI. In case of diet presentation as a mash versus pellet and wet versus dry, generally pelleting of feed reduces FI but improves growth performance due to improved nutrient digestibility of the feed (Wondra et al., 1995). Similarly, Offering feed as pellets increase FCE, as does wet feeding (Patience et al. 1995; Gonyou, 1999). Wet feeding improves VFI of both pelleted

and mash diets (Chae, 2000). In a recent study, presentation of a mash diet in a wet versus a dry form increased VFI 6% in growing pigs on a dry matter equivalent basis (Gonyou & Lou, 2000). Inclusion in pig diets of exogenous enzymes targeting the non-starch polysaccharides components of the feed increase VFI primarily by reducing the bulkiness of the feed (Campbell & Bedford, 1992). Additives such as spray-dried plasma that help maintain gut health and the general health of the pig may enhance VFI (Coffey & Cromwell, 1995). Contamination of feed grains with mycotoxins is a major challenge facing the swine industry worldwide. Feeding mycotoxin-contaminated grains to pigs reduces VFI and production performance in general. In case of water, is essential for various physiological functions including digestion and nutrient utilization (NRC 1999), its availability will certainly impact on VFI via mitigation of temperature effects on VFI (Mount et al., 1971).

As all those above-mentioned factors are related to FI and thus FE, therefore, understanding FI, to our maximum advantage, we may increase FE, reducing expenses and making the most use of feed resources. As it is regulated by more than one factor, integrated approach is necessary in commercial condition (Nyachoti et al., 2004).

2.5. Calculation of feed efficiency

Traditionally, FE has been measured as the ratio of feed consumed to growth or BW gain per unit of feed consumed. However, there are other practical errors, such as feed consumption, which is infrequently observed; feed disappearance is another possibility. Yet, the difference between feed consumed and feed vanished can range from 10% to 30%. However, feed consumed and feed disappeared can differ by 10 % and sometimes by as much as 30 % (Baxter, 1986).

When comparing groups of pigs for FE, it is important to take into consideration the variation caused by differences in BWs at which various animals are evaluated as animals of

different weights have varying maintenance requirements (Gaines et al., 2012). For instance, when initial or final weight fluctuate, utilizing FE as a standard can be problematic. Comparing animals from different diets with different particle sizes or comparing mash and pellets is equally challenging. These variations are small but can lead to big mistakes. As a result, FE must be tracked and evaluated, but it should only be used as a management tool if the FE values are thoroughly understood (Patience, 2012) .

FE is a ratio computed from feed input and weight gain (Herd et al., 2004; Koch et al., 1963). Gross gain efficiency (gain: feed) and feed conversion (feed: gain) ratios are two traditional FE measurements. Gross efficiency is defined as the ratio of weight growth to feed input per unit of time, and its inverse, FI to weight gain, is defined as the ratio of FI to weight gain (Archer et al., 1999). These ratios are normally expressed in terms of live weight; however, there has been discussion about expressing them in terms of carcass weight (Gaines et al., 2012). Furthermore, neither ratio considers the size, composition, or basal metabolic rate of the animal (Koch et al., 1963). As a result, various calculating methods have been created to account for some of these variables. As a result, the term "residual feed intake" (RFI) was coined. In order to evaluate individual animals more effectively, Koch et al. (1963), adjusted feed consumed for rate of rise and mean BW; this new approach evolved in pigs to assess growth rate as well as body composition and became known as RFI. RFI is calculated as the difference between observed and predicted FI. The latter is determined by the animal's pace of growth and the composition of its body back fat (Mrode & Kennedy, 1993; Koch et al., 1963). Animals with a lower RFI are more efficient than those with a higher RFI. The amount of edible product achieved with a given energy intake, rather than the fraction of energy in the feed that was converted to total BW, should be the most meaningful criterion for evaluating FE in meat-producing animals (Koch et al., 1963).

The gap between observed and expected FI based on expected requirements for certain production and maintenance parameters is referred to as RFI. Depending on the production features used to regulate daily FI, the RFI measure may differ (Young & Dekkers, 2012). Growth rate, backfat (Cai et al., 2008), milk, and piglet output are examples of traditional production traits used to adjust RFI values (Young & Dekkers, 2012). As a result, RFI records FI as the amount of feed predicted for a particular level of production, as well as the remainder that differs from the expected (Koch et al., 1963). Animals that use less feed than is expected for a given population have a lower RFI, are more feed efficient, and hence may be more economically desirable.

As dietary energy also another expression for FE dietary variations in terms of energy can potentially result in unforeseen or even invisible errors. A portion of this inaccuracy may result from incorrect calculations of dietary energy or measurement errors with the energy system. This can be a severe issue when comparing diets with protein, fat, or fibre contents (Arkfeld et al., 2015). Even when the fundamental principles of energy metabolism are understood, applying this knowledge in farm settings can be a truly challenging task because the presence of social and environmental stressors, variation in ad libitum FI, and disease load all affect how an animal responds to dietary energy content and which will affect FE measurement (Patience, 2012).

2.6. Estimated Breeding values (EBV)

A prediction of an animal's genetic merit for a certain feature in comparison to other animals in the same population is known as an EBV. EBVs are useful selection aids. Individuals with the best EBVs for a particular characteristic have the best chance of producing exceptional progeny in that trait. Because only half of an animal's genes are passed down to its offspring, a parent's predicted contribution to its offspring is on average one-half of its EBV (CCSI, June 2012).

Traditional EBVs based on pedigree data have led to ongoing genetic advancement, but they have a number of drawbacks (Dekkers et al., 2010). The precise assessment of EBV is complicated by the expensive and difficult observation of some significant phenotypes (Badke et al., 2014). Meuwissen et al. (2001) have found that many of those constraints are anticipated to be overcome by the use of genomic breeding values (GEBVs), which are calculated using numerous genetic markers distributed across the genome.

2.7. Importance of EBV

The domestication of most agricultural species utilized today began with the capture of individual animals over a thousand years ago. Early methods were centred on phenotypic assessments, with little attention paid to the underlying causes of various productivities and outward manifestations (Jonas & de Koning, 2015). The evolution of current breeds has been greatly aided by a combination of theoretical ideas and experimental successes. The majority of livestock species have organised breeding programs in place today (Nicholas, 2019). Breeding objectives set the direction of breeding programs and combine the primary profit drivers to maximize profitability in the context of genetic progress (Goddard, 1998). They rely on the routine recording of population pedigree and performance data, and they further incorporate the fundamental understanding of heredity into selection decisions for the advancement of the chosen population (Nicholas, 2019). Therefore, EBV is very important nowadays for selection of animals with desired traits for excellent production. EBVs are calculated using attributes assessed in a pedigree, sibling, progeny, and/or own-performance evaluation scheme in specialized testing facilities and/or chosen farm conditions, typically using the best linear unbiased predictions (Henderson, 1975).

EBV is also important for selection of animals for maternal traits. Due to the traditional breeding programs' emphasis on performance attributes in the sire lines, genomic selection in pig breeding has the potential to be a technique to improve maternal traits. A simulation study revealed that genomic selection may boost genetic gain for maternal characteristics in pigs (Lillehammer et al., 2011). The capacity of a producer to choose breeding stock with an acceptable combination of excellent breeding values for all economic traits is a prerequisite for genetic progress in a seedstock herd. A producer, for instance, should consider breeding values for growth rate, backfat thickness, FE, carcass leanness, and meat quality when selecting a boar to be utilized as a terminal sire. While in maternal lines, selection should focus on qualities related to fertility, litter size, and age at puberty as well as growth and carcass traits. Each of these features depends on numerous genes (Cassidy, 2019) and this is possible with the help of using EBV as selection process for animals.

2.8. Calculation of EBV

Henderson created the Best Linear Unbiased Prediction (BLUP) approach, which has been widely applied in the breeding of cattle and can determine each individual's breeding value (Henderson, 1975; Jonas & de Koning, 2015). The single step BLUP approach was created and is widely used in animal breeding to maximize the utilization of genetic and pedigree data (Aguilar et al., 2010; Zhang et al., 2015). BLUP, a sophisticated method known makes greater using of all available data to examine each animal's genetic makeup. PIGBLUP (Pig Best Linear Unbiased Prediction) is based genetic software system for pigs, which combines all the information on the trait recorded on the animal and its relatives (Hermesch et al., 2005). That means not just the pig's phenotype (e.g., ADG) is taken into account by PIGBLUP, but also information from all known relatives, past and present. PIGBLUP corrects for recorded biases caused by non-genetic (environmental) variables (Thekkoot, 2016). The EBVs created in PIGBLUP are merged into a

\$INDEX, a single tailored selection index based on the breeder's economic, production, and marketing data. By evaluating costs and returns, this combination establishes the fundamental EBVs for the animal's economic value. These indexes are still EBVs, but because they now include genetic and economic information for a number of aspects, they are more valuable.

2.9. Effect of animal selection for FE on carcass traits, carcass composition, pork and belly quality

2.9.1. Carcass traits and composition

Improvement in production efficiency provides a means to use fewer inputs to enhance carcass traits. Smith et al. (2011) selected Yorkshire barrows from the fifth generation of the Iowa State University RFI lines (Cai et al., 2008) and select line pigs (selected for reduced RFI /high efficiency) had showed significantly greater loin eye depths and percentage lean and have less backfat (Cai et al.,2008; Gilbert et al., 2007) than carcasses from control line pigs. Lefaucheur et al. (2011) also indicated that pigs from the low RFI line exhibited similar growth rate but leaner carcasses and decreased intramuscular fat content compared with pigs from the high RFI line. Different studies on lines selected for RFI have shown correlated responses on body leanness (Cai et al., 2008 ;Gilbert et al., 2007; Hoque & Suzuki, 2009) and on muscle characteristics. .Faure et al. (2013) pigs from the low RFI line exhibited leaner carcasses with less backfat, intramuscular fat content and internal fat.

Different researchers have indicated that high efficiency pigs (e.g., based on low RFI) fast-twitch glycolytic type IIB fibres were more prevalent, which show lesser protein turnover, greater cross-sectional area and less fat accretion (Lefaucheur et al., 2011). These reasons might partially explain the greater lean content in each primal cut in high efficiency pigs in our study.

2.9.3. Pork quality traits

There has been concern that pigs that have been highly selected for better FE may produce pork that is of lower quality. According to Faure et al. (2013); Gilbert et al. (2007); Lefaucheur et al. (2011) selection for low RFI decreased post-mortem pH, led to slightly inferior meat quality, decreased water holding capacity, low intramuscular fat content and decreased sensory quality. In addition, Smith et al. (2011) reported meat from low RFI pigs showed very minor colour changes and did not vary from controls in terms of drip loss or purge loss. Also Smith et al., (2011) reported pork loins from reduced RFI pigs may be less tender due to the presence of intact desmin at 2 and 7 d post-mortem. In contrast, Faure et al. (2013) and Hermesch et al. (2000) have found no increase of incidence in case of DFD (Dark firm dry) and PSE (Pale soft exudative) meat in case of selection improving FE and increasing leanness level.

2.9.4. Belly quality

Pork belly accounts for about 9% of live weight, 12–16.7% of chilled carcass weight and approximately 15–18.9% of the total carcass value (Fredeen, 1980; Stiffler et al., 1975) and factors that affect fresh pork belly quality are breed, sex, growth promoters, age or weight at slaughter and carcass processing parameters. However, publications addressing the effect of pig selection based on FE on belly quality do not exist to the best of our knowledge. Genetic, dietary or management strategies directed towards increased lean content in pork carcasses may result in belly softness which has been reported to be associated with increased handling/processing difficulties, reduced slicing and fabrication efficiency, reduced bacon yield etc. (Eggert et al., 2001; Soladoye et al., 2015). In addition, leaner pigs typically have greater concentration of linoleic acid (polyunsaturated fatty acid), and high iodine values in adipose tissue, which could be a reason for softer bellies (Tavarez, 2014). In addition, leaner carcasses show light belly weight and higher

belly lean meat percentage (Elbert et al., 2020). In addition, belly dimensional traits such as size, thickness, and firmness are important parameters towards belly quality as well. Whitney et al. (2006) have reported that belly thickness explained 33% of the variability in belly firmness. Increased belly fat deposition and thickness will enhance belly firmness. Also, Soladoye et al. (2017) reported that belly weight and length were positively correlated with belly-flop angle measurement and belly-flop angle has the potential to be used as an objective, inexpensive, non-destructive alternative for measuring firmness and for belly classification which have been done in this experiment.

Again, lean-to-fat ratio is driven by sex and barrows usually have a higher fat deposition leading to higher backfat than gilts (Cromwell et al., 1993;Lo Fiego et al., 2005) and therefore, greater challenges may hence be encountered for bacon processing with bellies from gilts due to fat softness and reduced product shelf life compared with barrows or bellies with firmer fat (Correa et al., 2008;Xu et al., 2010). Therefore, selection of barrows based on FE will be helpful for belly traits.

CHAPTER 3: RESEARCH HYPOTHESIS AND OBJECTIVES

3.1 Research Hypothesis

The following hypothesis were tested in this thesis:

1. Selecting pigs for HFE from two genetic lines (sire and dam line) will produce pigs with favourable carcass yield characteristics and carcass composition.
2. Selecting pigs for HFE will not have detrimental effect on meat and belly quality

3.2 Research Objectives:

The objective of the study is to study the influence of selection of pigs based on the EBV-FCR (high, intermediate and low feed efficient animals) within the LW breed genetic lines (dam line vs sire line) on carcass traits, carcass composition, meat and belly qualities.

CHAPTER 4: MANUSCRIPT I

Pork carcass composition, meat and belly qualities as influenced by FE selection in a sire and a dam line.

4.1 ABSTRACT

This study evaluated carcass attributes, meat and belly qualities in finisher boars (n=79) selected for FE (low, intermediate and high) based on the FCR and EBV within a LW dam and sire genetic lines. The sire line had lower trimmed fat proportions and higher lean than the dam line ($P < 0.01$). Genetic lines expressed slight colour changes and drip losses ($P < 0.05$), with no differences in pH, marbling level and cooking traits ($P > 0.05$). High-efficient animals presented the highest lean yield and the lowest proportion of trimmed fat ($P < 0.01$) compared with other efficient groups without effect on meat and belly quality attributes ($P > 0.05$). Interaction between efficiency group and genetic line was only detected for belly weight and thickness ($P < 0.01$). High-efficient animals offer a greater leanness level, with a minimum impact on meat and belly quality traits.

Keywords: carcass composition, Estimated Breeding Value, FE, meat quality, belly quality

4.2. Introduction

Pork is an essential component of global agricultural and economic activity and a staple in the diet of many people. FE is essential for the profitability of swine production because it accounts for 60 to 70 percent of the total cost of raising hogs. (Patience et al., 2015). FE in the swine business refers to the capacity of pig to convert feed into a product that can be consumed, pork; so, improvements in FE allow for obtaining pork with less inputs (Zijlstra & Beltranena, 2013). Most nutrients consumed by a pig are allocated primarily towards maintenance, and any extra is put to

use accumulating lipids after lean accretion (Patience et al., 2015). In commercial swine farms, the FCR (Hoque et al., 2007) the most widely utilized indicator of FE, is employed as the primary method of calculating FE (Gondret et al., 2017).

FE is heritable (h^2 0.30) and is used by pig genetic companies to select purebred pigs in their breeding programs (Hoque et al., 2007; Mrode & Kennedy, 1993; Ollivier & Henry, 1978). Genetic selection for FE has shown promise in improving swine production for providing advantages in most carcass yield traits and growth performance (Patience et al., 2015). This selection is to maximise FE and enhance carcass composition and growth performance (Patience et al., 2015), through EBVs, which are an estimation of an animal's genetic value and its capacity for particular traits (Van Der Peet-Schwering et al., 2021) are used. The estimation of EBV is based on Genomic Best Linear Unbiased Predictor (GBLUP), which considers not only the pig's phenotype (e.g., its own recorded FE) when generating an EBV, but also information from all known relatives, past and present (Ten Napel et al., 2018). Using EBV, generation intervals can be shortened by choosing animals when they are still young (Hayes et al., 2009). It helps breeders as a better decision-making tool for the selection of animals.

High efficiency pigs (i.e., lower EBV-FCR values) produce leaner carcass by consuming less feed (Beens et al., 2022). Arkfeld et al. (2015) studied barrows and gilts (high and low RFI lines) and observed in high efficiency pig's greater percent of carcass lean than carcasses from low FE pig. Cai et al. (2008) and Smith et al. (2011) has been shown through research on Yorkshire barrows from the five generations old of EBV-RFI lines that selection for lower RFI (high efficiency) led to a tendency towards decreased backfat. Those findings are in in accordance with other researchers (Hewitt et al., 2020; Hoque et al., 2007; Lefaucheur et al., 2011). Higher efficiency pigs would be less expensive to economically generate the same amount of output since

they would use less feed for presenting high protein, calcium and phosphorus digestibility (Been et al., 2022), making them valuable commercially.

Concerns have been expressed on pigs selected for high FE because they may produce pork with inferior quality (e.g., lower pH, excessive drip loss, and colour changes) which is a drawback for the producers (Cai et al., 2008; Lefaucheur et al., 2011). Nonetheless, contradictory results have been shown to date; so, it is not clear how selection programs to increase FE affect meat quality (Patience et al., 2015). For example, Cai et al. (2008) found that selecting for lower RFI (high efficiency) did not compromise loin pH, color, or marbling in Yorkshire pigs. In contrast, Gilbert et al. (2007) reported that high efficiency group presented lower pH, lighter coloured meat in the gluteus medius than LFE group and it may be caused by a decrease in the oxidative capability of skeletal muscle (i.e., high proportions of glycolytic myofibers type). Nevertheless, that decreased lipid content and postmortem protein breakdown may result in less tender pork loins from pigs with lower RFI levels (Smith et al., 2011). As a result, it is yet unclear how selection for FE affects pork quality, demanding further research.

Therefore, our objective was to investigate the influence of selection of pigs based on EBV-FCR (high, intermediate and low) within the LW breed genetic lines (dam line vs sire line) on carcass traits, carcass composition, meat and belly qualities.

4.3. Materials and methods

The University of Manitoba Animal Care Committee (F20-026) gave its approval for the experimental methods in order to comply with the standards set by the Canadian Council on Animal Care (CCAC, 2009).

4.3.1. Animals and treatments

The animals in the experiment were similar (i.e., herd management, diet, animal handling, and growth performance) to those used by Beens (2022). Briefly, a total of 2000 genotyped entire male pigs (LW sire and dam lines) with an average initial BW of 42.11 ± 1.23 kg were raised at Topigs Norsvin facility, and all the animals were monitored during an 80-day trial. They were fed a diet composed of a corn-wheat-canola meal-base diet that was created following the company's feeding regimen. The details of ingredients and nutrient composition were described previously by Beens (2022). Throughout the experiment, animals had ad libitum access to feed and water. FI and feeding behaviors were monitored individually by using Nedap feed system (Nedap ProSense, Groenlo, Netherlands).

At age of 23 weeks, a subgroup of boar candidates (n=100) was pre-selected for this study based on their EBV-FCR and FCR. Animals represented a wide range of EBV-FCR in each line for preliminary segregation from high to LFE group per line (sire line: -0.272 to 0.006; dam line: -0.391 to 0.080; n = 25 per combination group). Using the ssGBLUP method in MiXBLUP the EBV of individual pigs were estimated (Ten Napel et al., 2018). Using a tissue sample taken from the piglets' ears within 24 hours of birth, a 25K single-nucleotide polymorphism chip was utilized to genotype each pig to create the genomic relationship matrix. The genotype and genomic prediction of FCR, using information gathered over the previous 10 years by Topigs Norsvin Research Center (Beuningen, The Netherlands), where notable differences in FCR have been verified between efficiency groups (i.e., low FCR values for high efficiency pigs).

Five lots of finished boars were sent to harvest every week, representing the combination of genetic line x FE group in each lot (boars per combination group of 3-4, 4-5, 3-4, 6-7, 6-7 for

lots 1 to 5 respectively) with approximately 115 ± 1.40 kg of BW. The animals had 3-4 h feed withdrawal before slaughter.

4.3.2. Slaughtering and carcass evaluation

After arriving at the slaughterhouse, with free access to water animals rested for 1 hour before slaughtering. Pigs were slaughtered following a standard commercial procedure. After dressing, carcasses were split into two equal halves and weighed. The carcass sides were moved into the cooler and set to 2 °C. After 96 h postmortem, left carcass sides were ribbed and evaluated according to National Pork Producer Council (NPPC, 1991). The evaluation included muscularity profile (where: 1 = thin; 2 = Intermediate; 3 = thick), backfat thickness (on first rib, last rib and last lumbar) and depth (between 10 and 11 rib interface), ribeye depth and area (between 10 and 11 rib interface), muscle colour (where: 1 = Pale pinkish gray to white and 6 = Dark purplish red), and marbling (where: 1 = Devoid and 10 = Abundant).

4.3.3. Carcass fabrication

Carcasses were fabricated according to the European Community reference procedure (Branscheid et al., 1990). Briefly, following chilling, carcass's left side (without head, feet on) was weighed and fabricated. The carcass was divided into primal cuts (shoulder, loin, belly, ham). The shoulder was cut from the loin between the fourth and fifth ribs perpendicular to the length-axis direction of the spinal column, with the shoulder blade being left intact. Loin and ham were separated by cutting perpendicular to the length of the back between the last lumbar vertebra and first sacral. The separation of loin and belly were a straight cut that passes the tenderloin muscles (psoas major and minor) and 6th thoracic vertebra just ventrally (below). The remaining ventral portion of the belly was removed along with the ribs and milk glands. A rectangular profile could be seen on the belly. The primal had further dissection to obtain the muscle, bone, and external fat

and skin. Following the fabrication process, the weights of boneless cuts and by-products (such as fat and bone) were noted. The overall yield of product, including the total amount of lean edible meat and the specific primal cuts, co products were calculated as a percentage (%) of the cold carcass weight.

4.3.4. Chemical analysis subsampling

A sub-sample of soft tissues (muscle, skin and fat) from 26 dissected left side pork carcasses (last slaughter lot; 6-7 boars per combination group) were collected and shipped to the University of Manitoba for grinding. Soft tissues from each primal and carcass were identified including sire and dam line with their respective EBV efficiency groups. Soft tissue from each primal was individually ground (Biro mixer grinder mini-32, Marblehead, Ohio) to a coarse homogenate, then reground with a fitting 0.95 cm plate to create a fine, homogenous mixture. For each carcass, three arbitrary tissue homogenate subsamples (each weighing 1000 g) were gathered for chemical analysis. For subsequent examination, the subsamples were vacuum-packed and kept at - 40 °C for further analysis.

4.3.5. Loin and belly sampling

Sixty-four boneless loins and skin-on boneless bellies subsamples were obtained from the right carcass side, vacuum-packaged, transported in ice box to the Pilot Plant of the Food and Human Nutritional Sciences Department at the University of Manitoba and kept in a walk-in cooler (4 °C) for further evaluation.

After 24 hours of arriving at the lab, loins were sliced into 4 pieces of 2.5 cm thick chops for drip loss, pH, colour and Warner Bratzler shear force (WBSF) measurements, which were analyzed immediately; except for WBSF samples. For a gravimetric water holding capacity analysis, a cylindrical strip of 2.5 cm in diameter by 2.5 cm in length was taken from one pork

chop (drip loss). Another pork chop was used for both pH and objective colour evaluation (AMSA, 2012). For additional research, the two pork chops for WBSF were vacuum sealed and maintained at -30 °C.

4.3.6. Loin evaluation

4.3.6.1. *Drip loss measurement*

Drip loss was measured following the procedure described by Rémignon et al. (1996), with a few changes. Briefly, a cylindrical strip (2.5 cm diameter × 2.5 cm length) was airtightly sealed and suspended perpendicularly in a volumetric flask with a flat bottom. This prevented the tissue from touching the surfaces of the flask. The flasks were maintained at 4 °C for 48 hours, and the drip loss % was calculated using the formula: Drip loss percent = [(initial weight - final weight)/initial weight] *100.

4.3.6.2. *pH measurement*

The pH was measured at 4 °C using a non-glass probe meat pH metre (HI 99163 Meat pH metre, Hanna Instruments, Carrollton, TX; calibrated using two buffers pH 4.0 and 7.0). For the readings, the pH metre probe was placed directly into the muscles (Samuel & Trabelsi, 2012).

4.3.6.3. *Instrumental Colour evaluation*

Pork chops were exposed to air for approximately 30 minutes at 4 °C to allow the oxymyoglobin formation. The chops' instrumental colour was assessed using a Konica Minolta Chroma Meter (CR-410, Minolta Canada Inc., Mississauga, ON) with illuminant D65, 2 standard observer angle, and 2.54 cm aperture (Commission Internationale de l'éclairage, 1978). The metre was calibrated by scanning a standard white tile. On each sample, the CIE L* (lightness), a* (redness), and b* (yellowness) and hue angle ($\tan^{-1} b^*/a^*$) and chroma $[(a^{*2} + b^{*2})^{1/2}]$ were

calculated, values were assessed at two randomly selected spots (AMSA, 2012). The results of the two scans were averaged and statistical analysis was performed.

4.3.6.4. Cooking loss and Warner-Bratzler shear force

Preparing and cooking the sample were performed following Research Guidelines for Instrumental Tenderness and Cookery measurements from the American Meat Science Association (AMSA, 2015). In summary, frozen 2.54 cm chops were thawed for 24 hours at 4°C, trimmed for visual fat, and their initial temperature and weight were recorded. Following that, the chops were put on an electric grill (George Foreman GRP99, Spectrum Brands Holdings, Inc. Middleton, Wisconsin, United States), heated to about 165°C, turned once while cooking (at 35 °C internal temperature), and then taken off the grill when they reached the desired internal temperature of 71°C, as determined by meat thermometers (35100-K AquaTuff™ Waterproof Thermocouple Instrument, Cooper 198 Atkins, United States). Once the grill had been removed, the final internal temperature, cooking time, and cooking weight were immediately noted. Cooking loss (%) was calculated using the formula $[(\text{thawed weight, g} - \text{cooked weight, g}) / \text{thawed weight, g}] \times 100$.

After that, pork chops were put on metal trays, wrapped in polyvinyl chloride film, and refrigerated for 24 hours at 4°C. Using a WBSF analyzer, WBSF data were obtained by extracting eight 1.27-cm-diameter cores parallel to the orientation of the muscle fibres and shearing across the muscle fibres at a crosshead speed of 200mm/min (TA-XT Plus, Texture Technologies).

4.3.7. Belly evaluation

An electrical scale was used to weigh the carcasses' ribbed bellies from the left side. (Ohaus Ranger 7000, Parsippany, NJ, USA) to determine initial weight. Fresh bellies were measured for: 1) length and width at midpoint and at shoulder end, 2) thickness at 8 different locations throughout the belly using calipers, and 3) flop distance (Soladoye et al., 2017). The ribbed bellies were then hanging skin side down over a round wooden bar with a diameter of 8.3 cm, allowing both the caudal and cranial ends to fall freely. Following two minutes of suspension on the bar (in comparison to firm bellies, soft bellies will drop more and have smaller separation between ends), the distance between the two dropping ends of the belly was recorded. Later, to subjectively group bellies into one of the following classes, a 5-point visual and tactile response scale based on industry standards was also utilised. (1) Firm fat, no finger depression, nearly horizontal (firmest belly class) ;(2) Firm fat, no finger depression, partially floppy; (3) Soft spongy fat, finger depression still present, floppy, roll over with resistance; (4) Soft spongy fat, finger depression still present, very floppy, roll over easily;(5) Soft spongy fat, finger depression still present, very floppy, roll over easily, oily; (softest belly class). In order to allocate ratings between these groups, bellies were evaluated. All of these measures make up the dimensional factors taken into account in the current investigation, and all of these belly fabrications took place at a temperature of 2 to 4 °C in a cooler.

4.3.8. Protein and fat content analysis

Frozen subsamples were shipped to Central Testing Lab (Winnipeg, MB) for protein and fat analysis. For the purpose of calculating the sample's moisture content percentage, samples were dried in a forced-air oven at 60°C for five days. Protein analysis will subsequently be performed on dried materials (Benedict, 1987) and total fat (ANKOMHCl Hydrolysis System and

ANKOMXT15 Extractor; ANKOM Technology, Macedon NY, USA. Method Am 5-04; AOCS, 2004; Seenger et al., 2008).

4.3.9. Statistical analysis

Data collected were analyzed using SAS, Version 9.4, SAS Institute INC., Cary, NC (SAS, 2012). Each pig was sorted into percentiles in each genetic line based on EBV-FCR and a new efficiency groups were created (low, intermediate and high): Twelve sire line high efficient (EBV: -0.238 ± 0.15), 13 sire line intermediate (EBV: -0.163 ± 0.015), 13 sire line low efficient (EBV: -0.053 ± 0.015), 14 dam line high efficient (EBV: -0.294 ± 0.014), 14 dam line intermediate (EBV: -0.155 ± 0.015) and 13 dam line low efficient (EBV: -0.036 ± 0.014). In total 79 carcasses were selected for the study. Also, carcasses with missing components were not considered in the study.

Data were analyzed as a completely randomized design with a factorial arrangement with genetic line (dam and sire line), efficiency group (low, intermediate and high) and their interaction. Slaughter date was considered as a random effect. The data related to chemical analysis of soft tissues did not include “intermediate efficiency groups” because only two efficiency groups (low and high efficiency) were represented. The least significant differences produced by the PDIFF option were used to distinguish the least squares mean for subclasses with different numbers (F test, $P < 0.05$). The Kenward-Roger technique was used to modify the degrees of freedom in the denominator.

In the current study slaughter weights were significantly different among genetic lines. Hence, data sets were subjected to a simple regression test to see if slaughter weight was correlated with any of the traits assessed in this study in order to ascertain whether composition differences may be caused by the weight difference. Thus, when a significant correlation with any one of the dependent variables was found, slaughter weight was added as a covariate to the model.

4.4. Results

4.4.1. Carcass traits

Genetic line x efficiency group interaction was not significant on carcass traits ($P > 0.05$). Table 1 shows carcass traits affected by genetic lines and EBV-FCR. Slaughter weight, fat depth, loin area, loin depth was affected by the effect of genetic line ($P < 0.05$). Sire line boars were heavier with greater loin area and loin depth than dam line ($P < 0.05$). In contrast, dam line had greater fat deep than the sire line. ($P < 0.01$).

On the other hand, efficiency groups (low, intermedium, and high) presented significant differences on thickness of fat at first rib, last rib, and last lumber, loin area, and loin depth ($P < 0.05$). LFE group had the thickest fat at first, last rib and last lumber than the other efficiency groups. Intermediate and high efficiency groups presented greater loin area and depth than the LFE groups ($P < 0.05$).

Table 1 Carcass trait affected by large white genetic line and estimated breeding value for FE.

| Variable | Line (L) | | Efficiency (E) | | | SEM | P-value | | |
|---|----------------|---------------|----------------|-----------------|----------------|------|---------|-------|-------|
| | Sire n = 38 | Dam n = 41 | Low n = 26 | Inter n = 27 | High n = 26 | | L | E | L x E |
| Slaughter weight, kg | 119.63 | 111.51 | 115.45 | 115.86 | 115.40 | 1.79 | <0.01 | 0.96 | 0.70 |
| Hot carcass weight, kg ^{ab} | 86.45 | 85.83 | 87.31 | 85.27 | 85.44 | 1.95 | 0.84 | 0.51 | 0.90 |
| Dressing, % ^b | 75.15 | 74.70 | 75.86 | 74.19 | 74.70 | 1.18 | 0.86 | 0.53 | 0.91 |
| Fat thickness, mm ^b | | | | | | | | | |
| First rib | 34.53 | 32.41 | 37.23a | 33.85a | 29.33b | 2.11 | 0.53 | <0.01 | 0.68 |
| Last rib ^b | 12.87 | 13.14 | 15.80a | 12.20b | 11.02b | 0.84 | 0.83 | <0.01 | 0.20 |
| Last lumbar | 10.93 | 12.94 | 14.48a | 11.23b | 10.05b | 0.83 | 0.17 | <0.01 | 0.14 |
| Fat depth | 9.37 | 13.60 | 12.72 | 12.01 | 9.72 | 0.94 | <0.01 | 0.09 | 0.79 |
| Loin area, cm ² ^b | 46.94 | 39.54 | 40.68a | 43.77b | 45.28b | 0.89 | <0.01 | <0.01 | 0.26 |
| Loin depth, mm ^b | 64.38 | 57.91 | 59.46 | 61.03 | 62.95 | 0.91 | <0.01 | 0.04 | 0.89 |
| Marbling score ^{1b} | 1.32 | 1.50 | 1.46 | 1.67 | 1.10 | 0.24 | 0.65 | 0.24 | 0.87 |
| Color score ^{2b} | 1.92 | 2.26 | 2.10 | 2.25 | 1.92 | 0.22 | 0.36 | 0.30 | 0.47 |

^a: Without head

^b: Adjusted by co-variance analysis, using slaughter weight as co-variable

¹Marbling score: descriptive scale from 1 to 10 (1= Devoid; 10= very abundant).

²Color score: descriptive scale from 1 to 6 (1= Pale pinkish gray to white; 6= Dark purplish red).

4.4.2. Carcass cut-out and composition

Between genetic lines, the sire line had lower fat percentage of and a higher lean percentage based on carcass weight than the dam line ($P < 0.05$; Table 2). However, there were no differences detected in wholesale primal cuts yield between genetic lines or efficiency groups ($P > 0.05$).

Based on dissection values of individual primals, the sire line presented greater proportion of lean in ham and loin ($P < 0.05$; Table 3) along with lower fat proportion in those primals in comparison to the dam line. Interestingly, the sire line had lower proportion of bone than the dam in ham as well ($P < 0.03$). However, no difference was detected between genetic lines in lean proportion in shoulder, but dam line showed higher proportion of fat than the sire line ($P < 0.05$). In contrast, high efficiency pigs presented reduced proportion of dissectible fat ($P < 0.05$), and the highest proportion of lean ($P < 0.05$) was in shoulder, ham and loin. Also, high efficiency group presented the lowest proportion of feet in shoulder, but the highest proportion flank end and bone in belly and loin; respectively ($P < 0.05$).

The dissection results are consistent with the chemical analysis of soft tissues from each primal (Table 4), which evidenced low amount of fat content in all the primals evaluated in high efficiency pigs ($P < 0.05$). Nevertheless, no difference was detected in fat content affected by genetic line ($P > 0.05$). On the other hand, high efficiency pigs presented higher moisture and lower protein contents in ham, belly, and loin than low-efficiency pigs ($P < 0.05$).

Table 2. Carcass composition and wholesale primal cut yields affected by Large White genetic lines and estimated breeding value for feed conversion.

| Variable | Line (L) | | Efficiency (E) | | | SEM | P-value | | |
|-------------------------------|----------------|---------------|----------------|-----------------|----------------|------|---------|-------|-------|
| | Sire n = 37 | Dam n = 42 | Low n = 27 | Inter n = 26 | High n = 26 | | L | E | L x E |
| Carcass composition, % | | | | | | | | | |
| Bone | 18.44 | 18.84 | 18.78 | 18.35 | 18.77 | 0.29 | 0.38 | 0.39 | 0.56 |
| Fat | 5.76 | 7.86 | 8.10a | 6.67b | 5.64c | 0.31 | <0.01 | <0.01 | 0.64 |
| Lean | 52.89 | 50.05 | 50.01a | 51.44ab | 52.96b | 0.67 | 0.02 | <0.01 | 0.59 |
| Wholesale primal cut yield, % | | | | | | | | | |
| Shoulder | 32.16 | 32.18 | 32.08 | 32.29 | 32.14 | 0.65 | 0.99 | 0.84 | 0.45 |
| Belly | 13.73 | 13.96 | 14.15 | 13.63 | 13.76 | 0.17 | 0.34 | 0.08 | 0.46 |
| Ham | 28.94 | 28.41 | 28.40 | 28.94 | 28.63 | 0.45 | 0.44 | 0.18 | 0.67 |
| Loin | 17.61 | 17.88 | 17.75 | 17.69 | 17.82 | 0.35 | 0.57 | 0.95 | 0.96 |

^a: Adjusted by co-variance analysis, using slaughter weight as co-variable

Table 3. Dissection values of individual primals affected by Large White genetic lines and estimated breeding value for feed conversion.

| Variable | Line (L) | | Efficiency (E) | | | SEM | P-value | | |
|---------------|----------------|---------------|----------------|-----------------|----------------|------|---------|-------|-------|
| | Sire n = 37 | Dam n = 42 | Low n = 27 | Inter n = 26 | High n = 26 | | L | E | L x E |
| Shoulder, % | | | | | | | | | |
| Feet | 3.50 | 3.23 | 3.57 a | 3.32 ab | 3.20 b | 0.12 | 0.20 | 0.02 | 0.86 |
| Jowl | 5.14 | 5.20 | 5.39 | 5.02 | 5.10 | 0.30 | 0.91 | 0.40 | 0.31 |
| Skin | 4.40 | 4.93 | 4.66 | 4.55 | 4.79 | 0.35 | 0.40 | 0.36 | 0.39 |
| Fat | 6.76 | 9.30 | 9.24 a | 7.89 b | 6.97 b | 0.42 | <0.01 | <0.01 | 0.57 |
| Bone | 19.57 | 19.55 | 19.23 | 19.42 | 20.04 | 0.46 | 0.99 | 0.28 | 0.38 |
| Lean | 62.47 | 59.41 | 59.83 a | 61.54 b | 61.43 b | 1.20 | 0.15 | 0.04 | 0.30 |
| Belly, % | | | | | | | | | |
| Bone | 23.09 | 22.99 | 23.54 | 22.99 | 22.59 | 0.53 | 0.89 | 0.29 | 0.07 |
| Teat lines | 8.97 | 7.53 | 8.24 | 8.11 | 8.42 | 0.78 | 0.28 | 0.91 | 0.72 |
| Flank end | 5.97 | 5.03 | 5.08 a | 5.10 a | 6.32 b | 0.38 | 0.09 | 0.05 | 0.50 |
| Skin-on belly | 62.26 | 64.46 | 63.26 | 63.99 | 62.82 | 0.70 | 0.06 | 0.45 | 0.13 |
| Ham, % | | | | | | | | | |
| Feet | 7.31 | 7.16 | 7.12 | 7.26 | 7.32 | 0.36 | 0.81 | 0.82 | 0.40 |
| Skin | 3.68 | 3.50 | 3.81 | 3.52 | 3.45 | 0.67 | 0.89 | 0.18 | 0.27 |
| Tail | 3.34 | 3.61 | 3.59 | 3.49 | 3.35 | 0.50 | 0.79 | 0.49 | 0.56 |
| Fat | 5.32 | 7.04 | 7.30 a | 6.08 b | 5.16 b | 0.42 | 0.01 | <0.01 | 0.74 |
| Bone | 11.95 | 12.95 | 12.89 | 12.36 | 12.11 | 0.45 | 0.03 | 0.24 | 0.74 |
| Lean | 68.78 | 65.88 | 65.76 a | 67.54 b | 68.69 c | 0.37 | <0.01 | <0.01 | 0.06 |
| Loin, % | | | | | | | | | |
| Tenderloin | 4.94 | 5.35 | 5.01 | 5.13 | 5.31 | 0.25 | 0.30 | 0.63 | 0.94 |
| Skin | 4.67 | 5.19 | 4.81 | 4.75 | 5.23 | 0.20 | 0.11 | 0.15 | 0.37 |
| Fat | 9.34 | 12.97 | 13.85 a | 10.90 b | 13.85 c | 0.56 | <0.01 | <0.01 | 0.22 |
| Bone | 24.43 | 24.77 | 24.11 a | 24.20 a | 25.48 b | 0.43 | 0.57 | 0.04 | 0.52 |
| Lean | 56.68 | 51.85 | 52.36 a | 55.07 b | 55.35 b | 0.67 | <0.01 | <0.01 | 0.69 |

^a: Adjusted by co-variance analysis, using slaughter weight as co-variable

Table 4. Protein and fat chemical content individual primals affected by Large White genetic lines and estimated breeding value for feed conversion.

| Variable | Line (L) | | Efficiency (E) | | SEM | L | P-value | |
|-------------|----------------|---------------|----------------|----------------|------|------|---------|-------|
| | Sire n = 14 | Dam n = 12 | Low n = 13 | High n = 13 | | | E | L x E |
| Shoulder, % | | | | | | | | |
| Fat | 20.07 | 18.30 | 20.59 | 17.78 | 1.17 | 0.14 | 0.02 | 0.99 |
| Protein | 22.17 | 2.04 | 22.47 | 22.74 | 0.59 | 0.16 | 0.66 | 0.99 |
| Moisture | 56.27 | 57.42 | 55.19 | 58.37 | 1.61 | 0.54 | 0.06 | 0.97 |
| Belly, % | | | | | | | | |
| Fat | 23.39 | 25.11 | 26.58 | 21.91 | 1.77 | 0.34 | 0.01 | 0.88 |
| Protein | 23.11 | 23.95 | 24.42 | 22.63 | 0.62 | 0.19 | <0.01 | 0.75 |
| Moisture | 52.51 | 49.88 | 48.20 | 54.19 | 1.94 | 0.19 | <0.01 | 0.85 |
| Ham, % | | | | | | | | |
| Fat | 14.17 | 13.73 | 15.60 | 12.30 | 0.97 | 0.66 | <0.01 | 0.79 |
| Protein | 22.72 | 22.67 | 23.31 | 22.08 | 0.49 | 0.93 | 0.02 | 0.76 |
| Moisture | 62.10 | 62.50 | 59.92 | 64.68 | 1.28 | 0.75 | <0.01 | 0.96 |
| Loin, % | | | | | | | | |
| Fat | 21.08 | 20.25 | 23.42 | 17.91 | 1.59 | 0.61 | < 0.01 | 0.43 |
| Protein | 23.86 | 25.28 | 25.23 | 23.91 | 0.68 | 0.04 | 0.06 | 0.32 |
| Moisture | 53.63 | 53.61 | 50.41 | 56.83 | 1.41 | 0.99 | <0.01 | 0.59 |

4.4.3. Pork quality

No differences were detected on pH; however, drip loss at 24 hours, L^* , a^* and Hue were affected ($P < 0.05$; Table 5) by genetic line, where sire line presented higher drip loss than dam line (no more than 1% of magnitude difference). Additionally, L^* and Hue values were slightly higher on pork chops from sire line than dam lines (brighter and lesser grayish pink; $P < 0.05$). No variation in cooking traits and WBSF were observed between genetic lines ($P > 0.05$; Table 5). On the contrary, there was no significant difference in any traits among efficiency groups ($P > 0.05$).

Table 5. Pork quality traits affected by Large White genetic lines and estimated breeding value for feed conversion.

| Variables | Line (L) | | Efficiency (E) | | | SEM | P-value | | |
|-----------------------------|----------------|---------------|----------------|-----------------|----------------|------|---------|------|-------|
| | Sire n = 32 | Dam n = 32 | Low n = 19 | Inter n = 25 | High n = 20 | | L | E | L x E |
| pH | 5.57 | 5.62 | 5.64 | 5.63 | 5.53 | 0.04 | 0.21 | 0.07 | 0.22 |
| Drip loss ₂₄ , % | 5.08 | 4.00 | 4.84 | 4.00 | 4.75 | 0.55 | 0.02 | 0.32 | 0.13 |
| Drip loss ₄₈ , % | 6.61 | 6.16 | 6.78 | 6.24 | 6.12 | 0.87 | 0.53 | 0.79 | 0.41 |
| L^* | 57.49 | 55.81 | 56.26 | 56.52 | 57.18 | 0.66 | <0.01 | 0.44 | 0.84 |
| a^* | 17.29 | 18.13 | 17.62 | 17.68 | 17.84 | 0.34 | <0.01 | 0.83 | 0.54 |
| b^* | 10.15 | 9.82 | 10.07 | 9.85 | 10.03 | 0.23 | 0.14 | 0.70 | 0.77 |
| Chroma | 20.07 | 20.65 | 20.32 | 20.26 | 20.50 | 0.36 | 0.07 | 0.81 | 0.51 |
| Hue | 30.49 | 28.43 | 29.73 | 29.25 | 29.40 | 0.58 | <0.01 | 0.79 | 0.90 |
| Cooking time, min | 8.43 | 8.48 | 8.98 | 8.15 | 8.23 | 0.55 | 0.93 | 0.36 | 0.72 |
| Cooking loss, % | 15.70 | 16.12 | 16.78 | 14.53 | 16.41 | 0.90 | 0.60 | 0.06 | 0.72 |
| WBSF, kg ^a | 3.81 | 4.33 | 3.85 | 4.13 | 4.26 | 0.36 | 0.13 | 0.62 | 0.46 |

^a: Adjusted by co-variance analysis, using slaughter weight as co-variable

Drip loss₂₄: drip loss at 24 h

Drip loss₄₈: drip loss at 48 h

L^* =Lightness; a^* =Redness b^* =Yellowness

WBSF: Warner-Bratzler shear force

4.4.4. Belly quality

LFE pigs presented 2 cm more of belly length than intermediate and high efficiency pigs ($P = 0.03$; Table 6). Ribbed belly weight and thickness were affected by the interaction genetic line x efficiency group ($P < 0.01$; data no shown), where sire LFE group had the heaviest (4.57 kg and 3.29 cm) and thickest belly and sire high efficiency group had the lightest weight and thinnest belly (3.60 kg and 2.10 cm). The rest of genetic and efficiency groups had intermediate values.

Table 6. Belly evaluation traits affected by Large White genetic lines (sire vs dam) and estimated breeding value for feed conversion (high vs intermediate vs low).

| Variables | Line (L) | | Efficiency (E) | | | SEM | P-value | | |
|------------------------|----------------|---------------|----------------|-----------------|----------------|------|---------|-------|-------|
| | Sire n = 32 | Dam n = 32 | Low n = 19 | Inter n = 25 | High n = 20 | | L | E | L x E |
| Ribbed belly, kg | 4.11 | 3.76 | 4.13 a | 3.99 a | 3.70 b | 0.11 | <0.01 | <0.01 | <0.01 |
| Length, cm | 49.24 | 48.97 | 50.72 a | 48.49 b | 48.11 b | 0.91 | 0.73 | 0.03 | 0.08 |
| Width, cm ^a | 24.35 | 23.86 | 24.30 | 24.30 | 24.07 | 0.49 | 0.38 | 0.85 | 0.83 |
| Thick, cm | 2.75 | 2.45 | 2.88 a | 2.68 a | 2.26 b | 0.17 | 0.04 | <0.01 | <0.01 |
| Flop distance, cm | 6.87 | 7.90 | 8.27 | 7.16 | 6.73 | 0.80 | 0.13 | 0.23 | 0.58 |
| Flop score | 2.70 | 2.71 | 2.68 | 2.84 | 2.60 | 0.10 | 0.89 | 0.11 | 0.53 |

^a: Adjusted by co-variance analysis, using slaughter weight as co-variable

Subjectively scale from 1 to 5 (from 1= Firm fat, no finger depression, almost horizontal [firmest belly class]); 5=Soft spongy fat, finger depression remains, very floppy, roll over easily, oily [softest belly class]).

4.5 Discussion

4.5.1 Carcass traits and carcass cut-out

It was determined that the sire line boars were superior to the dam line boars in terms of carcass traits and cut-out, because sire lines are chosen for traits in faster growth rates and leaner

carcass (Whittemore, 2006). However, no data comparing sire and dam line within LW are available. The author found a report comparing carcass traits from two LW sire lines (Top York vs Tempo) in different offspring sex classes. Regardless of sex class, the study found no difference on back fat depth, carcass dressing percentage and predicted carcass lean percentage (by Autofom classification system), except for carcass weight for which Tempo line was heavier (Morales et al., 2011). In addition, Top York crossbreds presented greater fresh and trimmed ham yield, while Tempo crossbreds had higher chilled loin yield (Morales et al., 2011).

Selection for FE have also shown a constant increase in carcass leanness reflected in some of the carcass yield traits (i.e., reduction in backfat) in different pig breeds (Cai et al., 2008; Gilbert et al., 2007; Hoque & Suzuki, 2009; Johnson et al., 1999). Smith et al. (2011) reported carcasses, Yorkshire gilts, when compared to carcasses from control line pigs chosen for low RFI had considerably larger loin depth and lean % but tended to have less backfat. In agreement, Lefaucheur et al. (2011) showed that LW pigs with low RFI had leaner carcasses, higher estimated muscle content, and thinner backfat. Thus, choosing for FE could result in relative increases in primal and sub primal cut weights (Hermesch, 2008; Schinckel et al., 2008; Wiseman et al., 2007). Moreover, in the current study, despite high level of leanness in high efficiency pigs was not translated in high protein content determined chemically in belly, ham, and loin due to high moisture in those primal, which might induce a dilution effect that reduced the protein concentration.

Different researchers have indicated that high efficiency pigs (e.g., based on low RFI) fast-twitch glycolytic type IIB fibres were more prevalent, which show lesser protein turnover, greater cross-sectional area and less fat accretion (Lefaucheur et al., 2011). These reasons might partially explain the greater lean content in each primal cut in high efficiency pigs in our study.

4.5.2 Pork and belly quality

Publications addressing the effect of genetic line within the same breed on pork and belly quality are nonexistent to the best of author's knowledge. Although, there was not significant difference on pH, minimal colour and drip losses (at 24 hours) changes in sire line were observed in the current study, which cannot be explained solely by pH. Other factors such as a reduction in intramuscular fat content or an increase in the fraction of IIB fibres, myofiber cross-sectional area are linked to a reduction in water-holding capacity (Lefaucheur et al., 2011; Smith et al., 2011), which were directly associated with colour and drip loss.

Although, concerns have been raised that high efficiency pigs may produce pork with inferior quality. Our study did not find any indication of pork quality deterioration. In agreement, Cai et al. (2008), found that selecting for lower RFI did not compromise loin pH, colour, or marbling in Yorkshire pigs. Also, Smith et al. (2011), selecting for lower RFI, did not find any significant difference in ultimate pH, purge loss, drip loss and cook loss in loin chop. In contrast, other researchers (de Vries et al., 1994; Gilbert et al., 2007; Lefaucheur et al., 2011) reported that high efficiency group presented lighter colored meat, lower pH and greater drip loss in the gluteus medius and LM muscles than LFE group regardless of pig breed.

Researchers have indicated that in high efficiency pigs more fast-twitch glycolytic type IIB fibres were present along with an increase of glycogen content (Lefaucheur et al., 2011), which could induce a major dropping of pH in high efficiency pigs and reduce the water holding capacity (Smith et al., 2011). Also, greater percentage of IIB fibers might increase shear force values due to lower myofibril fragmentation index caused by greater calpastatin content (Castro Bulle et al., 2007; Lefaucheur et al., 2011; Lewis et al., 1984; McDonagh et al., 2001; Smith et al., 2011). In addition, limited proteolysis cannot increase myofilament space to hold onto water, which reduces

the product's ability to hold water. to retain water (Bee et al., 2007; Zhang et al., 2006; Smith et al., 2011).

Leaner carcasses show light belly weight and higher belly lean meat percentage (Elbert et al., 2020). This supports our results showing that high efficiency sire was leaner and had the lightest weight and thinnest belly. Pigs that are leaner typically have higher levels of linoleic acid (polyunsaturated fatty acid), and high iodine values in adipose tissue, which might make bellies softer (Tavarez, 2014). Thus, the fatty acid composition plays a significant role in determining the physical attributes and overall quality of the belly. However, belly firmness did not differ among genetic lines or efficiency groups ($P > 0.05$) in the current study. Moreover, the animals evaluated in the experiment were boars, which present higher lean-to-fat ratio and degree of unsaturation in the fat tissue than barrows and gilts (Soladoye et al., 2015; Soladoye et al., 2017). Fat content has a negative relationship with belly moisture, a positive relationship with belly-flop angle, and a negative relationship with belly softness score; thus, that fat buildup causes an increase in belly firmness (Soladoye et al., 2017).

Size, thickness, and firmness of the belly are crucial processing criteria because they affect handling, processing, and slicing challenges, bacon yields, and the appearance of the finished product (Soladoye et al., 2015). Also, Soladoye et al. (2017) revealed a positive correlation between belly-flop angle measurement and belly weight and length. Both subjective and objective belly firmness values can be affected by those parameters. In our experiment, even though weight and thickness were reduced in high efficiency sire line, belly firmness was not affected by genetic lines or efficiency groups or their interaction. In addition, the belly thickness reported in the current study were under the “average” belly thickness category (approximately 2.5 cm) for bacon

manufacture which consumers consider them with acceptable palatability characteristics (Person et al., 2005).

4.6. Conclusions

This study indicates variations in carcass traits and composition between genetic lines. Boars from the sire line resulted in leaner carcasses and primal pork cuts than boars from the dam line with minimal colour changes and drip losses. On the other hand, high-efficient animals showed advantageous performance in most carcass yield traits, which provide a favourable response in leaner animals and greater loin without detrimental effect on meat and belly quality. Also, changes on belly weight, belly thickness and leanness vary according to interaction genetic line x efficiency group; suggesting that low efficient pure sire line could be used in the final mating to obtain marketed offspring to satisfy bacon processors (heavy and thicker bellies), while high efficient sire pure lines could satisfy consumers preference for leaner bacon.

It is unknown how high efficiency animals possess higher muscle deposition and it is imperative to conduct comprehensive research to unravel the key stages of pre and postnatal muscle development, through an Omics centered approach, and originate complex datasets including data from genomics, transcriptomics, proteomics, metabolomics, and phonemics, this offers unique possibilities to understand the processes governing how animals develop their muscles. Those new discoveries could drive changes at post-mortem level in order to identify important metabolic pathways underlying muscle transformation to meat and meat quality development.

CHAPTER 5: GENERAL DISCUSSION

FE is heritable (h^2 0.30) and is used by pig genetic companies to select purebred pigs in their breeding programs (Hoque et al., 2007; Mrode & Kennedy, 1993; Ollivier & Henry, 1978). Genetic selection for FE has shown promise in improving swine production for providing advantages in most carcass yield traits and growth performance (Patience et al., 2015). This selection is to maximize FE and enhance carcass composition and growth performance (Patience et al., 2015), through EBV, which are an estimation of an animal's genetic value and its capacity for particular traits (Van Der Peet-Schwering et al., 2021) are used. Selection based on EBV-FCR may also affect meat and belly quality traits. Chapter 4 evaluated the influence of genetic lines (dam line vs sire line) and pigs segregated as high, intermediate and low FE based on the EBV-FCR within the LW breed on carcass traits, carcass composition, meat, and belly qualities.

5.1 Impact of EBV for FCR in carcass quality, carcass composition and meat quality traits

Carcass traits are affected by the impact of EBV-FCR. Several pig breeds selected for FE have also demonstrated a consistent rise in carcass leanness, as seen by certain of the carcass yield features (such as decrease in backfat) (Cai et al., 2008; Gilbert et al., 2007; Hoque & Suzuki, 2009). According to Smith et al. (2011), carcasses from Yorkshire gilts chosen for low RFI had significantly larger loin depth, higher lean percentages and tended to have less backfat. Cruzen, (2012) found leaner and less fat (both subcutaneous and intramuscular) in carcasses than control.

In case of carcass composition, Lefaucheur et al. (2011) have found that pigs from the low RFI line exhibited leaner carcasses, as reflected by a greater lean meat content (LMC) and loin:backfat ratio. In the current study, HFE pigs were also found to have a higher level of leanness. Pigs with HFE, as indicated by low RFI, tend to have a higher prevalence of fast-twitch glycolytic

type IIB fibers, which are associated with lower protein turnover, larger cross-sectional areas, and less fat accumulation (Lefaucheur et al., 2011). These reasons might partially explain the greater lean content in each primal cut in high efficiency pigs in our study. Selection for lean growth efficiency in Duroc pigs has resulted in improved carcass composition, but compromised tenderness due to increased the rate of pH decline and decreased water holding capacity of pork (Lonergan et al., 2001). High efficiency pigs present more fast-twitch glycolytic type IIB fibres, which posses high glycogen content (Lefaucheur et al., 2011) and could induce a major dropping of pH and reduce the water holding capacity (Smith et al., 2011). In addition, those muscle fiber present high calpastatin activity which inhibits postmortem protein degradation and may ultimately negatively impact tenderness and also, protein degradation reduction might conserve energy required for breaking proteins down in low-RFI line (Cruzen, 2012). Limited proteolysis cannot increase myofilament space to hold onto water, which reduces the product's ability to hold water to retain water (Bee et al., 2007; Zhang et al., 2006; Smith et al., 2011). However, the current research could not find any significant differences in efficient groups on pH, marbling level, drip loss, objective and subjective colour score, and shear force ($P > 0.05$). Therefore, our study demonstrated that high efficiency pigs in LW breed can be used without compromising the meat quality.

CHAPTER 6: GENERAL CONCLUSION AND FUTURE DIRECTIONS

6.1. Conclusions

Previous studies have consistently shown that selecting pigs for HFE results in leaner pigs (Cai et al., 2008; Smith et al., 2011). Chapter 4 of this research evaluates and also confirms differences in carcass traits and composition between genetic lines from diverse FE. Boars from sire line resulted in leaner carcasses and primal pork cuts than boars from dam line with minimal colour changes and drip losses. On the other hand, high-efficient animals show advantageous performance in most carcass yield traits, which offer a favourable response in greater loin and leaner animals without detrimental effect on meat and belly quality. Also, changes on belly weight, thickness and leanness vary according to interaction genetic line x efficiency group, suggesting that low efficient pure sire line could be used in the final mating to obtain marketed offspring to satisfy bacon processors (heavy and thicker bellies), while high efficient sire pure lines could satisfy consumers preference for leaner bacon.

We accept our hypothesis for the study, where the selection of HFE animals increases the level of leanness without significant difference in the pork and belly quality traits. Selection of animals for FE based on EBV-FCR is a major progress in pig sector as highly efficient pigs will produce leaner carcass without affecting meat quality and reducing feed cost bringing more profit to the producers. However, past research disagreements with our results might happens for differences in experimental settings such as breeds (Duroc vs LW), genetic lines (only sire lines), terms used to quantify FE (RFI vs FCR), sex class (boars vs barrows vs gilts), facility (commercial finisher barn vs nucleus).

6.3 Future research

This research has demonstrated benefits on carcass composition and pork quality using genetic selection based on EBV-FCR in pure LW sire and dam lines (genetic lines). These results served as the incentive for further research into biological processes using a OMIC centered approach, and originate complex datasets including genomics, transcriptomics, proteomics, metabolomics, and phonemics data, which provides new opportunities to understand the mechanisms regulating animals' muscle development. Those new discoveries could drive changes at post-mortem level in order to identify important metabolic pathways underlying muscle transformation to meat and meat quality development.

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