Factors Affecting the Prediction of Saleable Meat Yield in Lamb Carcasses using Electronic Probe Technology

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ABSTRACT

Factors Affecting the Prediction of Saleable Meat Yield in Lamb Carcasses Using Electronic Probe Technology

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This thesis is an investigation of the use of electronic probe technology (Viewtrak PG-207 optical probe) for predicting saleable meat yield (SMY) in lamb carcasses. 370 lambs were used in this study to compare probe versus carcass measures of backfat and *longissimus* muscle depth. Pearson correlation coefficients were determined to test probe accuracy versus actual carcass measures. Multiple regression analysis evaluated relationships among probe and carcass measures to SMY. ANOVA was used to determine significant predictors of saleable meat yield and develop prediction equations. Coefficients of determination (R^2) for models with probe measurements on the hot carcass ranged from 0.014 to 0.284 ($P \leq 0.86$) and 0.120 to 0.316 ($P \leq 0.50$) on the chilled carcass. In this study, Viewtrak PG-207 optical probe measurements could not be used alone to accurately predict SMY in lamb carcasses.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

A- Measurement being the greatest width of the eye muscle *M. longissimus thoracis*

ASP- AUS-Meat Sheep Probe

B - Measurement was the greatest depth of eye muscle taken at right angles to A

BL – Border Leicester

BLM - Border Leicester x Merino

C- Measurement was the depth of subcutaneous fat directly above B

CarcSMY – Saleable Meat Yield calculated by total dissection in present study

FatC- is the fat depth at the 12th rib over the *M. longissimus thoracis et lumborum* at the deepest part of the muscle

Fat5- fat depth at the 5th rib, 110 mm from midline

FTC – Swedish FTC Lamb Probe

GR – grade rule

HCW – Hot Carcass Weight

HGP- Hennessey Grading Probe

J - Measurement was the depth of subcutaneous fat above ventral edge of *M. serratus ventralis*

LED – Light emitting Diode

LMA – *Longissimus* Muscle Area

M - Merino

mo – months of age

PD – Polled Dorset

LIST OF ABBREVIATIONS AND SYMBOLS (CONTINUED)

P8 - site in the hanging carcass is the point of intersection for a vertical line from the dorsal tuberosity of the tripartite tuber ischia parallel with the chine bone, and a horizontal line from the crest on the spinous process of the third sacral vertebra (Moon, 1980)

RSD – Residual Standard Deviation

RUA – Ruakura GR Lamb Probe

SD or σ^2 – Standard deviation

SMY – Saleable Meat Yield

T - Texel

VIA – Video Image Analysis

$\overline{X}$ – Mean

1.0 Introduction

The structure of the Canadian lamb industry is quite diverse with numerous breeds, marketing options and management regimens. The goal of the lamb industry is to maximize saleable meat yield in their lambs. The saleable meat yield (SMY) is the proportion of the carcass that is saleable as meat (boneless muscle tissue). Carcass SMY was estimated as sum of trimmed and deboned leg, saddle, shoulders and meat trim as a proportion of hot carcass weight (Jones et al., 1996). This trait is important because it impacts profitability for producers and processors. The current lamb carcass grading system in Canada is limited to subjective grading of the carcass. The Canadian lamb graders classify carcasses on the basis of SMY using a combination of a grade rule (GR) measurement and subjective conformation scores for three anatomical regions including the leg, loin and shoulder (Stanford et al., 1997). The conformation score reflects the amount of muscling found across the anatomical regions of the carcass. The GR or grade rule (Stanford et al. 1997) is defined as the total tissue depth (including lean and fat), from the rib to the surface of the carcass at the 12th rib, 11 cm from the midline on lamb carcasses (Kirton et al., 1984). The subjective scores are based on assessing the amount of muscling present on the carcass as packers and processors want a product with sufficient fat content to preserve meat quality but does not cause excess trimming. Carcasses are assigned a subjective conformation score based on an index in which a score of 1 represents little muscling while 5 represents excellent muscling (Stanford et al., 1997). However, a subjective scoring system depends on the expertise of the grader and there may be considerable grader-to-grader variability. In countries outside of Australia and New Zealand, it can be difficult to find experienced lamb graders (Stanford et al., 1998). This can lead to misclassification of the finish of carcasses and inconsistent payouts for sheep producers. Inaccurate grading may hinder farm-level decisions regarding genetic selection and feeding programs designed to produce superior carcasses.

As a result, there is a need for a Canadian lamb grading system based on objective measurements to ensure consistent and accurate payouts for producers. These objective measurements would provide needed information to producers such that they could alter their management practices to prevent marketing of over- or under- finished lambs. Marketing over-finished lambs leads to the producer being penalized due to the extra processing that needs to occur to market the product. Under-finished carcasses have less saleable meat leading to lower returns for the producer.

Objective methods of carcass grading are in use by other Canadian meat industries. The Canadian pork industry classifies carcasses based on lean yield content. The carcass lean yield is predicted using measurements of subcutaneous backfat and loin muscle thickness, and in Canada these measurements are taken with an optical electronic probe (Pomar and Marcoux, 2003). From these measurements, lean yield can be estimated using a prediction equation programmed into the probe. Studies by Usborne et al. (1987) and Goenaga et al. (2008) found electronic probes to be accurate predictors of lean yield in the pork carcass. Goenage et al. (2008) reported coefficients of determinations (R^2) values of 0.801 and 0.794 for Fat-O-Meater and Hennessey probe respectively when using the probes to evaluate carcass lean percentage. In addition, Hopkins (1989) evaluated the Hennessey probe for grading cattle carcasses and found the probe could accurately predict subcutaneous backfat depth in beef carcasses. With this success in pigs and cattle, there is potential for using an optical grading probe for lamb grading to replace the current subjective system. Earlier experiments by Garrett et al. (1992) and Jones et al. (1992) had success using Hennessey optical grading probes for lamb grading, whereas more recent work by Siddell et al. (2012) and Hopkins (2013) have found that the Hennessey probe cannot accurately predict saleable meat yield. Different probes operate in their own distinctive way which is based on the wavelength of light emitted, the sensitivity of the reflection measurement device and software interpretation (Pomar and Marcoux, 2003). In this study, the optical probe Viewtrak PG-207 (Viewtrak Manufacturer, Edmonton, Alberta) was used to evaluate its ability to predict saleable meat yield in lamb carcasses. This probe is currently successfully used for pig grading in commercial pig packing plants across Canada.

When use of a probe is not an option at the abattoir, then carcass measures need to be evaluated to determine their ability to reliably predict saleable meat yield. For the potential for probes to be deemed effective, the equivalent carcass measurements for subcutaneous backfat and *longissimus* muscle depth must also be effective predictors of saleable meat yield. GR or grade rule (Stanford et al., 1997) is defined as the total tissue depth (including lean and fat), from the rib to the surface of the carcass at the 12th rib, 11 cm from the midline on lamb carcasses (Kirton et al., 1984). Equivalent carcass measures to probe measurements of *longissimus* depth and backfat have been found to accurately predict saleable meat yield in lambs similar to the Hennessey grading probe (Garrett et al., 1992). Yet Hopkins et al. (2008) found carcass subcutaneous backfat and *longissimus* depths to be marginal predictors of saleable meat yield in lambs. GR is currently used in addition to subjective conformation scores for lamb grading. In the work by Jones et al. (1996) and Hopkins et al. (2008), GR was the single best predictor of lean yield when compared to using measurements of backfat and *longissimus* muscle depth obtained from either a Hennessey probe (Jones et al., 1996) or equivalent carcass measures (Hopkins et al., 2008). Also, Kirton et al. (1984) found GR to be highly correlated to carcass fat content in lamb carcasses. Measurements such as the cross sectional area of *the longissimus thoracis* muscle (LMA) were a significant predictor of saleable meat yield in studies by Hopkins et al. (1998) and Safari et al. (2001). In contrast, Jones et al. (1992) found LMA to be an insignificant predictor of saleable meat yield. There appears to be no apparent reason why the studies differ regarding the significance of LMA for predicting saleable meat yield. External and animal factors could also be playing a role in the prediction of saleable meat yield. Safari et al. (2001) stated that in a diverse population of lambs, use of a prediction equation based on one group of lambs is not suitable due to animal factors such as sex and breed. Prediction equations may need to be evaluated to take these factors into account, although this could be problematic for incorporating this information at a packing plant for real time lamb grading.

The objectives of this study were:

1. To evaluate the accuracy of the Viewtrak PG-207 optical probe for predicting saleable meat yield in lambs.
2. To evaluate the relationships between probe and carcass measures for predicting saleable meat yield.
3. To examine how variation in management factors affected the prediction of saleable meat yield.

2.0 LITERATURE REVIEW

2.1 Evaluation of optical grading probes

2.1.1 Motivation for an objective grading tool

The current lamb carcass grading system in Canada relies on subjective grading of the carcass. The Canadian inspectors classify carcasses on the basis of SMY by a combination of GR measurement and subjective conformation scores for three anatomical regions including the leg, loin and shoulder (Stanford et al., 1997). The GR or grade rule (Stanford et al. 1997) is defined as the total tissue depth, which includes lean and fat, from the rib to the surface of the carcass at the 12th rib, 11 cm from the midline (Kirton et al., 1984). The subjective score is based on an index in which a score of 1 represents little muscling while 5 represents excellent muscling (Stanford et al., 1997). A limitation of subjective carcass grading is that it relies on the experience and objectivity of the grader for accurate assessment of lamb carcass quality (Stanford et al., 1998). The Canadian sheep industry has expressed concern that a subjective scoring system could be biased towards certain genders and breeds and be inconsistent (Stanford et al., 1997). There are few experienced graders in countries outside New Zealand due to low slaughter numbers in these countries (Stanford et al., 1998). The lack of experienced personnel limits consistent and accurate assessment of lamb carcass quality. Consumers want lamb that is lean with only sufficient fat cover to preserve optimal meat quality (Stanford et al., 1998). The inaccuracy of predicting lean carcasses provides producers with misleading feedback on carcass finish that can lead to production of over- and under-finished carcasses and inconsistent payouts. Packers want leaner carcasses to avoid excess trimming and waste costs involved with processing fatter carcasses. An objective measurement of carcass quality will help the producer deliver a consistent product which will result in fair returns for the producer.

The Canadian sheep industry has been interested in replacing subjective carcass quality assessment by the use of optical grading probes. Optical grading probe systems are based on first penetrating the carcass with a blade at a specific site. This allows light to enter the site where the blade has penetrated. Optical probes consist of a light emitting diode which illuminates the meat from under the optical window (Stanford et al., 1997). When the optical window subtended by the diodes passes from the muscle into the fat as the probe is withdrawn from the carcass, the light detector picks up an increase in reflected light (Swatland et al., 1994). Simultaneously, the depth of the probe is read from a device connected to a plate on the surface of the carcass, so that a microprocessor can use these inputs to determine the depth of fat and then estimate meat yield (Swatland et al., 1994)**.** Optical probes can be programmed to take into account the difference in reflectance of light between muscle and fat with the understanding that muscle reflects light at a lower frequency; this information is used to calculate lean and fat depth measurements (Fortin et al., 1984, Berg et al., 1997). This is the basis for probes currently used in carcass grading, such as the Hennessey Grading Probe and Destron probes which provide fat and lean depth measurements. The probes also integrate the depth measurements into a regression equation to calculate saleable meat or lean yield values which estimate the amount of lean found in the carcass. These equations are calibrated for the relevant species being assessed. Each brand of optical probe works distinctively based on wavelength of light emitted and sensitivity of the reflection measurement device and software (Pomar and Marcoux, 2003).

2.1.2 Accuracy of optical grading probes in beef and swine carcasses

Optical grading probes have been used for assessing carcass quality in other red meat species. Hopkins (1989) evaluated the Hennessey Grading Probe (HGP) for ability to accurately measure subcutaneous fat depth over the rump muscles in beef cattle at the P8 site. The P8 site in the hanging carcass is the point of intersection for a vertical line from the dorsal tuberosity of the tripartite tuber ischia parallel with the chine bone, and a horizontal line from the crest on the spinous process of the third sacral vertebra (Moon, 1980). Hopkins (1989) compared HGP measures to a traditional cut and measure technique where a small incision is made in the fat to the muscle, while the depth of fat to muscle surface is measured with a ruler (Phillips et al. 1987). While a linear equation was adequate for predicting cut and measure measurements from HGP measurements, Hopkins (1989) found 3% of HGP readings were inaccurate although the paper did not state whether actual carcass values were over or under-estimated. Phillips (1987) postulated that differences in fat tissue colour due to bruising underneath the viewing surface on fatter carcasses could lead to error in HGP measurements. Probing the incorrect site on leaner carcasses could also lead to error (Phillips et al., 1987).

Usborne et al. (1987) evaluated the HGP and compared to the Destron PG-100 probe for accuracy in grading warm pork carcasses. These probes use different LED wavelengths for determination of muscle and fat measurements (Swatland et al., 1994). Hog carcasses were probed on the left side between the 3rd and 4th last rib, 7 cm off the midline (the standard site used for assessing swine carcasses), using both the HGP and Destron probes and ruler measurements. Regression equations were used to compare lean yield based on cutout data with probe and ruler measurements (Usborne et al., 1987). There were strong correlations between ruler measurements and both Destron and Hennessey probes. Usborne et al. (1987) concluded that either probe had adequate prediction capability for pork carcasses. In 1994, optical probes were approved for carcass grading in the Canadian pork industry (Pomar and Marcoux, 2003). Further assessment of the HGP and Destron probes by Pomar and Marcoux (2003) found the two probes gave significantly different lean yield predictions with the Destron predicting lower yields than the HGP. This may be because of the need to refine the regression equations. The HGP prediction equation was derived from cut-out data from a previous national survey (1992) whereas Destron measurements were regressed to the equivalent lean values of the Hennessey probe (Pomar and Marcoux, 2003). The authors suggested that grading equations need to be evaluated periodically to ensure accuracy. Since the Pomar and Marcoux (2003) study did not compare the accuracy of the probes to a gold standard, no conclusion can be made on the effectiveness of each probe as a predictor of lean yield. Goenaga et al. (2008) examined the HGP and Fat-O-Meater probes for predicting lean meat content in gilts and barrows in Argentina. The Fat-O-Meater is based on similar principles as other optical grading probes which measure the difference in reflectance as the probe is retracted. The two probes were evaluated at the 3rd and 4th last ribs, 6 cm from the split carcass where fat and muscle depth measurements on the carcass were taken for this site which was different from the previous studies mentioned (Goenaga et al., 2008). Data were analyzed using multiple regression to predict lean content. The study found an R^2 of 0.801 for Fat-O-Meater and 0.794 for HGP for predicting lean content of pork carcasses. Goenaga et al. (2008) found this prediction was accurate enough to be adopted in national carcass grading.

The literature does show that in beef and swine carcasses, optical grading probes are a useful grading tool. This leads to the potential that the success in these species can be applied to grading lamb carcasses in Canada.

2.1.3 Comparable accuracy of optical and mechanical probes for measuring GR as a predictor of carcass fat cover and SMY in lamb carcasses

The success of optical grading probes in commercial hog grading has led to the hypothesis that they may also be useful for lamb carcass grading. Kongsro et al. (2009) noted two challenges with using optical probes on lamb carcasses: the subcutaneous fat is more difficult to assess on lambs due to the lack of rind to support the probe; and there is a heterogenous distribution of fat in lamb carcasses so that repeatability of the readings is low. It was suggested that optical probes need to be modified for grading lambs. Kirton et al. (1984) evaluated a prototype total depth indicator probe to measure tissue thickness in lambs. Tissue thickness is defined as the carcass wall thickness between the 11th and 12th ribs, 11 cm from the midline. This device measures the distance between the optical detection site on the tip of the probe and the base plate pressed against the external surface of the carcass, and gives a distance in mm between the external and internal surface (Kirton et al., 1984). Regression equations were created to predict carcass fatness. Hot carcass weights for lambs ranged from 9.6 to 21.4 kg with an average of 15.0 kg. Back fat was measured between the 11th and 12th ribs measured at the deepest part of M. *longissimus dorsi*, ranging from 1 to 7 mm with an average of 3.1 mm. GR measurements on the right side of the carcass ranged from 4 to 17 mm and averaged 11.3 mm (Kirton et al., 1984). The prototype total depth indicator probe was found to be acceptable for predicting the carcass wall tissue thickness at the M5 location which is between the 11th and 12th ribs, 11 cm from the midline which is the GR site. Kirton et al. (1984) mentioned that more work was needed to determine if the probe could be used at slaughter chain speed.

Cabassi (1990) used the Aus-Meat Sheep Probe (ASP) to evaluate total tissue thickness over the 12th rib and compared the findings to simple use of the GR knife. The GR knife consists of a blade, handle and block which moves along the blade to indicate fat depth. The GR knife is inserted into the intercostal space at the GR site until it reaches the 12th rib. At the highest point of the rib, the block is moved until it rests gently on the tissue surface (Aus-Meat Limited Manual, 2000). This was done at slaughter chain speed. The ASP works similarly to the total depth indicator in which tissue thickness is measured from the optical detection site at the probe tip to the base plate on the external surface to give a distance in mm at the GR site. ASP measures were converted to fat score and compared to GR knife fat score. Hot carcass weights averaged 14.1 kg with a range from 10.4 to 18.1 kg. The average fat score was 2.9 and ranged from 1 to 5. The average GR was 10.6 mm and ranged from 4 to 22 mm (Cabassi, 1990). Linear regression equations were used to predict the percentage of trimmed fat and a student t-test was used to determine differences in coefficients for each term in prediction equations (Cabassi, 1990). The ASP measurements were able to predict dissectible fat or fat trim as precise as to using a GR knife or caliper at the 12th rib to measure carcass fatness. Since these measurements are the basis for the subjective lamb grading, Cabassi (1990) concluded that the ASP measurement should be introduced to the lamb meat industry as it could accurately predict carcass fatness at slaughter chain speed. Several studies have evaluated implementing use of the HGP in the lamb industry.

Kirton et al. (1995) compared four different electronic probes designed to measure total tissue as to to their ability to predict GR using both the right and left sides of the carcass; the HGP, ASP, Swedish FTC Lamb Probe (FTC) and Ruakura GR Lamb Probe (RUA). The latter two probes measure GR using optical reflectance technology similar to that used in the ASP. Two mechanical point probes were also used to measure GR. Hot carcass weights ranged from 10 to 31 kg with an average of 19.7 kg. Fat percent of carcasses ranged from 12 to 36% with an average of 25.1%. GR averaged 10.8 (right side) and 10.6 (left side) (Kirton et al., 1995). Least squares regression was used to compare the various measures (GR, percent water and percent fat) determined by the electronic and mechanical probes. Estimates of coefficients and effects were analyzed using restricted maximum likelihood (Kirton et al., 1995). All probes predicted GR equally well. All probes with the exception of the ASP, predicted the percentage of water in the carcass equally well (Kirton et al., 1995). Carcass water correlates strongly with carcass muscle and therefore lean content of the carcass (Kirton et al., 1984). Kirton et al. (1995) found that models containing manual GR measurements on the cold carcass accounted for more of the variation in carcass water and fat than optical probe measurements on the hot carcass. The authors attributed the difference in predictive ability to increased accuracy in prediction on cold carcasses. The authors concluded that any of the three current commercial probes would be acceptable for use in a commercial setting while the fourth probe (ASP) requires improvement.

Probes designed to measure total tissue thickness have been shown to be effective at measuring GR. Though Kirton et al. (1995) found the ASP was not effective at measuring carcass lean, it does measure GR as accurately as the other probes and can be used at slaughter chain speed. GR has been shown to be an effective predictor of saleable meat yield (Jones et al., 1996; Hopkins et al., 2008) so probes measuring GR do have the potential to be used in Canadian lamb carcass grading.

2.1.4 Comparable accuracy of the hennessey grading probe for measuring backfat thickness, *longissimus* muscle thickness and SMY in lamb carcasses

An American study (Garrett et al., 1992) evaluated the HGP for the American lamb industry. Lamb carcasses were probed between the 12th and 13th ribs, 3.8 cm from the backbone on both the hot and cold carcass. Carcasses were trimmed into wholesale and tray-ready cuts. Wholesale cuts were trimmed to 0.64 cm fat trim whereas tray-ready cuts were trimmed to 0.25 cm fat trim (Garrett et al., 1992). Carcass weights averaged 33.91 kg for carcasses fabricated into wholesale cuts and 28.68 kg for carcasses fabricated into tray ready cuts. Fat thickness measured at the 12th rib was .71 cm for wholesale cut carcasses and .53 cm for tray ready carcasses (Garret et al., 1992). Using multiple regression, the HGP was found to underestimate fat on the hot carcass and overestimate fat on the cold carcass. Variables used within models included hot and chilled probe fat measurements, carcass fat thickness measurement, carcass weight and kidney and pelvic fat percentage. The HGP measured fat more precisely on the cold carcass when carcasses were lean, but when carcasses were fat the HGP measured fat more precisely on the hot carcass (Garrett et al., 1992). This discrepancy was explained that hot carcass fat is more fluid and easily manipulated. Despite these conditions, Garrett et al. (1992) found that both hot and cold probe fat measures were highly correlated to actual measurements.

A similar study by Jones et al. (1992) evaluated the HGP for Canadian lambs and found that probe fat measures between the 12th and 13th ribs were more precise than measurements between the 10th and 11th ribs. Hot and cold carcasses were probed 2.5 cm from the midline. Lamb weights ranged from 32 to 77 kg for all genders. Lambs were divided by age and weight with four weight groups (32-40 kg, 41-49 kg, 50-58 kg and 68-77 kg) and 4 age groups (3-6 months of age (mo), 6-9 mo, 9-12 mo, 12-15 mo) (Jones et al., 1992). Although precision was not equal, it improved when the carcasses were probed cold (Jones et al., 1992). Measurement of fat thickness over the loin eye at midpoint between the 12th and 13th ribs for predicting lean and fat content of the carcass by probe measurements were similar to using a GR measure at the same rib which suggests the HGP would be acceptable for this measure. While the probe was used to measure loin eye area and muscle thickness, these measures were poor predictors of carcass lean and fat content. The study also evaluated the effect of gender and found that the prediction of lean content was generally more precise with rams than ewes and wethers. This was due to increased accuracy of carcass measures as predictors of lean content in carcass (Jones et al., 1992).

Jones et al. (1996) examined the prediction of saleable meat yield in lamb carcasses. Lambs were selected to represent 3 hot carcass weight ranges including 18 to 22.9 kg, 23 to 25.9 kg and 26 to 30 kg. Three fatness ranges were also selected, i.e. <3 mm, 3 to 5 mm and >5 mm (Jones et al., 1996). Carcass measurement were taken on the left side of carcass and including HGP measurements at 3-4 cm from the mid-line of *M. Longissimus thoracis* between 10th and 11th ribs and 12th and 13th ribs. Data were analyzed using SAS GLM with a model including carcass weight, fatness and gender as main effects. Carcass measurements for predicting saleable meat yield were analyzed using stepwise multiple regression (Jones et al., 1996). The authors found that the HGP measurements were less accurate for predicting saleable meat yield than carcass measurements taken with a ruler including GR, fat and muscle depth measurements across all lamb carcasses in the study (Jones et al., 1996).

In a comprehensive study of electronic technology to assess lamb carcass conformation, Berg et al. (1997) evaluated the HGP between the 12th and 13th ribs, 3 and 6 cm from the midline. Lamb hot carcass weights ranged from 19.5 to 37.6 kg with an average of 29.3 kg. Average fat depth at the 12th rib measured at 3 cm from the medial plane was 5.3 mm with a range from 0.3 to 12.3 mm (Berg et al., 1997). Data were analyzed using a linear regression procedure using SAS along with STEPWISE regression based on maximum R^2 and minimum root mean square error (Berg et al., 1997). Their findings were similar to Garrett et al. (1992) in that greater accuracy was found probing the cold carcass due to the softness of fat on the hot carcass. Although as stated by Garrett et al. (1992) the improvement in accuracy between hot and chilled carcass is dependent on the fatness level of the lamb carcass. Berg et al. (1997) concluded that optical probes were only marginal predictors of carcass yield with R^2 values for models containing probe measurements either on hot or chilled carcass to be 0.453 and 0.343 respectively.

Some more recent research has examined objective measures for evaluating lamb carcasses. Kongsro et al. (2009) evaluated four different grading technologies for the lamb industry in Argentina: computer tomography; European (EUROP) classification; carcass shape and length measurement; and optical grading probe. EUROP classification is a subjective scoring system used to grade carcasses and was developed in the European Union (Johansen et al., 2006). Scores are assigned for each conformation and fat class using either a five point scale (previously used) or 15 point scale (currently used) (5 classes with + or - for each class) (Johansen et al., 2006). The scores equate to E for excellent for the highest score to P for poor for the lowest (Johansen et al., 2006). The study evaluated 2 two probe sites including one between the 12th and last rib, 2 cm from the midline to evaluate total tissue, fat deposition over the loin eye and loin eye muscle depth. The second probe site was located between the midline and rib end between 10th and 11th ribs to measure total tissue thickness (Kongsro et al., 2009). Although the study did not take equivalent mechanical carcass measures to compare accuracy, probe measures were correlated to deboned weights of fat and muscle. The hot carcass weights for lambs in this trial averaged 18.67 kg. Total fat weight in kg for the lambs averaged 3.34 kg (Kongsro et al., 2009). The HGP appears to accurately predict the weight of fat tissue (correlation greater than 0.9 and a low prediction error with a value less than 1.0 kg) and muscle weight ($r = 0.85$) (Kongsro et al., 2009). The authors had difficulties using the probe on very small carcasses (not defined) due to problems with probing the loin perpendicularly (Kongsro et al., 2009). If the probe is not inserted perpendicular it could lead to inaccurate readings, thus affecting the results of the study. In conclusion, the authors claim that HGP measures were the second best predictors of fat and muscle in the study behind computer tomography (Kongsro et al., 2009).

Siddell et al. (2012) evaluated HGP measures and other carcass measures to predict meat yield in fatscore 3 lambs. Fatscore 3 as described by the authors, would represent a GR measurement of 11 to 15 mm deep (Anon, 2005). The lambs were divided by fatscore with 1 being the leanest and 5 being the fattest lamb carcasses. The lamb carcasses were probed between the 12th and 13th ribs over the greatest depth of muscle. The average cold carcass weight was 24.5 kg (15.1 - 38.9 kg). Average GR was 15.9 mm (3 - 26 mm). The fat depth taken at the deepest part of *M. longissimus* at the 12th rib (fatC) averaged 6.2 mm (2 – 15 mm) (Siddell et al., 2012). Regression was used to determine prediction of meat yield using various carcass measures along with including HGP measures of fat and loin depth. HGP or equivalent carcass measures did not contribute significantly to lean meat yield prediction when primal weights or other carcass predictors were included in the model (Siddell et al., 2012). Furthermore, there was no advantage of using HGP measures rather than GR and weight of the forequarter. Siddell et al. (2012) concluded that the HGP is not an alternative for predicting meat yield as compared to a GR measurement and weight of forequarter.

Recent work by Hopkins et al. (2013) re-evaluated the HGP by measuring 557 lambs between the 12th and 13th ribs over the deepest muscle depth at slaughter chain speed. Data on carcass weights and fat thicknesses of lambs in trial were not given. Data were modeled using a random linear regression to ascertain effectiveness of the HGP. It is unclear from the study what is meant by random linear regression. HGP probe measures for subcutaneous fat depth or muscle depth could not provide reliable estimates for carcass predictions. The authors stated that the large range in data points derived by Garrett et al. (1992) and Kongrso et al. (2009) may explain why these studies found HGP probe measures to have high correlations with dissected weights of lean and fat tissue compared to their study. These authors concluded that the HGP was not a viable alternative to the ASP for use in the Australian lamb industry.

The research into use of optical grading probes in lamb carcasses is contradictory at this time. Conditions in which data were collected along with animal and external factors could be reasons for the differences in findings in the literature at this time. Although more recent studies (Siddell et al., 2012; Hopkins et al., 2013) have concluded that Hennessy grading probe measurements are not effective predictors of saleable meat yield, studies from the early 1990's and Kongrso et al. (2009) do show the potential for use of the optical grading probe as a lamb carcass grading tool.

2.2 Lamb carcass composition and accuracy of prediction using carcass measures

As mentioned previously, the Canadian graders classify carcasses on the basis of saleable meat yield by a combination of GR measurement and subjective conformation scores for three anatomical regions including the leg, loin and shoulder (Stanford et al., 1997). Obtaining reliable estimates of SMY from carcass measures is important to not only grade carcasses appropriately for payment but also for genetic improvement of carcass conformation (Hopkins et al., 1995). To do this, research needs to determine which carcass measurements give the best prediction of saleable meat yield.

2.2.1 Measurements of fat depth as a predictor of lamb carcass composition

Wood and MacFie (1980) evaluated the significance of breed for prediction of lamb carcass composition from subcutaneous and intermuscular fat depots. They examined the relationship between fat thickness measurements and tissue weights in two ewe breeds (Clun Forest, Colbred) and two ram breeds (Suffolk, Hampshire). 350 lambs were used in this trial with castrated males, females and singles and twins evenly represented (Wood and MacFie, 1980). Lamb carcass weights were classified into four categories with mean weights of 15, 17, 19 and 21 kg. Half carcasses were dissected and four carcass measurements including fatness measurements C and J; C measurement was the depth of subcutaneous fat directly above B with B being the greatest depth of the eye muscle; and J measurement was the depth of subcutaneous fat above ventral edge of *M. serratus ventralis* (Wood and MacFie, 1980). Pearson correlation coefficients between the 4 measurements and carcass and tissue weights were determined. Regression analysis was also performed using stepwise regression (Wood and MacFie, 1980). The J measurement was found to be a slightly more accurate predictor for weights of lean, subcutaneous fat and intramuscular fat than C measurement when combined with carcass weight (Wood and MacFie, 1980).

Research from Hopkins et al. (1995) examined how carcass fatness along with other factors affected the weight of different retail cuts. This study evaluated data obtained from 258 lambs (86 ewes, wethers and cryptorchids); the term, cryptorchids most likely referring to ram lambs which have had rings applied to the scrotum after first pushing the testicles up next to the body wall, more commonly called short-scrotumed. This included 130 lamb carcasses fabricated as boneless, heavily trimmed cuts while 128 lamb carcasses were fabricated as traditional bone-in retail cuts. Trimmed lamb cuts were prepared as 1 of 4 possible combinations: 1) silvertop roast and boneless loin; 2) silvertop roast and eye of loin, topside; 3) silverside and boneless loin; and 4) topside, silverside and eye of loin. The silvertop roast is the portion of leg after the round roast, patella, cap and connective tissues are removed. The silverside was prepared by cutting following the seam between topside and silverside muscle (Hopkins et al., 1994). The traditional cuts included short hindleg, chump, short loin, fillet, ribloin (8-rib) and four rib forequarter and neck and shank cuts (Hopkins et al., 1995). The ewes, cryptorchids and 51 wethers were sired by Poll Dorset rams bred to Border Leicester X Merino ewes while the breed composition of the remaining wethers were unknown. The average hot carcass weights with kidney and kidney fat removed was 21.4 kg for trim cuts and 21.1 kg for traditional cuts (Hopkins et al., 1995). The measurement, Average FatC, is the fat depth at the 12th rib over the *M. longissimus thoracis et lumborum* at the deepest part of the muscle; values were 3.1 mm for trim cuts and 3.0 mm for traditional cuts. Average GR determined with a GR knife was 12.5 mm for trim cuts and 12.4 mm for traditional cuts (Hopkins et al., 1995). Multiple regression procedures were used to develop models with independent variables being hot carcass weight and GR. Analysis of covariance was performed to determine the influence of sex on the weight of various carcass components using covariates, GR and cold carcass weight. Adjusted lean square means for each component were compared using Tukey test (Hopkins et al., 1995). The models developed using GR and hot carcass weight to determine weight of cuts and carcass components ranged from 0.46 to 0.93 (R^2 values) with all component weights being strongly correlated to hot carcass weight

Jeremiah (2000) reviewed how various factors affected Canadian lamb carcass composition and meat quality One study found that increasing slaughter weight was associated with greater carcass fatness (Wise, 1978). The review states that ram lambs generally have the lowest GR measurements in warm carcasses and that GR measurements increased with slaughter weight in young wethers (< 9 mo); however GR measurement is generally not related to chronological age when carcass weight is accounted for (Jeremiah, 2000). In the past, the GR measurement has been useful for carcass classification. The use of GR with carcass conformation was found to be the highest predictor of saleable meat yield in one study whereas another study found GR, loin eye area and hot carcass weight accounted for breed type differences in lean meat yields (Jeremiah, 2000). In the past, subcutaneous fat thickness is often measured 1.5 cm from midline between the 12th and 13th thoracic ribs using a ruler; this measure is greater for ewe vs. ram lambs (Jeremiah, 2000).

Safari et al. (2001) evaluated several carcass measurements across different lamb genotypes to predict saleable meat yield. Carcass data were gathered from 591 lambs representing cryptorchids and ewes. Lambs were composed of six genotypes including T X BLM, PD X BLM, T X M, PD X M, BL X M and M X M. After slaughter, hot carcass weight was recorded excluding kidneys, kidney fat and channel fat. GR was measured on the cold carcass with a GR knife. Conformation scores were determined by one operator using the EUROP classification system (Safari et al., 2001). After 3-7 days of chilling, carcasses were fabricated down into primals and trimmed cuts where other carcass measures could be obtained. Carcasses were split between the 12th and 13th ribs where a grid of 1 cm squares was used to measure the cross sectional area of *M. longissimus thoracis et lumborum* (LMA) along with maximum width and depth of this muscle. Fat depth over the deepest part of the muscle (FatC) was obtained along with fat depth at the 5th rib, 110 mm from midline (Fat5) (Safari et al., 2001). Partial correlation coefficients were calculated between the different carcass measurements adjusted for hot carcass weight. Multiple regression analysis was used for prediction of saleable meat yield using hot carcass weight, LMA and EUROP conformation with either GR, FatC or Fat5. Covariance analysis was used to determine measures of fatness between genotypes using hot carcass weight as covariate. Lambs in this study averaged 22.4 kg with a range of 14.4 to 33.8 kg. GR measurements averaged 12 mm with a range of 3 to 20 mm. Fat5 measurements averaged 6.7 mm with a range of 1 to 14 mm. FatC averaged 3.5 mm with a range of 0.5 to 10 mm. The authors found that at a given hot carcass weight, all fat measurements were moderately correlated with GR having a greater correlation coefficient to Fat5 than FatC (0.47 vs. 0.39). Multiple regression analysis found Fat5 providing a small advantage for prediction of saleable meat yield as compared to using GR and FatC although the contribution using these fat measures were small. The authors state that work by Jones et al. (1996) found GR to contribute significantly to prediction of saleable meat yield across a specific genotype or breed.

Hopkins et al. (2008) evaluated how alternative site for fat and muscle depth measures could be used to predict lamb carcass composition. For the study, 312 crossbred lambs (Polled Dorset X Merino) were used with an average live weight of 47 kg. Lambs were slaughtered with internal fat and kidneys removed before determining hot carcass weight; GR measurement was then determined using a GR knife. One day after slaughter, carcasses were split and a section of the left hindleg was removed by a cut 30 mm distal to the lumbar-sacral junction. At this site, the depth of the rump muscles was measured along with subcutaneous fat depth overlaying the *M. gluteus medius*. Also, subcutaneous fat depth on the *M. longissimus* at the 12th rib was measured along with depth of the muscle at this site along with the width of *M. longissimus*. The area of the *M. longissimus* was calculated using depth of M. longissimus X width X 0.008 (Hopkins et al., 2008). Lambs were slaughtered on Tuesdays and Thursdays with carcass sides from Thursday lambs being scanned by dual energy X-ray absorptiometry using a Hologic QDR 4500A fan beam X-ray bone densitometer which measured fat and lean weight. X-ray absorptiometry works on the principle that any dual energy X-rays can determine composition of any known materials. A given high and low energy is produced from fat and fat free mass; when a third material (bone) is present in the dual X-ray beam, body composition is estimated from tissue points nearby (Kelly et al., 1998). Using the Kelly procedure, lean and fat percentage for each carcass were derived. Multiple regression was used to create prediction models for lean and fat percentage using carcass measures. Linear regression was used to examine fat depth measurements at different sites (Hopkins et al., 2008). Hot carcass weights averaged 22 kg with a range of 12.4 to 32.5 kg. GR averaged 11.1 mm with a range of 2 to 21 mm. Fat depths over the 12th rib at *M. longissimus* averaged 3.3 mm and ranged from 1.5 to 8 mm. Fat depths over the *M. gluteus medius* averaged 5.6 mm and ranged from 1 to 11 mm (Hopkins et al., 2008). GR measurement was found to be the single best predictor of lean percentage in lambs accounting for 48.1% of variation. Fat depth over the rump provided less precise measurement than either GR or Fat depth over 12th rib. Hot carcass weight inclusion with GR or fat depth at 12th rib added a small improvement to lean percentage prediction. The main purpose of the study was to evaluate the difference in fat measurements at the rump and 12th rib site for predicting carcass composition. Hopkins et al. (2008) concluded that fat depth measurements at the rump site were not as useful as fat depth measurement at the 12th rib site and therefore not a viable alternative for predicting carcass composition.

Throughout the literature, measurements of fatness have been found to be a useful in classifying lamb carcasses. In particular, GR has been found to be a more useful predictor of saleable meat yield than other measurements. While past studies (Safari et al., 2001; Hopkins et al., 2008) have disagreed about the usefulness of a rump fat depth measurement taken at the rump site for predicting SMY, both studies agreed that GR did a better job of predicting SMY than other fat thickness measurements.

2.2.2 *Longissimus* muscle measurements as a predictor of carcass composition

As an alternative to carcass fat measurements, measurements from the *longissimus* muscle should also be evaluated to determine their effectiveness as predictors of carcass composition. Jeremiah (1982) states that loin eye area is important for consumers since it relates directly to lean to bone ratio in the most valuable cuts. This would indicate that evaluating its ability to predict carcass composition should be evaluated.

Woods and MacFie (1980) evaluated carcass fat and *longissimus* muscle measurements as a predictor of lamb carcass composition. The measurements taken were A and B; A measurement was the greatest width of the eye muscle (*M. longissimus thoracis*); B measurement was the greatest depth of eye muscle taken at right angles to A. Both fat measurements were more accurate predictors for weights of lean, subcutaneous fat and intramuscular fat than either A or B measurements. Another study found that the use of muscle thickness measurements in combination with fat thickness measurements does not increase the amount of variation explained in carcass composition compared to fat thickness measurements alone (Jones et al., 1992). This seems to agree with Woods and MacFie (1980) who found that muscle thickness measurements are less useful than fat thickness measurements.

Hopkins et al. (1997) then examined how differences in lamb carcass composition vary across six genotypes. Carcass measurements and composition data were obtained from 198 lambs represented by 104 cryptorchids and 94 ewes. The lambs were sired by a selection of Poll Dorset, Texel, Border Leicester and Merino rams bred to Border Leicester X Merino and Merino ewes (Hopkins et al., 1997). Carcass images were taken using VIASCAN video image analysis (VIA) while carcasses were was moving on the rail. Video image analysis uses digitalized images of the carcasses which are then analyzed and prediction equations are developed that determine meat yield (Stanford et al., 1998). Chilled carcasses were held for 3-7 days before being fabricated into primals using a bandsaw. Both boneless (round, topside, silverside, eye of loin, fillet and neck fillet roast) and bone-in cuts (chump, ribloin [7 rib], shoulder, shank and neck) were prepared (Hopkins et al., 1997). Muscularity was determined based on an equation incorporating weights of five leg muscles, *semimembranosus, adductor femoris, semitendinosus, bicep femoris* and *quadriceps femoris*, and femur length (Hopkins et al., 1997). The equation included the square root of the weight of the muscles divided by length of bone (Purchas et al., 1991). The cross-sectional area of the *M. longissimus thoracis* was determined at the 13th rib using a grid of 1 cm squares and the maximum width and depth measured at this site. Average hot carcass weights for these lambs were 20.9 kg while the mean GR on the hot carcass was 13.0 mm. ANOVA was used to examine the effect of genotype on carcass characteristics with hot carcass weight or GR as covariates. Bonferroni pairwise test was used to examine differences in means. Regression analysis was performed to examine relationship between muscularity and HCW and VIA measurements (Hopkins et al., 1997). Partial correlation coefficients were determined after adjusting for cold carcass weight; a partial correlation coefficient of 0.67 was calculated between the cross-sectional area *longissimus thoracis* and the muscle:bone ratio for all lamb genotypes, indicating a moderate correlation between these measurements.

Hopkins et al. (1998) examined factors affecting saleable meat yield and cut proportions for ewe and cryptorchid lambs. Carcass data were collected from 307 cryptorchid and 284 ewe lambs. The breed composition of the lambs included 6 genotypes: (Texel (T) x Border Leicester x Merino (BLM), Poll Dorset (PD) x BLM, T x Merino (M), PD x M, BLM, M X M), from several flocks across Australia (Hopkins et al., 1998). Hot carcass weight, and hot carcass weight without kidneys, kidney fat, and channel and skirt fat were recorded. Kidneys, kidney fat and channel and skirt fat were also recorded. Hot GR measurement was determined with a GR knife while fat depth was determined over the 12th rib at the *M. longissimus thoracis et lumborum* at the deepest part of muscle (FATC). The researchers also measured the cross-sectional area of the *M. longissimus thoracis et lumborum* using 1 cm squares along with maximum width and depth of the muscle. ANOVA was used to examine effects of genotype on carcass characteristics with either cold carcass weight or GR as covariates (Hopkins et al., 1998). Genotype and saleable meat yield were examined using cold carcass weight as a covariate with Bonferroni pairwise test used to examine differences in genotype means. Simple linear regression was used to determine effects of hot carcass weight without kidney and kidney fat on estimation of saleable meat yield. Multiple regression was then used to identify those individual variables in addition to hot carcass weight without kidneys and kidney fat that influenced estimation of yield**.** The average hot carcass weight without kidneys and kidney fat was 24.7 kg for cryptorchids and 18.7 kg for ewes. Hot GR averaged 13.5 mm for cryptorchids and 10.3 mm for ewe lambs. FATC averaged 4.2 mm for cryptorchid and 2.8 mm for ewe lambs. The researchers found that the hot carcass weight without kidneys and kidney fat alone explained small amounts of variation in saleable meat yield indicating carcass weight was not a useful measure. The addition of measuring the cross-sectional area of *M. longissimus thoracis et lumborum* had the most influence in improving accuracy for prediction of yield. Hopkins et al. (1998) concluded that cross-sectional area *of M. longissimus thoracis et lumborum* should be used in new prediction models.

Other researchers also found that addition of LMA added significantly to the prediction of saleable meat yield along with carcass weight and a fatness measurement. The researchers concluded that inclusion of LMA across a diverse production system provided a significant and improved accuracy more so than conformation (Safari et al., 2001). This study coincides with the previous work, yet the study by Jones et al. (1992) found that LMA was a poor predictor of carcass lean or fat content. They also state that the addition of LMA to models including fat thickness measurements from either a ruler or optical probe did not improve the prediction of carcass lean or fat content.

The literature suggests that measurement of *longissimus* muscle thickness (depth) is not a strong predictor of saleable meat yield in lamb carcasses. There is disagreement in the scientific literature about the usefulness of LMA for predicting SMY.

2.2.3 The effect of gender and genotype on lamb carcass composition

Along with evaluating how carcass measurements predict carcass composition, animal and external factors should be evaluated to determine how carcass composition is affected by factors including gender and genotype.

Genotype can have an impact of carcass composition and this was presented in the study by Woods and MacFie (1980). Terminal sire breeds, also known as carcass breeds, had deeper eye muscles than maternal breeds but the authors concluded that the difference in conformation between breeds did not invalidate use of a single prediction equation based on fat thickness (Wood and MacFie, 1980). The authors also concluded that breed effect is small in predicting saleable meat yield (Wood and MacFie, 1980). The amount of intra-abdominal fat differed between breed types with maternal breeds having more kidney knob and channel fat plus omental fat then terminal sire breeds. These are fat depots around the kidney, and abdominal region. Hopkins et al. (1997) also found differences in carcass composition between genotypes. The study found that Merino cryptorchid carcasses were significantly leaner as measured by GR at a common weight versus carcasses from Border Leicester X Merino cryptorchid crosses. Carcasses from Texel rams were not significantly leaner as measured by GR than Poll Dorset rams as was expected. The researchers also found that including genotype in the model significantly improved the accuracy of prediction (Hopkins et al., 1998). Safari et al. (2001) also evaluated the effect of genotype on lamb carcass composition. They found that measurements of GR, FatC, Fat5 and fat trim percentage were significantly different between genotypes in the study.

Along with genotype, gender can impact lamb carcass composition. Differences in LMA between genders have been noted to be greatest in ram lambs and smallest in ewe lambs independent of chronological age (Carpenter et al., 1969; Field, 1971); this contrasts to other studies where gender did not affect loin eye area (Ray and Mandigo, 1963, 1966). Jeremiah (2000) also states that gender did not impact LMA. Wether lambs have larger loin eye areas than ewe lambs (Wise, 1978). The review by Jermiah (2000) also stated that many studies have found ram lambs to be leaner than ewe lambs. Jones et al. (1992) states that prediction of carcass lean improved with rams due to the greater lean content of ram carcasses.

Safari et al. (2001) stated that in a diverse population, use of prediction equations for lamb carcass composition based on one group of lambs is not suitable due to factors such as sex and breed. This statement from the literature sums up the fact that genotype and gender impact carcass composition. Indication is that when applying a new grading system into lamb carcass grading, these factors will need to be taken into account to avoid a bias to one genotype or gender.

3.0 MATERIALS AND METHODS

3.1 Animals

Three hundred and seventy lambs were sourced from 18 producers across Ontario. Lambs were purchased from the Ontario Stockyards at Cookstown, Ontario and also bought directly from producers. Lambs were targeted for purchase around 50 kg live weight. Ages of lambs at slaughter were unknown. Ewe and ram lambs were represented with 82 ewes and 288 rams. No wether lambs were present in this study. Breed information was provided by producers for 226 lambs. Lambs were composed of several breeds including Dorset, Suffolk**,** Rideau, Canadian Arcott, OLIBS (Ontario Lamb Improvement Breeding Strategy), North Country Cheviot, and crosses of Texel, Charollais, British Milk Sheep, Suffolk, Rideau and Dorset.

3.2 Slaughter

The study was approved by the University of Guelph Animal Care Committee, based on guidelines and principles of the Canadian Council on Animal Care (Olfert et al., 1993). Lambs were slaughtered between the months of November 2011 to December 2012. One hundred and ninety lambs were brought to the University of Guelph Meat Laboratory from the Ontario Stockyards at Cookstown, 24 h prior to slaughter and fasted overnight with access to water. One hundred and ten lambs were delivered to the University of Guelph Meat Laboratory directly from the producer on the day of slaughter. Lambs were stunned using a captive bolt pistol and then exsanguinated. Lambs were then processed based on industry standards for dressing lamb carcasses approved by the Canadian Food Inspection Agency. The testes were removed when ram carcasses were dressed. Warm carcass weights were recorded. Cod fat, kidneys and kidney fat were removed and weighed individually with weights recorded. Cod fat was disposed of, while the kidneys and kidney fat were placed in cotton netting and suspended from the gambrel of the individual carcass to be chilled.

3.3 Use of optical probe

Each carcass was probed by one individual using the Viewtrak PG207 (Destron) optical probe (Viewtrak Technologies Inc., Edmonton, AB). This probes measures fat and lean depths at the specific location where the probe enters the carcass; the machine uses the fat and lean depth measurements to calculate saleable meat yield using a Destron equation previously developed for pig carcasses which is $68.1863 - 0.7833f + 0.0689m + 0.0080f^2 - 0.0002m^2 + 0.0006fm$ with f = subcutaneous fat thickness and m = *longissimus* muscle thickness. This prediction of saleable meat yield was not used in the present study. Carcasses were probed on both the hot and cold (chilled) carcass. Several probing methods were conducted to test the accuracy of the probe with a summary of procedures presented in Table 4.6.1. Sixty-nine carcasses were probed both hot and cold on both the left and right sides of the carcass in the identical manner as previously described with the exception that carcasses were probed between the 12th and 13th ribs, 3.5 cm from the midline on the *M. longissimus thoracis*. Carcasses were probed hot on both the left and right sides of the carcass. Location of probe site was marked with purple grading ink. At 24 h after slaughter, the probe was used on both the left and right sides of chilled carcasses carcass in the same location used for probing the hot carcass. Ninety-eight carcasses were probed between the 11th and 12th ribs, 3.5 cm from the midline through the *M. longissimus thoracis*. The location was changed due to inaccurate probe measurements for *longissimus* muscle depth as part of the tenderloin was caught when carcasses were probed between the 12th and 13th ribs. After these 98 carcasses were processed, the probing procedure was modified due to possible tissue deformation of the chilled carcass from probing the same location multiple times hot and chilled. Another 203 carcasses were probed between the 11th and 12th ribs, 3.5 cm from the midline using a modified protocol. With each carcass, one carcass side was probed hot while the opposite side was probed after the side was chilled for 24 h. The designated side for probing on the hot and chilled carcass sides was alternated between carcasses. The probe location on the hot carcass was marked with purple grading ink prior to placing the side in the cooler to chill. The probe location on the chilled carcass was also marked using purple grading ink. The carcass probing procedure resulted in approximately equal numbers of left and right carcass sides probed on the hot and chilled carcass.

3.4 Carcass measures

After probing of the chilled carcasses was completed, carcasses, kidneys and kidney fat were reweighed and the cold weight was recorded. Carcasses were then split using a bandsaw along the midline with carcass side weight recorded. For the 167 lambs probed on both left and right sides hot and cold, only the left side of the carcass was weighed while the right side was re-hung on the gambrel and placed back into the cooler. The left side was then split into 4 primal cuts (CFIA Meat Cut Manual, 2003) including the whole shoulder, flank, loin and leg. Each primal was weighed with the weights recorded. The whole shoulder was then further divided into square cut shoulder, neck, breast and shank. Each of these cuts was weighed with the weights recorded. The loin was weighed intact with the weight recorded prior to splitting the loin at the probe site location which was marked with purple grading ink. The tenderloin was removed from the loin and weighed separately with the weight recorded. Carcass measurements at the interface of the split loin were taken with a clear plastic ruler. These measurements included loin eye depth and fat depth at 3.5 cm from midline and visible probe site (if different from 3.5 cm from the midline), loin eye width, loin eye maximum depth. In addition, Grading Rule (GR) measurements were taken at 11 cm from the midline, measuring tissue depth; the GR measurements included the rib and a measurement with the rib removed. Loin eye area was traced onto acetate paper and quantified using an electronic planimeter (MOP-3; Carl Zeiss Canada LTD., Toronto, ON.). Carcass primal and subprimal cuts were then dissected into muscle, fat and bone. For each cut, the weights of the muscle, fat and bone components were recorded. Lean weights were summed together and expressed as a percentage of the side weight to determine saleable meat yield. For the 203 carcasses which were probed one side hot, one side cold, the previously described procedures were conducted on both sides of the carcass. Saleable meat yield was calculated as previously described. Carcass fat content was determined by calculating total dissected fat for the carcass side as a percentage of the side carcass weight.

3.5 Statistical analysis

Data in this present study were normally distributed. Normality was determined using Proc Univariate procedure with SAS version 9.3 (SAS, 2012). Outliers for hot carcass weight, electronic probe measures of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 (standard deviations) from the mean; outliers were removed from the data set prior to analysis. Outlier measurements were hypothesized to be due to equipment malfunction and / or operator measurement errors.

Pearson Correlation coefficients were calculated to determine probe measurement accuracy as well as how probe and carcass measurements correlated to saleable meat yield and carcass fat content. Coefficients were determined using the Proc Corr procedure with SAS version 9.3 (SAS, 2012). Multiple regression analysis was used to determine how probe and ruler measures predicted saleable meat yield and carcass fat percentage. This analysis used the Proc Reg procedure with SAS version 9.3 (SAS, 2012). Dependent variables for multiple regression analysis included SMY and carcass fat percentage. Independent variables for models included probe measurements of *longissimus* muscle depth and subcutaneous backfat on both the hot and chilled carcass, ruler measurements of *longissimus* muscle depth and subcutaneous backfat at 3.5 cm from the midline and at probe site, GR and *longissimus* muscle area. For Pearson correlation coefficients and coefficients of determination (R^2), 0 to 0.399 was considered a low/poor correlation, 0.4 to 0.699 was considered a fair/moderate correlation and 0.7 to 1.0 was considered a strong correlation (Moore and McCabe, 2006).

As previously described in Section 4.6.1, the lamb carcasses were divided into three groups based on different processing procedures (Table 4.6.1). Data from Group 1 were analyzed separately from the rest of the study, with determination of Pearson correlation coefficients and multiple regression analysis conducted as previously described. Group 2 lambs included 98 lambs probed between the 11th and 12th ribs. These lambs were probed on both the left and right sides of the carcass along with probe measurements conducted on hot and chilled carcass sides with one side from each lamb dissected into lean, fat, and bone components. Group 3 lambs included 203 lambs in which a designated side was probed hot and the opposite side was probed chilled; both carcass sides from each lamb were dissected into lean, fat, and bone components. Pearson correlation coefficients and multiple regression analysis were performed on combined groups two and three for carcass measurements and hot probe measurements as previously described. The chilled probe measurements from the 98 lamb data set (Group 2) were not included in the analysis because of the potential for error from probing at the same location on hot and chilled carcass. Chilled probe measurements for group three were analyzed separately using Pearson correlation coefficients and multiple regression analysis as previously described.

ANOVA tables were calculated using Proc Mixed procedure of SAS version 9.3 (SAS, 2012) using producer and probe side as random effects in the model with the last 58 lambs removed from the data set. The classification variables, breed type and gender were offered to the model as well as the interaction term, breed type*gender. For these classification variables, lambs were divided as maternal or terminal breed types and ewe or ram lambs. Carcass measurements at 3.5 cm from the midline for subcutaneous backfat and longissimus muscle depths as well as probe measurements on the hot and chilled carcass between 3 and 4 cm from the midline were used as covariates. For the covariate variables, both linear and quadratic terms for each variable were tested for significance as well as the linear and quadratic terms for the interaction term, backfat X longissimus depths. The backwards selection procedure was used to remove non-significant individual terms from the model. Individual terms were retained in the model at a P-value (P) ≤ 0.15 or when the individual terms were a component of higher ordered terms (individual and interaction) with $P \leq 0.15$.

Regression models were determined from the Proc Mixed procedure (as previously described) using carcass and probe measurements from data group two and a modified “group” 3 dataset. The modified group 3 dataset was created by removing data for the last 58 carcasses from the dataset which included 203 lambs that were probed on one side for the hot carcass and the alternate side for the chilled carcass. Prediction equations were developed from the regression models; the prediction equations were tested using the data from the last 58 lambs evaluated in the study based on models with and without classification variables. The Microsoft Excel formula function software was used to plot the prediction values vs. actual SMY data for the various models evaluated.

4.0 RESULTS AND DISCUSSION

4.1 Values for carcass traits

Normality plots using Proc Univariate showed data to be normally distributed. Table 4.6.2 presents the mean $(\overline{X})$ values for various carcass traits used in Pearson correlation and multiple regression analyses. The $\overline{X}$ hot carcass weight across all carcasses was 23.3 kg with carcass weights for rams being similar to carcass weights for ewes (23.4 vs. 23.3 kg respectively). Ram carcasses had numerically less subcutaneous fat than ewe lambs when measured at 3.5 cm from the midline (4.7 vs. 7.5 mm respectively) (in this study, gender differences were not tested statistically and the term, numerically has been included to point out numerical differences). This was also the case for GR measurements where total tissue depths for ram carcasses were less than corresponding value for ewe carcasses (14.7 vs. 18.4 mm respectively). These carcass measures for fatness were associated with dissection data to evaluate carcass fatness, as carcass fat content (% fat yield in the carcass) for ram carcasses was numerically lower than the value for ewes (18.7 vs. 23.5% respectively). *Longissimus* muscle depths were numerically similar between genders. *Longissimus* muscle width and area were numerically larger for ram vs. ewe carcasses which supports numerically greater saleable meat yield (% lean yield in the carcass) values for ram carcasses based on carcass dissection (58.7 vs. 55.4%). This agrees with Jeremiah (2000) who stated that ram lambs were leaner than ewe lambs and that rams had larger loin eye areas which again is similar with gender differences in this trial.

4.2 Pearson correlation coefficients for carcass measures from lambs probed between 11th and 12th ribs

4.2.1 Probe and carcass fat depth measurements– all lambs

Pearson correlation coefficients comparing probe to ruler measures of carcass traits by gender and hot carcass weight class are presented in Table 4.6.3. The probe values used in the correlation analysis include carcass traits (subcutaneous back fat and *longissimus* muscle depths) measured between 3 and 4 cm from the midline. For all lambs, Pearson correlation coefficients for the correlation between ruler and electronic probe measures of backfat ranged from 0.341 to 0.505 ($P < 0.01$) when probing the hot carcass, and 0.171 to 0.476 ($P \leq 0.16$) when probing the cold carcass (in this study, probe measurement differences between hot and chilled carcass sides were not tested statistically and the term, numerically has been included to point out numerical differences). The correlation between ruler and probe measures of backfat across all HCW (all lambs) was numerically greater when probing the hot vs. chilled carcass (0.429 vs. 0.375). These results contradict Garrett et al. (1992) which found stronger correlations using optical grading probes to measure carcass fat depth for wholesale cut yields, with Pearson correlation coefficients of 0.79 when probing the hot carcass vs. 0.83 when probing the chilled carcass. The Pearson correlation coefficients were similar for tray-ready cuts, 0.70 (probing hot carcass) vs. 0.83 (probing chilled carcass) in the Garrett et al. (1992) study. This contrasts to the present study and may be explained by Garrett et al. (1992) using a Hennessey probe between the 12th and 13th ribs compared to the present study which used the Viewtrak PG-207 to probe lamb carcasses between the 11th and 12th ribs. Recent work by Hopkins et al. (2013) concluded using linear regression analysis that the Hennessey probe could not provide a reliable estimate of backfat between the 12th and 13th ribs. This agrees with results from this study even though the present study used the Viewtrak PG-207 probe and probed the carcasses between the 11th and 12th ribs. Since backfat values would be expected to be positively related to hot carcass weight, data were sorted on the basis of hot carcass weight (HCW) to examine how correlations may be affected in specific carcass weight classes. While Pearson correlation coefficient was numerically greater for hot probe measurements on HCW (both genders combined) less than the $\overline{X}$ (r = 0.505; P < 0.01) vs. the r value (0.341) for heavier carcasses, this was contrasted by the Pearson correlation coefficient being numerically greater for cold probe measurements on HCW ≥ to the $\overline{X}$ (r = 0.476; P < 0.01) as compared to the r value (0.171) for lighter carcasses. In fact, there was no significant correlation (r = 0.171; P = 0.16) between cold probe and ruler measures of fat on HCW less than the mean. In conclusion whether on the hot or chilled carcass, the Viewtrak PG-207 probe could not provide a reliable estimate of backfat depth whether probed on hot or chilled carcass, although a numerical increase in accuracy is seen on the hot carcass.

4.2.2 Probe and carcass fat depth measurements–by gender

When the data are sorted by gender, Pearson correlation coefficients were numerically greater for ewe vs. ram lambs across all HCW regardless of the probe being used on a hot or chilled carcass. This could be due to gender differences in mean fat thickness at 3.5 cm from the midline for ram vs. ewe lambs (4.7 vs. 7.5 mm) (Table 4.6.2) which facilitates backfat measurements on ewe carcasses using an electronic probe. This difference in fatness between genders is consistent with a review by Jeremiah (2000) which stated that ewe lambs were fatter than rams at similar slaughter weights. There is a gender discrepancy for the strength of the relationship between ruler and probe measures of backfat and whether a hot or chilled carcass is probed when evaluating all data for a specific gender. For ewe lambs, Pearson correlation coefficients were numerically greater when the probe is used on the chilled carcass across all HCW ($r = 0.503$) vs. the numerically greater Pearson correlation coefficient for male lambs when the probe is used on the hot carcass ($r = 0.317$). When data are examined for specific gender/HCW subclasses, correlations tend to be numerically greater for ewe vs. ram carcasses when heavier carcasses are probed (hot or chilled). In contrast, there is no apparent relationship between HCW and the strength of the relationship between probe and ruler measures of backfat in ram carcasses regardless when the carcass is probed. The Pearson correlation coefficients are non-significant ($P \geq 0.115$) for specific gender/hot carcass weight subclasses which indicate there is no definitive relationship between probe and ruler measures of backfat. The Viewtrak PG-207 is used in many Canadian pork packing plants to measure fat and loin muscle depths for the determination of SMY that is used for producer settlement. A major difference between pork and lamb carcasses is the amount of subcutaneous backfat that is present on the carcass. Thin pork carcasses would have numerically similar backfat depths to the fattest lamb carcass evaluated in the present study. Species differences in backfat could explain why non-significant Pearson correlation coefficients are present for lighter lamb carcasses, as the probe was not originally designed to measure carcasses with lower backfat. However, this does not explain why significant Pearson correlation coefficients are not present for heavyweight ram lambs when the probe is used on the hot carcass ($r = 0.175$; $P = 0.14$). So in conclusion for both ram and ewe lamb carcasses, the Viewtrak PG-207 probe could not provide a reliable estimate of backfat depth, though ewe lambs did see a numerical increase in accuracy between probe and actual backfat depth.

4.2.3 Probe and carcass loin depth measurements–all lambs and by gender

Correlations between electronic probe and ruler measures of loin depth for combined ewe and ram lamb data were moderate, ranging from 0.415 to 0.682 ($P < 0.01$) when probing the hot carcass and 0.408 to 0.507 ($P < 0.01$) when probing the chilled carcass. Similar to backfat measurements, the Pearson correlation coefficient for loin depth measurements is numerically greater probing the hot vs. cold carcass (0.565 vs. 0.507) across all lambs in the data set. This trend is also present when lambs are separated by gender. These findings contrast to previous studies (Garrett et al., 1992; Berg et al., 1997) which state that probing was more accurate on chilled vs. hot carcasses; yet these past studies do not provide specific correlations for probe loin depths compared to ruler measurements. For the whole data set and within each gender, correlation coefficients are numerically greater for lighter lambs ($< \overline{X}$ HCW) than heavier lambs ($\geq \overline{X}$ HCW) for probe vs. ruler loin depth measurements. In general, statistically significant correlation coefficients are numerically greater probing the hot vs. chilled carcass for each gender and gender/HCW subclass. Additionally, the Pearson correlation coefficients are usually numerically greater for ram vs. ewe lambs for most weight classes. The exception is hot probe data for lightweight carcasses where the Pearson correlation coefficient appears to be greater for ewe lambs (0.813 vs. 0.627 respectively for ewe and ram data). Both r values for lightweight/gender lamb subclasses are associated with a moderate to strong correlations between probe and ruler measures of loin depth, indicating that the probe is doing a good job at predicting loin depth on lightweight, hot carcasses. The Pearson correlation coefficients were non-significant ($P \geq 0.14$) for various ewe carcass weight subclasses which indicate no relationship between probe and ruler measures of loin depth The non-significant P-values may be due to small number of ewes lambs in the data set and specific hot carcass weight subclasses or because of high variability in the dataset. Jones et al. (1992) stated that probing was more accurate for ram lambs due to the fact they have greater lean content. Although SMY based on side dissection was numerically greater for ram vs. ewe carcasses in the present study (58.7 vs. 55.4%) (Table 4.6.2), lean depth measurements were numerically similar between genders (28.0 vs. 28.1 mm) (Table 4.6.2).

As previously stated, study to study differences in findings may be related to use of a different probe at a different location on the carcass in previous work by Garrett et al. (1992) and Jones et al. (1992). Hopkins et al. (2013) concluded that the Hennessey probe could not provide a reliable estimate of *longissimus* depth between the 12th and 13th ribs. In the present study, the accuracy of the probe for measuring *longissimus* depth varied depending on gender/weight subclass. Hopkins et al. (2013) did not separate carcasses by weight which could help explain why they did not get reliable estimates for *longissimus* depth. Yet, for the present study, the probe only provided a moderate estimate of the actual *longissimus* depth which would agree with the Hopkins et al. (2013) findings.

Overall, these results indicate that the electronic probe does a moderate job at predicting loin depth. The probe provided numerically greater accuracy on the hot carcass vs. chilled especially when the probe is used on lightweight, hot carcass.

4.2.4 Optical probe measurements and carcass traits by backfat depth- all lambs and by gender

Correlation data were categorized by backfat depths at 3.5 cm from the midline for lamb carcasses (Table 4.6.4). Across specific fatness classes for all lambs across both genders and within specific genders, Pearson correlation coefficients ranged from 0.011 to 0.437 ($P < 0.01$ to $P = 0.96$) on the hot carcass, and -0.088 to 0.503 ($P < 0.01$ to $P = 0.72$) on the chilled carcass. When evaluating all lambs, Pearson correlation coefficients are numerically greater probing the hot vs. chilled carcass when data for both genders are combined and for ram lambs, while the converse is true for ewe lambs. The Pearson correlation coefficients were non-significant ($P \geq 0.112$) for leaner carcasses for both hot and chilled carcass probe measurements, indicating no apparent relationship between probe and ruler measures of backfat. The low numbers of ewe lambs in the data set could be responsible for the non-significant Pearson correlation coefficients for the gender across hot and chilled carcass data for backfat depths. In conclusion the probe still could not provide a reliable estimate of backfat when lamb carcasses were classified into gender/fatness subclasses.

Similar to backfat data, the probe does a low to moderate job of accurately measuring loin depth regardless of fatness levels or gender. The Pearson correlation coefficients ranged from 0.348 to 0.705 ($P \leq 0.01$) for hot carcasses, and 0.167 to 0.541 ($P < 0.01$ to $P = 0.604$) for chilled carcasses when comparing probe to ruler loin depths. When examining the data across all lambs for each gender and when genders are combined, Pearson correlation coefficients are numerically greater probing the hot vs. chilled carcass. In general, Pearson correlation coefficients for leaner lambs ($< \overline{X}$ backfat) are numerically greater than Pearson correlation coefficients for fatter lambs

($\geq \overline{X}$ backfat) regardless if the probe is used on a hot or cold carcass (hot: 0.646 vs. 0.483; cold: 0.541 vs. 0.407). This pattern was also present when the data were classified by hot carcass weight (Table 4.6.3). The Pearson correlation coefficients for lean ram carcasses are numerically greater than Pearson correlation coefficients for ewe carcasses regardless if the probe is used on a hot or cold carcass (hot: 0.705 vs. 0.603; cold: 0.526 vs. 0.396, P = 0.056). While this pattern reverses for Pearson correlation coefficients for fatter ewe vs. ram carcasses when probing the hot carcass (0.524 vs. 0.348), the Pearson correlation coefficient is non-significant (r = 0.167, P = 0.604) when the probe is used on fatter ewe carcasses that have been chilled before the carcass was probed. The Pearson correlation coefficients are numerically similar for ram carcasses regardless of fat depth when probing the cold carcass (0.526 vs. 0.534), indicating that accuracy is not affected by carcass fatness. The Pearson correlation coefficients for thinner carcasses are associated with moderate to strong correlations between probe and actual loin depth measurements (0.603 to 0.705) on the hot carcass, indicating the probe does a reasonable job at predicting loin depth. However, the opposite trend was found for fatter carcasses, as Pearson correlation coefficients are associated with low to moderate correlations (0.348 to 0.524), indicating the probe does a marginal job for predicting loin depth on fatter carcasses across genders. In conclusion probe loin depth measurements sorted by fatness subclass follow a similar pattern to sorting the data by weight subclass, in which there is not consistent relationship between probe loin depth for measuring carcass *longissimus* muscle depth depending on the gender/fatness subclass.

4.2.5 Carcass traits measured with the optical grading probe and prediction of carcass yields- all lambs and by gender

The relationship between electronic probe measures of carcass traits and yields

(SMY, fat yield) determined from carcass dissection are presented in Table 4.6.5. The Pearson correlation coefficients examining the relationship between electronic probe measures of subcutaneous fat to saleable meat yield in the carcass (CarcSMY) ranged from 0 to -0.341 ($P < 0.01$ to $P = 0.997$) on the hot carcass and -0.181 to -0.434 ($P < 0.01$ to $P = 0.396$) on the chilled carcass when examining all data within a specific gender or when all data for both genders are combined. The Pearson correlation coefficient is numerically greater probing the chilled vs. hot carcass when examining all data within a specific gender or when all data for both genders are combined. In contrast, the Pearson correlation coefficient is numerically greater for ewe vs. ram lambs (examining all data within a specific gender) when the probe is used on the hot carcass (-0.341 vs. -0.196), while Pearson correlations are numerically similar between genders when the probe is used on the chilled carcass (-0.372 vs. -0.375). When examining specific backfat subclasses, there is no statistically significant relationship ($P > 0.18$) between probe measures of backfat on the hot carcass and SMY regardless if leaner or fatter lambs are examined with the exception of a Pearson correlation coefficient of -0.276 ($P < 0.01$) for fatter lambs from both genders. There is no relationship ($P \geq 0.17$) between probe fat and CarcSMY when examining specific backfat subclasses for chilled ewe carcasses; this may be due to limited number of ewe lambs in the data set. For all lambs probed on the chilled carcass, the correlation of probe fat to CarcSMY tends to improve with the increase in fatness of the carcass (-0.198, $P < 0.08$ vs. -0.430, $P < 0.01$). The Pearson correlation coefficients examining hot probe backfat values to CarcSMY were all below $|0.35|$ indicating a limited relationship between backfat deposition and CarcSMY. When comparing probe values on the chilled carcass, there was an improvement in prediction on average but correlations were still low for predicting saleable meat yield. The relationships between CarcSMY and actual measures of fat deposition on the carcass are presented in Table 4.6.6. The correlation between ruler fat measurements at 3.5 cm from the midline and saleable meat yield (-0.664) in Table 4.6.6 is numerically greater than Pearson correlation coefficients for the relationship between SMY and probe measurements of carcass backfat in Table 4.6.5 across all genders, weight and fat classes: -0.434 (chilled carcass); -0.326 (hot carcass).

The correlations between probe measurements of backfat to fat content ranged from -0.113 to 0.300 ($P < 0.01$ to $P = 0.902$) on the hot carcass and 0.162 to 0.392 ($P < 0.01$ to $P = 0.403$) on the chilled carcass (Table 4.6.5). Based on hot carcass data, probe measurements of backfat are not able to accurately predict carcass fat content across both genders and across all fat classes with all Pearson correlation coefficients being ≤ 0.300, indicating a low correlation. The accuracy with probe fat measurements improved for predicting carcass fat content when the probe is used on the chilled vs. hot carcass (0.402 vs. 0.300). The Pearson correlation coefficients for ram and ewe carcasses were similar when examining data for all lambs within a gender (across all fat subclasses) (0.338 vs. 0.345 respectively). While there was a stronger correlation between probe fat and CarcSMY vs. carcass fat content, on average probe fat values did not correlate well to either yield measurement. In contrast, there was a much higher correlation between the actual measurement of carcass fat and carcass fat content (0.681; Table 4.6.6) vs. the correlation between carcass fat content and probe fat measures on either the hot or chilled carcass (0.300, 0.402 respectively) (Table 4.6.5). Berg et al. (1997) reported correlations for probe fat measurements at 3 cm from the midline that were numerically greater for total dissected lean, -0.326 (Table 4.6.5) vs. -0.38 (Berg et al., 1997) and -0.434 (Table 4.6.5) vs.-0.51 (Berg et al., 1997) for both probing the carcass hot and chilled. Berg et al. (1997) also performed correlations to fat percentage of the carcass and reported correlations that were also numerically greater than the present study when probing both hot and chilled carcasses, 0.300 (Table 4.6.5) vs. 0.38 (Berg et al, 1997) and 0.402 (Table 4.6.5) vs. 0.48 (Berg et al, 1997).

The relationship (Pearson correlation coefficient) between probe loin depth and CarcSMY ranged from -0.110 to 0.203 ($P < 0.09$ to $P = 0.992$) on the hot carcass and -0.468 to 0.316 ($P < 0.01$ to $P = 0.821$) on the chilled carcass (Table 4.6.5). For the most part, there was no relationship of probe loin depth on the hot carcass to CarcSMY. ($P > 0.09$). The relationship of probe loin depth on the chilled carcass to CarcSMY was generally low or non-significant except for the moderate Pearson correlation coefficient, -0.468 found when evaluating the relationship for all ewe lambs. While there was a moderate inverse relationship between probe loin depth and CarcSMY for thin ewe lambs (-0.418; $P < 0.05$), a low positive Pearson correlation coefficient was present between probe loin depth and CarcSMY for thin ram lambs (0.316; $P < 0.05$).

The relationship (Pearson correlation coefficient) between probe loin depth to carcass fat content ranged from 0.006 to 0.443 ($P = 0.01$ to $P = 0.961$) on the hot carcass and -0.131 to 0.579 ($P <0.01$ to $P = 0.966$) on the chilled carcass (Table 4.6.5). A low correlation (0.187; $P < 0.05$) was present examining the relationship of hot probe loin depth when compared to carcass fat content across the data set for both genders. Correlations for ram data were non-significant ($P \geq 0.318$) for both hot and chilled carcass measures, indicating no significant relationship between probe loin depth and carcass fat content. For ewe data, correlations were stronger with data for thin ewe lambs (0.443; $P < 0.05$) as compared to examining all ewes in the data set (0.335; $P < 0.1$). Overall, the results indicate that probe loin depth measurements on the hot carcass are weakly correlated to carcass fat content. When examining the relationship between carcass fat content and probe loin depth measurements on the chilled carcass, the Pearson correlation coefficients (0.141; $P < 0.1$) for all gender/weight subclasses tend to decrease vs. Pearson correlation coefficients (0.187; $P < 0.05$) obtained with probe loin depth measurements on the hot carcass. The opposite pattern is found when ewe lamb data are analyzed separately. For ewe data, the correlations involving probe loin depth measurements on the chilled carcass are numerically similar between thin and fat carcasses (0.514; $P < 0.01$ vs. 0.515; $P < 0.1$ respectively). Probe loin depth measurements on the chilled carcass appear to be a moderate indicator of carcass fat content for ewe carcasses, but otherwise is a poor indicator of carcass fat content for ram carcasses or when the genders are mixed. In conclusion neither probe measurement provides a reliable estimate of SMY or fat content in lamb carcasses whether taken on the hot or chilled carcass.

4.2.6 Relationship of carcass measurements to carcass yields- all lambs and by gender

The electronic probe was examined with respect to its ability to predict CarcSMY and carcass fat content for carcasses on a moving rail to provide the lamb industry with accurate information that can be used to alter production practices. This will enable producers to provide the lambs that packers and processors desire while at the same time lowering costs of production and increasing carcass returns. The next question to answer was how accurate more labor intensive measurements on the cut carcass are for predicting CarcSMY and carcass fat content. Table 4.6.6 presents the relationships between carcass measurements on the cut carcass and CarcSMY and carcass fat content. Correlations examining the relationship of ruler fat measurements at 3.5 cm from the midline to CarcSMY ranged from -0.563 to -0.667 ($P < 0.01$) (Table 4.6.6). In comparison, the best Pearson correlation coefficient for probe measures to CarcSMY is -0.468 (Table 4.6.5). This would indicate that the ruler fat measurement is a better predictor of SMY than any single probe measurement on either the hot or chilled carcass. The Pearson correlation coefficients were numerically larger for ewe vs. ram carcass data (all data within a gender and for thinner lambs) except for heavier carcasses where Pearson correlation coefficients were similar across gender (-0.584 vs. -0.596 respectively) (Table 4.6.6).

Correlations examining the relationship of ruler fat measurements at 3.5 cm from the midline to carcass fat content ranged from 0.518 to 0.716 ($P < 0.01$) (Table 4.6.6). In comparison, the best Pearson correlation coefficient for probe measurements is 0.579 for ewe lambs (Table 4.6.5). This would indicate with the exception of chilled probe lean depth for ewe lambs, ruler fat measurements at 3.5 cm from the midline is a better predictor of carcass fat content then probe measurements. The Pearson correlation coefficients tended to be numerically greater for heavier vs. thinner carcasses for the whole data set and within gender. Correlations were numerically greater for ewe vs. ram carcasses across all weight classes (0.663 vs. 0.554, respectively) and between specific gender/weight class subclasses (Table 4.6.6). Across both genders, there was a stronger correlation for ruler fat measurements with carcass fat content (0.681) vs. the correlation with CarcSMY (-0.664). This was also the case for ewe lamb data (0.663 vs. -0.627) while the converse was true for ram data (0.554 vs. -0.586).

The ruler measure of *longissimus* muscle depth at 3.5 cm from the midline was a not a predictor ($P \geq 0.245$) of CarcSMY with the exception of carcasses for the heavier weight subclass for all lambs and rams. When genders are combined, the r value (0.180; $P < 0.05$) is numerically similar than the Pearson correlation coefficient (0.225; $P < 0.05$) for ram lambs although the measurement of *longissimus* depth has a low correlation ($r < 0.25$) to CarcSMY. In comparison, the best Pearson correlation coefficient for probe loin depth in relation to CarcSMY is 0.316 (Table 4.6.5). This is numerically an increase in Pearson correlation coefficient but represents a low correlation to CarcSMY. These findings are supported by Jones et al. (1992) and Jeremiah (2000) which state that the addition of a muscle thickness measurement does not significantly add to the prediction of saleable meat yield.

The correlations examining *longissimus* muscle depth (measured at 3.5 cm from the midline) and carcass fat content were non-significant ($P \geq 0.141$) with the exception of ewes from all weight subclasses (0.222; $P < 0.1$). In contrast, the use of probe loin depth on the chilled carcass to estimate carcass fat content for ewes of all fat subclasses resulted in an Pearson correlation coefficient of 0.579 (Table 4.6.5). This would indicate there is potential for probe loin depth on the chilled carcass to be a better predictor of carcass fat content in comparison to ruler measurements of *longissimus* muscle depth.

Canadian inspectors classify lamb carcasses on the basis of SMY by a combination of GR measurement and subjective conformation scores for three anatomical regions including the leg, loin and shoulder (Stanford et al., 1997). Correlations examining the relationship of the GR measurement to CarcSMY ranged from -0.393 to

-0.684 ($P < 0.01$) (Table 4.6.6). The difference in range in Pearson correlation coefficients between ruler measures of fat and GR cannot be explained at the present time**.** The Pearson correlation coefficients examining GR as a predictor tended to be numerically similar regardless of carcass weight class when all data were examined across genders. There was a gender discrepancy where the Pearson correlation coefficient was numerically greater for ewe vs. ram lambs examining all data or when examining lightweight lambs, while the Pearson correlation coefficient was greater for ram vs. ewe lambs for data involving heavy carcasses. GR tended to have low to moderate correlations with CarcSMY with the numerically largest Pearson correlation coefficient found with lightweight ewe lambs. GR was not as strong of a predictor to CarcSMY as ruler fat (-0.571 vs. -0.664) when compared across all gender/weight classes. This seems to contradict Hopkins et al. (2008) which found that GR was the single best predictor of lean percentage in the carcass.

Correlations examining the relationship of the GR measurement to carcass fat content ranged from 0.588 to 0.758 ($P < 0.01$) (Table 4.6.6). GR has been used by the New Zealand Meat Producers Board for setting the lower limit of the grade in which producers are discounted for carcasses being overly fat (Kirton and Johnson, 1979). Similar to CarcSMY data, the Pearson correlation coefficients examining GR as a predictor tended to be numerically similar regardless of carcass weight class when all data was examined across genders. The Pearson correlation coefficient were numerically larger for ewe vs. ram data across all weight classes (0.742 vs. 0.623 respectively) and for specific gender/carcass weight subclasses. For both genders, Pearson correlation coefficients were numerically lower for heavier vs. lighter carcasses.

The Pearson correlation coefficients were numerically larger using GR to predict carcass fat content versus the use of ruler fat measurements (0.737 vs. 0.681 respectively) (Table 4.6.6) across the entire data set. This suggests that GR is strongly correlated to carcass fatness which is supported by Kirton et al. (1984) which found GR to be highly correlated to chemical fat percentage.

Correlations examining the relationship of Loin Muscle Area (LMA) to CarcSMY ranged from 0.180 to 0.319 ($P < 0.01$). There was a numerical increase in Pearson correlation coefficient for heavier carcasses across the whole data set and for specific carcass weight classes for both ewe and ram lambs. The Pearson correlation coefficients were similar between genders when all data were examined and for heavier carcasses. The low correlations of LMA to CarcSMY across all gender/weight classes suggest that the extended effort required to take this measurement on the carcass would not be worthwhile for predicting CarcSMY. Jones et al. (1992) also stated that loin muscle area was a poor predictor of carcass lean content.

4.2.7 Conclusions

Overall, measurements of subcutaneous fat depth over the *longissimus* muscle, 3.5 cm from the midline had the strongest correlation to CarcSMY than any other single carcass measure in this study. GR had the strongest correlation to carcass fat content compared to other measures having a moderate to strong correlation to carcass fat content. *Longissimus* muscle depth and area were both poor predictors of saleable meat yield and carcass fat content in lamb carcasses. Carcass measures of fatness were better predictors of both saleable meat yield and carcass fat content when compared to using probe measures of backfat. In contrast, probe measures of *longissimus* muscle depth were better predictors of saleable meat yield and carcass fat content compared to using carcass measures but both had poor correlations to saleable meat yield. Probe *longissimus* muscle depth taken on the chilled carcass showed a moderate ability to predict fat content for ewe lambs for all fat subclasses whereas the equivalent carcass measures for ewes had a poor ability to predict fat content.

4.3 Multiple regression analysis for carcass characteristics of lambs probed between the 11th and 12 ribs

4.3.1 Saleable meat yield as predicted by probe measurements on hot or chilled carcass- all lambs and by gender

Table 4.6.7 presents results from multiple regression analysis evaluating carcass and probe measures to predict saleable meat yield. Data were analyzed by gender and weight class with hot carcass weight included in all models. The coefficient of determination (R^2) for models examining probe measurements on the hot carcass ranged from 0.014 to 0.284 ($P < 0.05$ to $P = 0.860$). R^2 values for models examining probe measurements on the chilled carcass ranged from 0.120 to 0.316 ($P <0.05$ to $P = 0.501$). Carcass weight class appears to affect the accuracy of the probe at predicting SMY. Lighter carcasses had numerically lower R^2 values than heavier carcasses when either hot or chilled probe measurements were used to evaluate all lambs (all lambs). Ewes generally had numerically greater R^2 values than rams for both hot and chilled probe measurements when evaluating each gender across all HCW and for specific gender/HCW subclasses. Multiple regression analysis was not significant ($P \geq 0.418$) when evaluating use of hot probe measurements on lightweight carcasses for either gender. The R^2 for evaluating heavier ewe lambs tended to be numerically greater than the R^2 for lightweight lambs when the carcasses were probed hot; this was not the case when the chilled carcass was probed. Regardless of when the carcass was evaluated hot or chilled, Viewtrak probe measurements were poor at explaining the variation in saleable meat yield in lamb carcasses. These findings contradict earlier work by Jones et al. (1992) which reported R^2 values of 0.54 for rams and 0.53 for ewes when the Hennessey probe was used between the 12th and 13th ribs on the hot carcass to predict lean content. These authors also evaluated the probe at the same location with chilled carcasses and reported R^2 values of 0.58 for rams and 0.56 for ewes. Another study by Berg et al. (1997) found the probes to be marginal predictors for determining the amounts of total dissected lean on the carcass with R^2 values of 0.334 and 0.453 respectively when a Hennessey probe was used on hot and chilled carcasses. The improvement in R^2 when evaluating the probe on chilled vs. hot carcasses is similar to the present study. The low predictive ability of probe measurements for explaining the variation in SMY in the present study is supported by the conclusions of Siddell et al. (2012) and Hopkins (2013). While these past studies did not determine R^2 values, both authors conclude that the Hennessey optical probes do not do a good job for predicting saleable meat yield. In conclusion, regression analysis using probe measurements did a poor job at predicting saleable meat yield.

4.3.2 Saleable meat yield predicted by carcass measurements equivalent to probe measurements- all lambs and by gender

While the intent in carcass probing was to probe the carcass at approximately 3.5 cm from the midline, at times, the actual probe site varied from 3.5 cm from the midline. This was taken into account with multiple regression analysis to develop models using actual ruler carcass measures at the site where the electronic probe was used, along with models based on actual ruler carcass measures at 3.5 cm from the midline (Table 4.6.7).

Ruler measures on the carcass at the exact site of probing had numerically larger R^2 values across all HCW and for all gender/weight subclasses than either hot or chilled probe models. Similar to probe models, the R^2 values based on ruler measures were numerically larger for ewe vs. ram lambs. Ruler measures at exactly 3.5 cm from the midline provided a numerical increase in R^2 across all gender/weight subclasses compared to measurements taken at the actual probe site. This is important as it may be difficult to probe carcasses online at an exact location with carcasses moving on a rail. Similar to multiple regression data evaluating probe measurements, the R^2 values tend to increase for models based on heavier vs. lighter carcasses for each gender and when genders were combined. The results for probe and equivalent ruler measures in the present study contradict Garrett et al. (1992) who found no differences in the amount of variation explained by probe or carcass measures for explaining the yields in wholesale cuts. The present findings also contradict Jones et al. (1992) who found that prediction of lean content was generally more precise with rams than ewes. Although carcass measures taken with a ruler explained more variation than probe measurements in the present study, ruler measures only explained 25 to 48.1% of the variation in saleable meat yield. Multiple regression analysis by Hopkins et al. (2008) found that a model containing hot carcass weight and carcass measures of backfat and *longissimus* depth at the 12th rib only explained 49.2% of the variation in carcass lean content percentage. The Hopkins et al. (2008) study did not separate their data by gender or weight subclasses as found in the present study, but their R^2 value is numerically similar to the 45.6% variation (Table 4.6.7) explained by carcass measures model at 3.5 cm from the midline for all gender/weight subclasses. Therefore, since probe measurements were limited in accuracy for measuring the equivalent carcass measures (Table 4.6.3), the limited amount of variation explained with electronic probe models is expected if use of actual carcass measures only explains a marginal amount of the variation in saleable meat yield.

4.3.3 Saleable meat yield predicted by probe and carcass measures for dataset classified by carcass fatness- all lambs and by gender

A similar multiple regression analysis was conducted using the lamb carcass data sorted by backfat (Table 4.6.8). For regression models using probe measurements, R^2 values ranged from 0.014 to 0.231 ($P < 0.05$ to $P = 0.812$) for models examining probe measurements on the hot carcass. Models examining probe measurements on the chilled carcass ranged from 0.076 to 0.316 ($P < 0.05$ to $P = 0.556$). Similar to multiple regression analysis of the dataset sorted by hot carcass weight, R^2 values were numerically greater for ewe vs. ram carcasses regardless if the probe was used on a hot or chilled carcass. For the most part, probe measures were limited for explaining the variation in SMY based on low R^2 values which were often non-significant ($P \geq 0.146$), indicating that respective models do not accurately explain the variation in SMY found in the dataset. Similar to multiple regression analysis of the dataset sorted by hot carcass weight, models using probe measurements of backfat and *longissimus* muscle depth had limited ability to explain the variation in SMY.

Multiple regression analysis was also conducted using equivalent carcass measures for lamb carcass data sorted by backfat (Table 4.6.8). R^2 values ranged from 0.156 to 0.414 ($P < 0.05$ to $P = 0.112$) based on data collected at the exact site of probing which explained more variation then any model examining hot probe values for all lambs or specific gender/backfat subclasses. Use of carcass measurements provided a numerical improvement in R^2 versus models based on probe measurements for chilled carcasses with the exception of numerically similar R^2 values for the fatter subclass of lambs from both genders. The R^2 values for models for carcass measures of backfat and *longissimus* muscle depth at exactly 3.5 cm from the midline ranged from 0.152 to 0.456 ($P < 0.01$). These models accounted for explaining more of the variation in SMY than models based on the probe or carcass measures at the exact probe sites with the exception of rams from the fatter subclass. As carcass fatness increased, the models explained less of the variation in SMY for ram lambs but not with ewe lambs, regardless if carcass backfat and *longissimus* muscle depths were measured with a ruler at either the probe site or exactly 3.5 cm from the midline. While models based on carcass measures at either the probe site or 3.5 cm from the midline explain more of the variation in SMY than models based on probe data, the best model only explains 45.6% of the variation in SMY. This indicates that use of actual carcass measurements only do a fair job for explaining total variation in SMY.

4.3.4 Fat content of carcass as predicted by probe and carcass measures - all lambs and by gender

Multiple regression analysis was also performed to examine how well probe and carcass measures explained the variation in fat content of the carcass (Table 4.6.9) using data sorted by fatness subclass. Models examining probe measurements taken on the hot carcass ranged 0.106 to 0.412 ($P < 0.10$). Whereas models examining chilled probe measurements ranged from 0.115 to 0.408 ($P < 0.05$ to $P = 0.404$). Ewes had numerically greater R^2 values for models examining probe measurements on either hot or chilled carcasses compared to ram lambs for all fat subclasses and when examining the whole dataset. For data where genders are mixed, sorting the data by fatness subclass for both hot and chilled probe measurements resulted in similar r values between leaner and fatter carcass subclasses. The R^2 values were numerically similar for ram lambs for probe models across the fatness subclasses. This was not the case with ewe lambs models as the R^2 tended to increase as ewe lambs became fatter when the hot carcass was probed while the converse was true when the chilled carcass was probed. A limited number of ewe lambs for the trial may be responsible for the non-significant ($P = 0.404$) R^2 when the probe was used on chilled carcasses from fatter ewes. The R^2 values were numerically larger for probe models for explaining the variation in carcass fat content vs. saleable meat yield (Tables 4.6.8, 4.6.9). Probe measures only explain at most 40.8% of total variation in carcass fat content whereas equivalent carcass measures explain a maximum of 58.8% of total variation. Use of probe measures on either the hot or chilled carcass can only account for marginal variation in fat content for lamb carcasses. Berg et al. (1997) found that R^2 increased marginally when the Hennessey probe was used on a chilled rather than hot carcass (0.417 vs. 0.393 respectively) but in either case, probe measurements could not extensively explain the variation in carcass fat content.

Equivalent carcass measures at the probe site were also regressed with HCW to account for the variation in carcass fat content for lamb carcasses (Table 4.6.9). The R^2 values ranged from 0.226 to 0.545 ($P < 0.05$) using ruler measures at the exact site where the carcass was probed. Models examining carcass measures at exactly 3.5 cm from the midline ranged from 0.204 to 0.588 ($P < 0.05$). Similar to probe models, R^2 values were numerically greater for ewe vs. ram carcasses across all fat subclasses. Fatter carcasses had numerically lower R^2 values then leaner carcasses across both genders. Carcass measures models explained more variation then probe models on either hot or chilled carcass whether carcass measures were taken at exact probe site or 3.5 cm from the midline. Equivalent measures taken at exactly 3.5 cm from the midline provided numerically similar R^2 values across all gender/fat subclasses compared to carcass measures at the exact probe site. Carcass measures for ewe lambs provided a moderate explanation of the total variation in carcass fat content with the exception of fatter lambs where the R^2 value decreased. The use of carcass measures for ram lambs was not able to explain much of the variation in carcass fat content with R^2 values < 0.4. Carcass measures were able to explain more of the variation in carcass fat content as compared to saleable meat yield (Tables 4.6.8, 4.6.9). Hopkins et al. (2008) found that a model containing hot carcass weight, and carcass measures of backfat and *longissimus* depth at the 12th rib explained 52.2% of the variation in fat content percentage of the carcass. As stated above, their data were not separated by gender/fat subclasses but is numerically similar to our results for carcass measures of all gender/fat subclass at 3.5 cm from the midline where 49.5% of the variation in carcass fat content was explained. Actual carcass measures provided an increased ability to explain variation in carcass fat content compared to models containing either hot or chilled probe measurements. These results are expected due to previous results (Tables 4.6.5, 4.6.6) which indicated carcass backfat depth at 3.5 cm from the midline had a higher correlation to carcass fat content then probe measures. However, actual carcass measures are still only explaining a moderate amount of the variation in carcass fat content.

4.3.5 Saleable meat yield as predicted by various carcass measurements- all lambs and by gender

Table 4.6.10 examines how well models including more labour intensive carcass measures perform in explaining the variation in SMY. The R^2 values ranged from 0.343 to 0.502 ($P < 0.05$) for a model containing ruler measures of carcass backfat and *longissimus* depth along with *longissimus* width (loin width). Numerically larger R^2 values were found for ewe vs. ram carcasses across all weight subclasses. Lighter carcasses had a numerically lower R^2 values than heavier carcasses for both genders. The R^2 values for all models containing *longissimus* width were numerically greater than models based on probe measures models but this is to be expected as the R^2 values for all models based on carcass backfat and *longissimus* depth at 3.5 cm from the midline were numerically greater than R^2 values based on probe models. For within gender comparisons, the addition of *longissimus* width into the model provided numerically similar R^2 values for lambs of both genders across all weight subclasses. For ewe lambs, the addition of *longissimus* width only provided a small numerical increase in explaining the variation in SMY as compared to models based on HCW, backfat, and *longissimus* muscle depth (Table 4.6.7). In contrast, models with inclusion of *longissimus* width for ram data resulted in a numerical decrease in R^2 for heavier carcasses and an increase in R^2 for lighter carcasses as compared to models excluding *longissimus* width (Table 4.6.7). Based on the minimal benefit of including *longissimus* width into the model, it would not be worthwhile to include this measurement in models predicting saleable meat yield.

Grading Rule or GR has been considered the best single predictor of carcass lean percentage in past studies (Jones et al., 1996; Hopkins et al., 2008). GR can be quickly measured manually on the carcass with a device called a GR ruler and is used as part of carcass grading in Canada along with a visual conformation score assessing conformation scores on the leg, loin and shoulder. The R^2 values for models containing just HCW and GR ranged from 0.167 to 0.469 ($P < 0.05$). When the data for both genders were combined, R^2 values were numerically similar across the weight subclasses. When data for each gender was analyzed on its own, a gender discrepancy was present with ewes having a numerically larger R^2 values for lighter carcasses compared to heavier carcasses whereas rams had larger R^2 values heavier carcasses compared to lighter carcasses. The R^2 values were numerically larger for ewe vs. ram data with the exception of the heavier weight subclass. The best probe model R^2 value was 0.316 for evaluating SMY which is within the range in R^2 values for models based on GR. Use of GR only appears to provide a small increase in the amount of variation in SMY that is accounted for as compared to models based on probe measures. Models containing carcass measures of backfat and *longissimus* depth at 3.5 cm from the midline (Table 4.6.7) provided numerically larger R^2 values than models containing GR and HCW with the exception of the R^2 value for lightweight ewes. The best R^2 value for models containing backfat and *longissimus* depth measurements was 0.481 for evaluating SMY which is numerically greater than the best GR model (0.469). These results contradict Jones et al. (1996) and Hopkins et al. (2008) which found GR to be the best single predictor of SMY. Models containing GR and HCW do not provide an increase in the amount of variation in SMY explained compared to models based on carcass measures of backfat and *longissimus* depth.

Table 4.6.6 examined correlations between carcass backfat, GR and *longissimus* muscle area (LMA) to saleable meat yield. These three measurements were then put into a single model using multiple regression to explain the variation in SMY (Table 4.6.10). The R^2 values ranged from 0.392 to 0.682 ($P < 0.05$). R^2 values tended to increase for lambs of both genders and ram lambs as HCW increased; in contrast, the R^2 value decreased for the heavier weight subclass with ewe lambs. The R^2 values tended to be numerically greater for ewe vs. ram carcasses when all data within a gender was combined or for comparing lightweight carcasses. The R^2 values tended to be similar between genders for heavier carcasses. This model explained the most variation in SMY as compared to all other models containing either probe or carcass measures. This seems to coincide with Hopkins et al. (1998) and Safari et al. (2001) which concluded that the addition of LMA added significantly to the prediction of saleable meat yield, although this would increase labour inputs at the packing plant. Jones et al. (1992) stated that LMA alone is a poor predictor of lean content which coincides with our correlation of LMA to SMY (Table 4.6.6). Yet, these results seem to indicate that in addition to a fat measurement, LMA does increase the ability of regression models to explain the variation in SMY. Although this model had the greatest R^2 value of 0.682 of all models examined, this model does not provide enough advantage for practical application at this time.

4.4 Pearson correlations and multiple regression analysis for lambs probed between the 12th and 13th ribs- ram lambs only

Table 4.6.11 presents Pearson correlation coefficients for carcasses probed between the 12th and 13th ribs. This data set consisted of 68 ram lambs and 1 ewe lamb. The ewe lamb data was removed from the analysis due to insufficient number of ewe lambs available in the dataset. The relationships (r values) between probe backfat depth to carcass backfat ranged from -0.333 to 0.307 (P = 0.069 to P = 0.290) for hot carcass data and 0.158 to 0.297 (P = 0.085 to P = 0.623) for chilled carcass data. Probe measurements of backfat did not accurately estimate actual carcass back fat on hot and chilled carcasses. This evaluation is limited to rams only due to the lack of ewe and wether data. In the present study, the probe was not accurate for predicting backfat depth between the 12th and 13th ribs.

The relationships (r values) between probe *longissimus* depth measurements to carcass *longissimus* depths ranged from 0.437 to 0.701 ($P < 0.01$ to $P = 0.03$) for the hot carcass and 0.561 to 0.778 ($P < 0.01$) for chilled carcass data. There was a numerical increase in r value for probe measurements on the chilled vs. hot carcass for all lambs in the data set and for specific carcass weight subclasses. When the data were sorted by carcass weight subclass, r values were numerically lower for lightweight vs. heavyweight carcasses. While use of probe *longissimus* depth measurements provided a strong estimation of the actual carcass muscle depth for heavier carcasses, the measure only provided a moderate ability to predict carcass *longissimus* depth for lightweight carcasses. Use of probe measurements of *longissimus* depth between the 12th and 13th ribs resulted in numerically greater r values than ram data for carcasses probed between the 11th and 12th ribs (Table 4.6.3).

Probe measurements between the 12th and 13th ribs were limited for explaining the variation in saleable meat yield in lamb carcasses based on multiple regression analysis (Table 4.6.12) as all models were non- significant ($P \geq 0.106$). However, this was also the case with multiple regression analysis using actual carcass measures for explaining the variation in saleable meat yield with model P values > 0.34.

4.5 Analysis of Variance (ANOVA) results for prediction equations for SMY based on probe and carcass measures

4.5.1 Prediction equations for SMY based on probe and carcass measures without animal factors

Figures 1 and 2 represent prediction equations for determining SMY based on ANOVA of significant probe measurements on 58 carcasses (40 rams and 18 ewes) from the last 4 kills of the study. ANOVA was used to evaluate how SMY was predicted by linear and quadratic terms for probe measurements (backfat and *longissimus* muscle depths) and there interactions. Based on ANOVA, probe measurements of backfat depth were the only factors affecting ($P < 0.01$) prediction of SMY for both hot and chilled carcass data. For carcass measurements of subcutaneous backfat and *longissimus* depths measured at 3.5 cm from the midline, only the subcutaneous backfat measurement was significant ($P < 0.01$).

Figure 4.7.1 tests the equation, SMY = 60.99586 – 0.46084*Hot probe backfat depth ($P < 0.01$). The R^2 value for this equation was 0.28, indicating that hot probe backfat measures are of limited value in predicting SMY. This agrees with previous multiple regression analyses (Tables 4.6.7, 4.6.8) which found models based on probe measurements taken on the hot carcass to be poor predictors of SMY.

Figure 4.7.2 examined the equation, SMY = 61.67153 – 0.40022*Chilled probe backfat depth. The R^2 value for this equation was 0.49, indicating a moderate predictive ability of probe backfat measurements on the chilled carcass to estimate SMY. This improvement of R^2 on chilled compared to hot carcasses agrees with findings by Garrett et al. (1992) and Jones et al. (1992) who reported that predictions of SMY improved when the probes were used on chilled vs. hot carcasses. These results contradict the multiple regression analyses (Tables 4.6.7, 4.6.8) performed on all carcasses which found that the probe was unable to accurately predict *longissimus* and backfat depths on chilled carcasses. The dataset for all carcasses include 98 lambs where the identical side was used for hot and chilled probe measurements on the hot and chilled carcass side. This may bias the data due to probing the chilled carcass at the identical location to where the hot carcass was probed. However elimination of the 98 lambs from the data set resulted in R^2 values of 0.258 ($P < 0.05$) and 0.175 ($P < 0.05$) respectively for hot and chilled probe models (data not presented) which are dissimilar to corresponding R^2 values for the 58 lamb dataset. This is just another indication that the probe cannot be used consistently predict SMY.

These results for the 58 lamb data set are not in agreement with Siddell et al. (2012). These authors found that Hennessey probe measurements of backfat and *longissimus* muscle depth were non-significant predictors of SMY whereas probe backfat depth (measurements on the hot or chilled carcass) for the present study was a significant ($P < 0.01$) predictor of SMY. In conclusion, the chilled probe backfat measurement is a poor predictor of SMY.

Figure 4.7.3 shows the SMY predicted by the equation SMY = 61.9894 – 0.72575*carcass backfat when measured at 3.5 cm from the midline. This equation, has a moderate R^2 of 0.49 ($P < 0.01$) which has a similar moderate strength to the prediction equation based on chilled probe backfat (Figure 4.7.2). These findings don’t agree with the multiple regression results presented in Tables 4.6.7 and 4.6.8 which found that models using carcass measures explained more variation in SMY then models using probe measurements. However, these results agree with Garrett et al. (1992) who found no difference between predictions made by the Hennessey probe fat depth values and the equivalent ruler measurement of carcass fat depth values. Siddell et al. (2012) found that carcass measures equivalent to Hennessey probe measurements were not significant ($P > 0.05$) for prediction of meat yield when primal weights or other carcass predictors such as GR were included in the model. However, the authors never mentioned whether equivalent carcass measures of backfat and *longissimus* depths alone are significant. This seems to indicate that when more detailed carcass cut-out data are available (i.e. primal weights), probe and equivalent carcass measures are not accurate for predicting SMY. While the present study found both chilled probe backfat and carcass backfat models significant ($P < 0.01$) in prediction equations for SMY, the models were poor predictors of SMY.

Figure 4.7.4 presents the prediction equation SMY = 65.89876 – 0.51240 * GR ($P < 0.01$); $R^2 = 0.39$, where GR represents a single carcass measure. Equations based on carcass backfat and probe fat on the chilled carcass ($R^2 = 0.49$, 0.49 respectively; Figures 4.7.2 and 4.7.3) were slightly better for predicting SMY. These results are not in agreement with Jones et al. (1996) where a regression equation based on a single measurement of GR had an R^2 value of 0.55. Hopkins et al. (2008) also reported a numerically greater R^2 value (0.481) for a prediction model using only GR vs. the present study. Carcass backfat had a stronger correlation to SMY then GR (Table 4.6.6) which would explain why carcass backfat models explained more variation than GR. Yet, probe backfat measurements on the chilled carcass had a lower correlation to SMY than GR but the regression equation based on chilled fat explained more of the variation in SMY. Siddell et al. (2012) found equations based on GR and forequarter weight to be superior to prediction equations based on Hennessey probe or equivalent carcass measures. A prediction equation based on GR may need to include a primal weight to improve the prediction of SMY. In conclusion, no prediction equation adequately predicted SMY - whether using data obtained by optical probe or by carcass measurement.

4.5.2 ANOVA results for prediction equations for SMY based on probe and carcass measures with animal factors included

Safari et al. (2001) stated that in a diverse population, use of a prediction equation based on one group of lambs is not suitable due to factors such as sex and breed. Therefore, prediction equations were determined taking into account breed type and gender. Figures 4.7.5 to 4.7.8 present the results from prediction equations based on inclusion of breed type and gender with Table 4.6.13 showing the prediction equations used in the models.

Figure 4.7.5 presents a prediction equation based on breed type and gender along with the covariate, probe backfat measured on the hot carcass. The R^2 for this equation was 0.40. This equation explains more of the variation in SMY than an equation where breed type and gender are not accounted for (Figure 4.7.1; $R^2 = 0.28$) such as the case of collecting data at a packing plant. Yet, this model still explains less variation than models based on carcass subcutaneous backfat (Figure 4.7.2; $R^2 =0.49$) or probe backfat measured on the chilled carcass (Figure 4.7.3; $R^2 = 0.49$) which also do not incorporate breed type and gender in the analysis. Models based on probe backfat measured on the hot carcass did a poor job of predicting saleable meat yield regardless if breed type and gender are factored into the models.

Figure 4.7.6 presents the prediction equation based on probe backfat measured on the chilled carcass with breed type and sex factored into the model. The R^2 value for the model is 0.65 which is numerically greater than the model based only on carcass subcutaneous backfat (Figure 4.7.2; $R^2 =0.49$). Again as mentioned previously, these models contradict earlier regression analysis (Tables 4.6.7, 4.6.8) which found probe measurements taken on the chilled carcass to poorly explain the variation in SMY. Safari et al. (2001) found genotype to significantly affect different measurements of fatness including subcutaneous backfat depth and GR. This model is an improvement for explaining the variation in SMY but the practicality of separating lambs by gender and breed type at a slaughter plant and using multiple prediction equations does not seem realistic.

Figure 4.7.7 evaluates a model based on carcass subcutaneous back fat with genotype and gender offered into the model. The model has a R^2 value of 0.58 which is an improvement compared to the model which does not include breed type and gender. This improvement in R^2 is similar to that of probe models which also found an improvement in variation explained when models factored in breed type and gender. In comparison, the previous model with probe backfat depth measured on the chilled carcass had a slightly numerically larger R^2 value (0.65; Figure 4.7.6). These models are not in agreement with previous multiple regression analysis (Tables 4.7.6, 4.7.7) where probe models based on the chilled carcass did not explain as much of the variation in SMY as models including carcass measures at 3.5 cm from the midline. The last 58 carcasses evaluated in this trial were part of the study in which carcasses were probed on alternating sides, hot and chilled. The hot probe measurements models agree with previous multiple regression analysis (Table 4.6.7, 8) in which hot probe measures are limited for accounting for extensive variation in SMY for lamb carcasses. Whereas, chilled probe measures show improved ability for determining SMY based on previous multiple regression analysis (Table 4.6.7, 8). Carcass models containing subcutaneous backfat showed an advantage compared to chilled probe models in previous multiple regression models (Tables 4.6.7, 4.6.8) yet in this analysis they have similar or a greater ability to predict SMY depending on whether external factors were included or not. Carcass measures models were evaluated from measurements taken from the side of the carcass in which the carcass was probed hot. This difference in the specific carcass side probed could potentially lead to the differences in R^2 found between models. For this model, the labour involved to sort animals by breed type and gender along with developing multiple equations would not likely be worth the added effort for the limited improvement in variation for SMY explained.

Figure 4.7.8 presents a model which evaluates the contribution of GR and breed type for explaining the variation in SMY. Gender was initially examined in the model but was non-significant ($P > 0.15$) and then subsequently dropped from the model. The R^2 for the model including GR and breed type was 0.46 and only provides a small numerical improvement to the previous GR model without breed type included ($R^2 = 0.39$; Figure 4.7.4). This model does not provide an improvement to models containing either carcass backfat depth or probe backfat depth measured on the chilled carcass. Again, contrary to previous work by Jones et al. (1996) and Hopkins et al. (2008), GR is not the single best predictor of SMY. GR models do not provide a reliable estimate of SMY even when breed type is accounted for.

Overall, the results based on the prediction equations agree with Safari et al. (2001) which stated that use of a prediction equation based on one group of lambs is not suitable due to factors such as sex and breed. The incorporation of breed type and gender information with probe models dramatically increased R^2 values. The R^2 values increased from 0.28 to 0.40 when this added information was used with probe backfat on the hot carcass. In contrast, the R^2 increased from 0.49 to 0.65 when this added information was used with probe backfat measures on the cold carcass. Although R^2 values numerically increase when the added information from breed type and (or) gender are added to model(s), the minimal improvement in accounting for the variation in SMY may not be large enough to justify the extra labour that is required to implement a system of multiple prediction equations and to ensure that carcass settlement based on probe predictions of SMY are equitable to the packer and producer.

The amount of variation in SMY explained by a model based on probe backfat measurements on the chilled carcass is similar to the amount of variation in SMY explained by a model based on actual carcass backfat. Models based on GR measurements do not appear to be a reliable alternative to models based on carcass backfat or probe measures of backfat on chilled carcasses.

Models which incorporate measures of *longissimus* depth to predict SMY were not significant ($P > 0.15$) whether measured with a ruler or by electronic probe. The following models were significant ($P < 0.01$) but are only poor to moderate at explaining variation in SMY: GR measures, probe measurements of backfat on hot carcass, probe or ruler measures of backfat on the chilled carcasses. When models took into account animal factors such as breed type and gender, all models showed improvement in the amount of variation in SMY explained. Although models showed improvement, the extra labour involved in using multiple prediction equations and separating lambs at the slaughter plant does not make any of these models practical. Based on our findings of a low to moderate ability of probe measures to predict SMY, the use of the optical probe for determining SMY payout to producers cannot be recommended.

4.6 Tables

Table 4.6.1 Summary of probing procedures.

Number of Lamb Carcasses (Group #)	**Probing Location**	**Probing Procedure**
69 (Group 1)	Between 12th and 13th ribs, 3.5 cm from the midline	Probed hot and chilled carcass on left and right sides.
98 (Group 2)	Between the 11th and 12th ribs, 3.5 cm from the midline	Probed hot and chilled carcass on left and right sides.
203 (Group 3)	Between the 11th and 12th ribs, 3.5 cm from the midline	Both hot and chilled carcass sides were probed, only one carcass side was probed hot while the opposite side was probed after the side was chilled for 24 h.

Table 4.6.2. Values for lamb carcass traits[z]

Trait		Gender		
		All Lambs (n = 272)	**Rams (n = 205)**	**Ewes (n = 67)**
Hot carcass weight (kg)	**Mean**	23.3	23.4	23.3
	Min	19	19	19.1
	Max	28	28	28
	SD	1.9	1.9	2.1
Subcutaneous Fat Depth (mm)[y]	**Mean**	5.4	4.7	7.5
	Min	1	1	2
	Max	14	14	14
	SD	2.8	2.4	2.6
Longissimus Muscle Depth (mm)[y]	**Mean**	28	28	28.1
	Min	20	20	20
	Max	36	36	36
	SD	3.0	3.0	2.9
Longissimus Muscle Width (mm)[y]	**Mean**	60.2	60.7	58.6
	Min	47	47	50
	Max	70	70	70
	SD	4.2	4.1	4.2

Table 4.6.2. (continued)

Trait		Gender		
		All Lambs	**Rams (n = 205)**	**Ewes (n = 67)**
GR[x] (mm)	**Mean**	15.6	14.7	18.4 (n = 66)
	Min	7	7	7
	Max	28	23	28
	SD	3.7	3.1	4.1
Loin Muscle Area (mm^2)	**Mean**	1398.4	1406.8	1371.9 (n = 65)
	Min	937.9	937.9	1025.5
	Max	1995.6	1995.6	1881.2
	SD	199.1	202	188.5
Saleable Meat Yield (CarcSMY %)[w]	**Mean**	58	58.7	55.4
	Min	50.9	51.6	50.9
	Max	64.6	64.6	63.3
	SD	3.1	2.9	2.8
Carcass fat content[v] (%)	**Mean**	19.9	18.7	23.5
	Min	8.9	11.5	8.9
	Max	29.1	26.2	29.1
	SD	3.7	2.9	3.6

[z] Outliers for hot carcass weight, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from data sets.

[y] Ruler measurements at the interface between the 11th and 12th ribs, 3.5 cm from the midline.

[x] GR measurement of total tissue depth 11 cm from the midline on the 12th rib.

[w] CarcSMY = saleable meat yield determined via dissection of carcass into lean, fat, and bone components.

[v] Carcass fat content = Fat percentage determined via dissection of carcass into lean, fat, and bone components.

Table 4.6.3. Pearson correlation coefficients determining accuracy of probe measures versus ruler measures for lamb carcass traits with data sets classified by mean ($\overline{X}$) hot carcass weight (HCW, kg)[z]

Specific Carcass Measures at Probe Site[y]	Weight Subclasses	Pearson Correlations (for specific gender classes) for carcass measures between 3 and 4 cm from midline[x]		
		Lambs from Both Genders	Ram Lambs	Ewe Lambs
Ruler Fat at Probe Site to Hot Probe Fat	Across all HCW	0.429 (P < 0.01; n = 181)	0.317 (P < 0.01; n = 131)	0.437 (P < 0.01; n = 50)
	Values < $\overline{X}$ HCW	0.505 (P < 0.01; n = 84)	0.417 (P < 0.01; n = 57)	0.310 (P = 0.115; n = 27)
	Values ≥ $\overline{X}$ HCW	0.341 (P < 0.01; n = 97)	0.175 (P = 0.136; n = 74)	0.645 (P < 0.01; n = 23)
Ruler Fat at Probe Site to Cold Probe Fat	Across all HCW	0.375 (P < 0.01; n = 152)	0.257 (P < 0.01; n = 116)	0.503 (P < 0.01; n = 36)
	Values < $\overline{X}$ HCW	0.171 (P = 0.160; n=71)	0.099 (P = 0.469; n = 56)	0.338 (P = 0.218; n = 15)
	Values ≥ $\overline{X}$ HCW	0.476 (P < 0.01; n = 81)	0.342 (P < 0.01; n = 60)	0.508 (P = 0.019; n = 21)
Ruler Loin Depth at Probe Site to Hot Probe Loin Depth	Across all HCW	0.565 (P < 0.01; n = 181)	0.566 (P < 0.01; n = 131)	0.558 (P < 0.01; n = 50)
	Values < $\overline{X}$ HCW	0.682 (P < 0.01; n = 84)	0.627 (P < 0.01; n = 57)	0.813 (P < 0.01; n = 27)
	Values ≥ $\overline{X}$ HCW	0.415 (P < 0.01; n = 97)	0.486 (P < 0.01; n = 74)	0.046 (P = 0.834; n = 23)
Ruler Loin Depth at Probe Site to Cold Probe Loin Depth	Across all HCW	0.507 (P < 0.01; n = 152)	0.534 (P < 0.01; n = 116)	0.396 (P = 0.017; n = 36)
	Values < $\overline{X}$ HCW	0.496 (P < 0.01; n = 71)	0.547 (P < 0.01; n = 56)	0.394 (P = 0.146; n = 15)
	Values ≥ $\overline{X}$ HCW	0.408 (P < 0.01; n = 81)	0.475 (P < 0.01; n = 60)	-0.136 (P = 0.557; n = 21)

[z] $\overline{X}$ HCW: all lambs = 23.3 kg; female lambs = 23.3 kg; male lambs = 23.4 kg.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection, with measures obtained using electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and *longissimus* muscle depth (Loin depth).

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to correlation analysis.

Table 4.6.4. Pearson correlation coefficients determining accuracy of probe measures with data sets classified by mean ($\overline{X}$) backfat at 3.5 cm from the midline[z]

Specific Carcass Measures at Probe Site[x]	**Backfat Subclasses**	**Pearson Correlations (for specific gender classes) for Carcass Measures between 3 and 4 cm from midline[y]**		
		Lambs from Both Genders	**Ram Lambs**	**Ewe Lambs**
Ruler Fat at Probe Site to Hot Probe Fat	Across all backfats	0.429 ($P < 0.01$; $n = 181$)	0.317 ($P < 0.01$; $n = 131$)	0.437 ($P < 0.01$; $n = 50$)
	Values $< \overline{X}$ backfat[w]	0.016 ($P = 0.874$; $n = 97$)	0.024 ($P = 0.851$ $n = 69$)	0.011 ($P = 0.959$; $n = 26$)
	Values $\geq \overline{X}$ backfat	0.403 ($P < 0.01$; $n = 84$)	0.209 ($P = 0.103$ $n = 62$)	0.393 ($P = 0.057$; $n = 24$)
Ruler Fat at Probe Site to Cold Probe Fat	Across all backfats	0.375 ($P < 0.01$; $n = 152$)	0.257 ($P < 0.01$; $n = 116$)	0.503 ($P < 0.01$; $n = 36$)
	Values $< \overline{X}$ backfat	-0.088 ($P = 0.425$; $n = 84$)	-0.048 ($P = 0.724$; $n = 56$)	0.333 ($P = 0.112$; $n = 24$)
	Values $\geq \overline{X}$ backfat	0.327 ($P < 0.01$; $n = 68$)	0.349 ($P < 0.01$; $n = 60$)	0.236 ($P = 0.460$; $n = 12$)
Ruler Loin Depth at Probe Site to Hot Probe Loin Depth	Across all backfats	0.565 ($P < 0.01$; $n = 181$)	0.566 ($P < 0.01$; $n = 131$)	0.558 ($P < 0.01$; $n = 50$)
	Values $< \overline{X}$ backfat	0.646 ($P < 0.01$; $n = 97$)	0.705 ($P < 0.01$; $n = 69$)	0.603 ($P < 0.01$; $n = 26$)
	Values $\geq \overline{X}$ backfat	0.483 ($P < 0.01$; $n = 84$)	0.348 ($P < 0.01$; $n = 62$)	0.524 ($P < 0.01$; $n = 24$)
Ruler Loin Depth at Probe Site to Cold Probe Loin Depth	Across all backfats	0.507 ($P < 0.01$; $n = 152$)	0.534 ($P < 0.01$; $n = 116$)	0.396 ($P = 0.017$; $n = 36$)
	Values $< \overline{X}$ backfat	0.541 ($P < 0.01$; $n = 84$)	0.526 ($P < 0.01$; $n = 56$)	0.396 ($P = 0.056$; $n = 24$)
	Values $\geq \overline{X}$ backfat	0.407 ($P < 0.01$; $n = 68$)	0.534 ($P < 0.01$; $n = 60$)	0.167 ($P = 0.604$; $n = 12$)

[z] $\overline{X}$ Backfat at 3.5 cm from midline All lambs = 5.4 mm; Female lambs = 7.5 mm; Male lambs = 4.7 mm.

[y] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to correlation analysis.

[x] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and *longissimus* muscle depth (Loin depth).

[w] Backfat measured at 3.5 cm from the midline at the interface between the 11th and 12th ribs.

Table 4.6.5. Pearson correlation coefficients comparing probe measures to saleable meat yield and carcass fat percentage with data sets classified by mean ($\bar{X}$) backfat at 3.5 cm from midline[z]

		Pearson Correlations (for specific gender classes) for Carcass Measures between 3 and 4 cm from midline with outliers removed from data set[y, x]		
		Lambs from Both Genders	**Ram Lambs**	**Ewe Lambs**
Hot Probe Fat to CarcSMY[w]	Across all backfats	-0.326 (P < 0.01; n = 181)	-0.196 (P = 0.025; n = 131)	-0.341 (P = 0.016; n = 50)
	Values < $\bar{X}$ backfat	-0.015 (P = 0.881; n = 97)	0 (P = 0.997; n = 69)	-0.132 (P = 0.520; n = 26)
	Values ≥ $\bar{X}$ backfat	-0.276 (P < 0.01; n = 84)	-0.118 (P = 0.358, n = 62)	-0.282 (P = 0.181; n = 24)
Cold Probe Fat to CarcSMY	Across all backfats	-0.434 (P < 0.01; n = 152)	-0.375 (P < 0.01; n = 116)	-0.372 (P < 0.01; n = 36)
	Values < $\bar{X}$ backfat	-0.198 (P = 0.071; n = 84)	-0.314 (P = 0.018; n = 56)	-0.181 (P = 0.396; n = 24)
	Values ≥ $\bar{X}$ backfat	-0.430 (P < 0.01; n = 68)	-0.356 (P < 0.01; n = 60)	-0.424 (P = 0.170; n = 12)
Hot Probe Fat to Carcass Fat Content[v]	Across all backfats	0.300 (P < 0.01; n = 181)	0.131 (P = 0.136; n =131)	0.260 (P = 0.068; n = 50)
	Values < $\bar{X}$ backfat	-0.113 (P = 0.270; n = 97)	-0.032 (P = 0.796; n = 69)	0.037 (P = 0.852; n = 26)
	Values ≥ $\bar{X}$ backfat	0.269 (P = 0.01; n = 84)	0.016 (P = 0.902; n = 62)	0.177 (P = 0.409; n=24)
Cold Probe Fat to Carcass Fat Content	Across all backfats	0.402 (P < 0.01; n =152)	0.338 (P < 0.01; n = 116)	0.345 (P < 0.01; n = 36)
	Values < $\bar{X}$ backfat	0.162 (P = 0.141; n = 84)	0.190 (P = 0.162; n = 56)	0.179 (P = 0.403; n = 24)
	Values ≥ $\bar{X}$ backfat	0.304 (P = 0.012; n = 68)	0.384 (P < 0.01; n = 60)	0.392 (P = 0.207; n =12)
Hot Probe Loin Depth to CarcSMY	Across all backfats	-0.045 (P = 0.549; n = 181)	0.001 (P = 0.992; n = 131)	-0.024 (P = 0.868; n = 50)
	Values < $\bar{X}$ backfat	0.102 (P = 0.319; n = 97)	0.203 (P = 0.094; n = 69)	-0.096 (P = 0.643; n = 26)
	Values ≥ $\bar{X}$ backfat	0.035 (P = 0.746; n = 84)	-0.110 (P = 0.394; n = 62)	0.134 (P = 0.532; n = 24)

Table 4.6.5 (continued)

		Pearson Correlations (for specific gender classes) for Carcass Measures between 3 and 4 cm from midline with outliers removed from data set[y, x]		
		Lambs from Both Genders	**Ram Lambs**	**Ewe Lambs**
Cold Probe Loin Depth to CarcSMY	Across all backfats	0.019 (P = 0.821; n = 152)	0.137 (P = 0.141; n = 116)	-0.468 (P < 0.01; n = 36)
	Values < $\overline{X}$ backfat	0.149 (P = 0.175; n = 84)	0.316 (P = 0.018; n = 56)	-0.418 (P = 0.042; n = 24)
	Values ≥ $\overline{X}$ backfat	0.067 (P = 0.591; n = 68)	0.134 (P = 0.308; n = 60)	-0.142 (P = 0.660; n = 12)
Hot Probe Loin Depth to Carcass Fat Content	Across all backfats	0.187 (P = 0.011; n = 181)	0.083 (P = 0.346; n = 131)	0.335 (P = 0.068; n = 50)
	Values < $\overline{X}$ backfat	0.113 (P = 0.271; n = 97)	0.075 (P = 0.540; n = 69)	0.443 (P = 0.024; n = 26)
	Values ≥ $\overline{X}$ backfat	0.082 (P = 0.452; n = 84)	0.006 (P = 0.961; n = 62)	0.201 (P = 0.347; n = 24)
Cold Probe Loin Depth to Carcass Fat Content	Across all backfats	0.141 (P = 0.084; n =152)	0.019 (P = 0.839; n = 116)	0.579 (P < 0.01; n = 36)
	Values < $\overline{X}$ backfat	0.034 (P = 0.759; n = 84)	-0.006 (P = 0.966; n = 56)	0.514 (P = 0.01; n = 24)
	Values ≥ $\overline{X}$ backfat	0.087 (P = 0.478; n = 68)	-0.131 (P = 0.318; n = 60)	0.515 (P = 0.086; n = 12)

[z] $\overline{X}$ Backfat at 3.5 cm, All = 5.4 mm; Females = 7.5 mm; Males = 4.7 mm.

[y] Prob > |r| under H0: Rho=0 <0.01 unless otherwise stated.

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to correlation analysis.
[w] CarcSMY = saleable meat yield determined via carcass dissection.
[v] Carcass Fat Content = carcass fat content or fat yield determined via carcass dissection.

Table 4.6.6. Pearson correlations comparing carcass measurements to carcass saleable meat yield and fat percentage with data sets classified by mean ($\bar{X}$) hot carcass weight (HCW, kg)[z]

		Pearson Correlations with outliers removed from data set[y]		
		Both	**Rams**	**Ewes**
Ruler[x] Fat to CarcSMY[w]	Across all HCW	-0.664 (P < 0.01; n = 272)	-0.586 (P < 0.01; n = 205)	-0.627 (P < 0.01; n = 67)
	Values $< \bar{X}$ HCW	-0.645 (P < 0.01; n = 130)	-0.563 (P < 0.01; n = 98)	-0.621 (P < 0.01; n = 34)
	Values $\geq \bar{X}$ HCW	-0.667 (P < 0.01; n = 142)	-0.595 (P < 0.01; n = 107)	-0.584 (P < 0.01; n = 33)
Ruler Fat to Fat Content[v]	Across all HCW	0.681 (P < 0.01; n = 272)	0.554 (P < 0.01; n = 205)	0.663 (P < 0.01; n = 67)
	Values $< \bar{X}$ HCW	0.630 (P < 0.01; n = 130)	0.518 (P < 0.01; n = 98)	0.627 (P < 0.01; n = 34)
	Values $\geq \bar{X}$ HCW	0.716 (P < 0.01; n = 142)	0.581 (P < 0.01; n = 107)	0.637 (P < 0.01; n = 33)
Ruler Lean to CarcSMY	Across all HCW	0.052 (P = 0.391; n = 272)	0.076 (P = 0.281; n = 205)	0.043 (P = 0.731; n = 67)
	Values $< \bar{X}$ HCW	-0.007 (P = 0.930; n = 130)	-0.009 (P = 0.928; n = 98)	0.019 (P = 0.914; n = 34)
	Values $\geq \bar{X}$ HCW	0.180 (P = 0.033; n = 142)	0.225 (P = 0.02; n = 107)	0.208 (P = 0.245; n = 33)
Ruler Lean to Fat Content	Across all HCW	0.090 (P = 0.141; n = 272)	0.039 (P = 0.578; n = 205)	0.222 (P = 0.071; n = 67)
	Values $< \bar{X}$ HCW	0.114 (P = 0.199; n = 130)	0.084 (P = 0.409; n = 98)	0.204 (P = 0.247; n = 34)
	Values $\geq \bar{X}$ HCW	-0.047 (P = 0.581; n =142)	-0.126 (P = 0.195; n = 107)	-0.005 (P = 0.976; n =33)
GR[u] to CarcSMY	Across all HCW	-0.571 (P < 0.01; n = 271)	-0.456 (P < 0.01; n = 205)	-0.572 (P < 0.01; n = 66)
	Values $< \bar{X}$ HCW	-0.541 (P < 0.01; n = 129)	-0.393 (P < 0.01; n = 98)	-0.684 (P < 0.01; n = 33)
	Values $\geq \bar{X}$ HCW	-0.570 (P < 0.01; n = 142)	-0.471 (P < 0.01; n = 107)	-0.430 (P < 0.01; n = 33)
GR to Fat Content	Across all HCW	0.737 (P < 0.01; n = 271)	0.623 (P < 0.01; n = 205)	0.742 (P < 0.01; n = 66)
	Values $< \bar{X}$ HCW	0.701 (P < 0.01; n = 129)	0.597 (P < 0.01; n = 98)	0.758 (P < 0.01; n = 33)
	Values $\geq \bar{X}$ HCW	0.733 (P < 0.01; n = 142)	0.588 (P < 0.01; n = 107)	0.615 (P < 0.01; n = 33)
LMA to CarcSMY	Across all HCW	0.214 (P < 0.01; n = 270)	0.200 (P < 0.01; n = 205)	0.204 (P < 0.01; n = 65)
	Values $< \bar{X}$ HCW	0.190 (P < 0.01; n = 129)	0.209 (P < 0.01; n = 98)	0.180 (P < 0.01; n = 33)
	Values $\geq \bar{X}$ HCW	0.319 (P < 0.01; n = 141)	0.292 (P < 0.01; n = 107)	0.299 (P < 0.01; n = 32)

Table 4.6.6 (continued)

[z] $\overline{X}$ $\overline{X}$ HCW: all lambs = 23.3 kg; female lambs = 23.3 kg; male lambs = 23.4 kg.

[y] Outliers for hot carcass weight, and saleable meat yield were identified as trait values > or < 2 σ^2 from the mean.

[x] Ruler Measures taken 3.5 cm from the midline.

[w] CarcSMY = saleable meat yield determined via carcass dissection.

[v] Fat Content = Fat percentage via carcass dissection.

[u] GR measurement of total tissue depth 11 cm from the midline on the 12th rib.

Table 4.6.7. Multiple regression analysis using electronic grading probe and carcass measures to predict saleable meat yield (SMY) with data sets classified by mean ($\overline{X}$) hot carcass weight (HCW, kg)[z,y]

Independent Variables Used to Predict SMY	**Hot Carcass Weight Class**	**Carcasses Probed Between 11th and 12th Ribs[x,w]**		
		Lambs from Both Genders	**Ram Lambs**	**Ewe Lambs**
Model Including Hot Probe Fat[v], Hot Probe Lean[v] and HCW	All Data	0.126 ($P < 0.05$; $n = 181$)	0.091 ($P < 0.05$; $n = 131$)	0.150 ($P = 0.056$ $n = 50$)
	Values < $\overline{X}$ HCW	0.087 ($P < 0.05$; $n = 84$)	0.014 ($P = 0.860$ $n = 57$)	0.114 ($P = 0.418$ $n = 27$)
	Values ≥ $\overline{X}$ HCW	0.138 ($P < 0.05$; $n = 97$)	0.091 ($P = 0.082$; $n = 74$)	0.284 ($P = 0.09$; $n = 23$)
Model Including Chilled Probe Fat[v], Chilled Probe Lean[v] and HCW	All Data	0.216 ($P < 0.05$; $n = 152$)	0.163 ($P < 0.05$; $n = 116$)	0.316 ($P < 0.05$; $n = 36$)
	Values < $\overline{X}$ HCW	0.151 ($P < 0.05$; $n = 71$)	0.150 ($P < 0.05$; $n = 56$)	0.341 ($P = 0.188$; $n = 15$)
	Values ≥ $\overline{X}$ HCW	0.221 ($P < 0.05$; $n = 81$)	0.134 ($P < 0.05$; $n = 60$)	0.120 ($P = 0.501$; $n = 21$)
Model Including Ruler Fat and Ruler Lean Measured at 3.5 cm from midline and HCW	All Data	0.456 ($P < 0.05$; $n = 272$)	0.362 ($P < 0.05$; $n = 205$)	0.448 ($P < 0.05$; $n = 67$)
	Values < $\overline{X}$ HCW	0.418 ($P < 0.05$; $n = 130$)	0.319 ($P < 0.05$; $n = 96$)	0.446 ($P < 0.05$; $n = 34$)
	Values ≥ $\overline{X}$ HCW	0.477 ($P < 0.05$; $n = 142$)	0.399 ($P < 0.05$; $n = 109$)	0.481 ($P < 0.05$; $n = 33$)

Table 4.6.7. (continued)

Independent Variables Used to Predict Dependent Variable, SMY	Hot Carcass Weight Class	Probed Between 11th and 12th Rib[x]		
		Lambs from Both Genders	**Ram Lambs**	**Ewe Lambs**
Model Including Ruler Fat and Ruler Lean taken at Probe Site and HCW	All Data	0.414 ($P < 0.05$; n = 190)	0.337 ($P < 0.05$; n = 139)	0.342 ($P < 0.05$; n = 51)
	Values < $\overline{X}$ HCW	0.406 ($P < 0.05$; n = 90)	0.250 ($P < 0.05$; n = 62)	0.440 ($P < 0.05$; n = 28)
	Values ≥ $\overline{X}$ HCW	0.416 ($P < 0.05$; n = 100)	0.378 ($P < 0.05$; n = 77)	0.422 ($P < 0.05$; n = 23)

[z] $\overline{X}$ HCW: all lambs = 23.3 kg; female lambs = 23.3 kg; male lambs = 23.4 kg.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection, with measures obtained using electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and *longissimus* muscle depth (Loin depth) measured on the interface of the *longissimus* muscle between the 11th and 12th ribs between 3 and 4 cm from the midline.

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to multiple regression analysis.

[w] Table values include Coefficient of Determination (R^2), P value and number of lambs in sub-class.

[v] Electronic probe measurements taken between 3 and 4 cm from the midline of vertebral column.

Table 4.6.8. Multiple regression analysis using electronic grading probe and carcass measures to predict saleable meat yield with data sets classified by mean ($\overline{X}$) backfat at 3.5 cm from midline^{zy}

Independent Variables Used to Predict Dependent Variable, SMY	Carcass Backfat Class	Carcasses Probed Between 11th and 12th Ribs^{xw}		
		Both Genders	**Ram Lambs**	**Ewe Lambs**
Model Includes Hot Probe Fat^{v}, Hot Probe Lean^{v} and HCW	Across all backfats	0.126 (P < 0.05; n = 181)	0.091 (P < 0.05; n = 131)	0.150 (P = 0.056 n = 50)
	Values < $\overline{X}$ backfat	0.014 (P = 0.720; n = 97)	0.065 (P = 0.223; n = 69)	0.042 (P = 0.812 n = 26)
	Values ≥ $\overline{X}$ backfat	0.093 (P < 0.05; n = 84)	0.080 (P = 0.180; n = 62)	0.231 (P = 0.146; n = 24)
Model Includes Chilled Probe Fat^{v}, Chilled Probe Lean^{v} and HCW	Across all backfats	0.216 (P < 0.05; n = 152)	0.163 (P < 0.05; n = 116)	0.316 (P < 0.05; n = 36)
	Values < $\overline{X}$ backfat	0.076 (P = 0.095; n = 84)	0.156 (P < 0.05; n = 56)	0.260 (P = 0.103 n = 24)
	Values ≥ $\overline{X}$ backfat	0.185 (P < 0.05; n = 68)	0.127 (P = 0.054; n = 60)	0.218 (P = 0.556; n = 12)
Model Includes Ruler Fat, Ruler Lean measured at 3.5 cm from the midline and HCW	Across all backfats	0.456 (P < 0.05; n = 272)	0.362 (P < 0.05; n = 205)	0.448 (P < 0.05; n = 67)
	Values < $\overline{X}$ backfat	0.267 (P < 0.05; n = 151)	0.189 (P < 0.05; n = 101)	0.320 (P < 0.05; n = 34)
	Values ≥ $\overline{X}$ backfat	0.219 (P < 0.05; n = 121)	0.152 (P < 0.05; n = 104)	0.411 (P < 0.05; n = 33)

Table 4.6.8 (continued)

Independent Variables Used to Predict Dependent Variable, SMY	**Carcass Backfat Class**	**Carcasses Probed Between 11th and 12th Ribs^{xw}**		
		Both Genders	**Ram Lambs**	**Ewe Lambs**
Model Includes Ruler Fat, Ruler Lean taken at Probe Site and HCW	Across all backfats	0.414 ($P < 0.05$; n = 190)	0.337 ($P < 0.05$; n = 139)	0.342 ($P < 0.05$; n = 51)
	Values < $\overline{X}$ backfat	0.205 ($P < 0.05$; n = 103)	0.156 ($P < 0.05$; n = 73)	0.225 ($P = 0.112$; n = 27)
	Values ≥ $\overline{X}$ backfat	0.168 ($P < 0.05$; n = 87)	0.187 ($P < 0.05$; n = 66)	0.274 ($P = 0.087$; n = 24)

[z] $\overline{X}$ Backfat All = 5.3 mm, Females = 7.5 mm, Males = 4.7 mm.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection, with measures obtained using electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and *longissimus* muscle depth (Loin depth) measured on the interface of the *longissimus* muscle between the 11th and 12th ribs between 3 and 4 cm from the midline.

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to multiple regression analysis.

[w] Table values include Coefficient of Determination (R^2), P value and number of lambs in sub-class.

[v] Electronic probe measurement taken between 3 and 4 cm from midline of the vertebral column.

Table 4.6.9. Multiple regression analysis using electronic grading probe and carcass measures to predict %fat in the carcass in data sets classified by mean ($\bar{X}$) backfat at 3.5 cm from midline[zyxw]

Independent Variables Used to Predict Dependent Variable, Fat Content	Carcass Backfat Class	Both Genders	Ram Lambs	Ewe Lambs
Model Includes Hot Probe Fat[v], Hot Probe Lean[v] and HCW	Across all backfats	0.177 ($P < 0.05$; $n = 181$)	0.169 ($P < 0.05$; $n = 131$)	0.342 ($P < 0.05$; $n = 50$)
	Values < $\bar{X}$ backfat	0.107 ($P < 0.05$; $n = 97$)	0.125 ($P < 0.05$; $n = 69$)	0.250 ($P = 0.091$; $n = 26$)
	Values $\geq \bar{X}$ backfat	0.106 ($P < 0.05$; $n = 84$)	0.135 ($P < 0.05$; $n = 62$)	0.412 ($P < 0.05$; $n = 24$)
Model Includes Cold Probe Fat[v], Cold Probe Lean[v] and HCW	Across all backfats	0.302 ($P < 0.05$; $n = 152$)	0.273 ($P < 0.05$; $n = 116$)	0.408 ($P < 0.05$; $n = 36$)
	Values < $\bar{X}$ backfat	0.135 ($P < 0.05$; $n = 84$)	0.169 ($P < 0.05$; $n = 56$)	0.342 ($P < 0.05$; $n = 24$)
	Values $\geq \bar{X}$ backfat	0.115 ($P < 0.05$; $n = 68$)	0.155 ($P < 0.05$; $n = 60$)	0.292 ($P = 0.404$; $n = 12$)
Model Includes Ruler Fat, Ruler Loin Depth at 3.5 cm from Midline and HCW	Across all backfats	0.486 ($P < 0.05$; $n = 190$)	0.378 ($P < 0.05$; $n = 139$)	0.534 ($P < 0.05$; $n = 51$)
	Values < $\bar{X}$ backfat	0.246 ($P < 0.05$; $n = 103$)	0.263 ($P < 0.05$; $n = 73$)	0.588 ($P < 0.05$; $n = 27$)
	Values $\geq \bar{X}$ backfat	0.204 ($P < 0.05$; $n = 87$)	0.237 ($P < 0.05$; $n = 66$)	0.376 ($P < 0.05$; $n = 24$)
Model Includes Ruler Fat, Ruler Loin Depth at Probe Site and HCW	Across all backfats	0.495 ($P < 0.05$; $n = 272$)	0.368 ($P < 0.05$; $n = 205$)	0.516 ($P < 0.05$; $n = 67$)
	Values < $\bar{X}$ backfat	0.248 ($P < 0.05$; $n = 151$)	0.272 ($P < 0.05$; $n = 101$)	0.545 ($P < 0.05$; $n = 34$)
	Values $\geq \bar{X}$ backfat	0.228 ($P < 0.05$; $n = 121$)	0.226 ($P < 0.05$; $n = 104$)	0.416 ($P < 0.05$; $n = 33$)

[z] $\bar{X}$ Backfat All = 5.3 mm, Females = 7.5 mm, Males = 4.7 mm.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection, with measures obtained using electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and longissimus muscle depth (Loin depth) measured on the interface of the longissimus muscle between the 11th and 12th ribs between 3 and 4 cm from the midline.

Table 4.6.9 (Continued)

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to multiple regression analysis.

[w] Table values include Coefficient of Determination (R^2), P value and number of lambs in sub-class.

[v] Probe measurement taken between 3 and 4 cm from midline

Table 4.6.10. Multiple regression analysis using alternative carcass measurements to predict saleable meat yield classified by mean ($\overline{X}$) hot carcass weight (HCW, kg)[zyx]

Independent Variables Used to Predict Dependent Variable, SMY	**Hot Carcass Weight Class**	**Both Genders**	**Ram Lambs**	**Ewe Lambs**
Model Includes Ruler Fat, Ruler Lean at 3.5cm Loin Width	All Data	0.456 (P < 0.05; n = 272)	0.353 (P < 0.05; n = 205)	0.444 (P < 0.05; n = 67)
	Values < $\overline{X}$ HCW	0.437 (P < 0.05; n = 130)	0.343 (P < 0.05; n = 98)	0.424 (P < 0.05; n = 34)
	Values ≥ $\overline{X}$ HCW	0.476 (P < 0.05; n = 142)	0.376 (P < 0.05; n = 107)	0.502 (P < 0.05; n = 33)
Model Includes GR[w] and HCW (all data)	All Data	0.327 (P < 0.05; n = 271)	0.208 (P < 0.05; n = 205)	0.328 (P < 0.05; n = 66)
	Values < $\overline{X}$ HCW	0.306 (P < 0.05; n = 129)	0.167 (P < 0.05; n = 98)	0.469 (P < 0.05; n = 33)
	Values ≥ $\overline{X}$ HCW	0.327 (P < 0.05; n = 142)	0.220 (P < 0.05; n = 107)	0.185 (P < 0.05; n = 33)
Model Includes Ruler Fat, GR, Loin muscle area (LMA)	All Data	0.545 (P < 0.05; n = 270)	0.440 (P < 0.05; n = 205)	0.543 (P < 0.05; n = 65)
	Values < $\overline{X}$ HCW	0.519 (P < 0.05; n = 129)	0.392 (P < 0.05; n = 98)	0.682 (P < 0.05; n = 33)
	Values ≥ $\overline{X}$ HCW	0.555 (P < 0.05; n = 141)	0.476 (P < 0.05; n = 107)	0.475 (P < 0.05; n = 32)

[z] $\overline{X}$ HCW: all lambs = 23.3 kg, ewes = 23.3 kg, rams = 23.4 kg.

[y] Outliers for hot carcass weight, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to multiple regression analysis.

[x] Table values include Coefficient of Determination (R^2), P value and number of lambs in sub-class.

[w] GR is measurement of total tissue thickness 11 cm from the midline.

Table 4.6.11. Pearson correlation coefficients determining accuracy of probe measures for lamb carcass traits to ruler measures by mean ($\overline{X}$) hot carcass weight (HCW, kg)[z]

Pearson Correlations for Carcass Measures between 3 and 4 cm from Midline[y,x]	**Ram Lambs**
Ruler Backfat to Hot Probe Fat	**0.224 (P = 0.183; n = 37)**
Ruler Backfat to Hot Probe Fat < $\overline{X}$	**0.307 (P = 0.069; n = 25)**
Ruler Backfat to Hot Probe Fat ≥ $\overline{X}$	**-0.333 (P = 0.290; n = 12)**
Ruler Backfat to Cold Probe Fat	**0.287 (P = 0.085; n = 37)**
Ruler Backfat to Cold Probe Fat < $\overline{X}$ HCW	**0.297 (P = 0.149; n = 25)**
Ruler Backfat to Cold Probe Fat ≥ $\overline{X}$ HCW	**0.158 (P = 0.623; n = 12)**
Ruler Loin Depth to Hot Probe Lean	**0.627 (P < 0.01; n = 37)**
Ruler Loin Depth to Hot Probe Lean < $\overline{X}$ HCW	**0.437 (P = 0.03; n = 25)**
Ruler Loin Depth to Hot Probe Lean ≥ $\overline{X}$ HCW	**0.701 (P = 0.01; n = 12)**
Ruler Loin Depth to Cold Probe Lean	**0.663 (P < 0.01; n = 37)**
Ruler Loin Depth to Cold Probe Lean < $\overline{X}$ HCW	**0.561 (P < 0.01; n = 25)**
Ruler Loin Depth to Cold Probe Lean ≥ $\overline{X}$ HCW	**0.778 (P < 0.01; n = 12)**

[z] $\overline{X}$ HCW = 24.6 kg.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection (Ruler backfat or Loin Depth), with measures obtained using electronic probe technology on the hot or chilled carcass (Hot Probe Fat or Lean, Cold Probe Fat or Lean).This includes subcutaneous fat depth (Fat) and longissimus muscle depth (Loin depth) measured on the interface of the longissimus muscle between the 12th and 13th ribs.

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to correlation analysis.

Table 4.6.12. Multiple regression analysis using electronic grading probe and carcass measures to predict saleable meat yield in data sets classified by mean ($\bar{X}$) hot carcass weight probed between 12th and 13th ribs (HCW, kg)[z]

Multiple Regression Analysis Probe distance >3 and <4 cm midline[y][x]	**Ram Lambs**
Hot Probe Fat and Loin Depth with HCW	**0.060 (P = 0.555; n = 37)**
Hot Probe Fat and Loin Depth with HCW < $\bar{X}$ HCW	**0.243 (P = 0.113; n = 25)**
Hot Probe Fat and Loin Depth with HCW ≥ $\bar{X}$ HCW	**0.035 (P = 0.959; n = 12)**
Cold Probe Fat and Loin Depth with HCW	**0.140 (P = 0.167; n = 37)**
Cold Probe Fat and Loin Depth with HCW < $\bar{X}$ HCW	**0.243 (P = 0.113; n = 25)**
Cold Probe Fat and Loin Depth with HCW ≥ $\bar{X}$ HCW	**0.516 (P = 0.106; n = 12)**
Ruler Fat and Loin Depth Probe Site with HCW	**0.068 (P = 0.50; n = 37)**
Ruler Fat and Loin Depth Probe Site with HCW < $\bar{X}$ HCW	**0.072 (P = 0.66; n = 25)**
Ruler Fat and Loin Depth Probe Site with HCW ≥ $\bar{X}$ HCW	**0.247 (P = 0.437; n = 12)**
Ruler Fat and Loin Depth at 3.5cm with HCW	**0.056 (P = 0.342; n = 61)**
Ruler Fat and Loin Depth at 3.5cm with HCW < $\bar{X}$ HCW	**0.033 (P = 0.772; n = 37)**
Ruler Fat and Loin Depth at 3.5cm with HCW ≥ $\bar{X}$ HCW	**0.121 (P = 0.449; n = 24)**

[z] $\bar{X}$ HCW = 24.6 kg.

[y] Specific Carcass Measures at Probe Site are comparing measures of traits on the carcass using a ruler or dissection, with measures obtained using electronic probe technology on the hot or chilled carcass. This includes subcutaneous fat depth (Fat) and longissimus muscle depth (Loin depth) measured on the interface of the longissimus muscle between the 12th and 13th ribs.

[x] Outliers for hot carcass weight, probe values of fat and loin depth, and saleable meat yield were identified as trait values > or < 2 σ^2 from mean and were removed from the data sets prior to multiple regression analysis.

4.6.13 Summary of prediction equations with animal factors included[z]

Figure #	Factors	Equations
4.7.5	Terminal Rams	59.4612-0.4111*Probe Fat on Hot Carcass
	Terminal Ewes	59.4612-1.7832-0.4111*Probe Fat on Hot Carcass
	Maternal Rams	59.4612+2.7551-0.4111*Probe Fat on Hot Carcass
	Maternal Ewes	59.4612+2.7551-1.7832-0.4111*Probe Fat on Hot Carcass
4.7.6	**Factors**	**Equations**
	Terminal Rams	60.2898-0.2844*Probe Fat on Chilled Carcass
	Terminal Ewes	60.2898-1.9041-0.2844*Probe Fat on Chilled Carcass
	Maternal Rams	60.2898+1.6537-0.2844*Probe Fat on Chilled Carcass
	Maternal Ewes	60.2898+1.6537-1.9041-1.9983-0.2844*Probe Fat on Chilled Carcass
4.7.7	**Factors**	**Equations**
	Terminal Rams	60.2721-0.5775*Carcass Backfat
	Terminal Ewes	60.2721-0.8428-0.5775*Carcass Backfat
	Maternal Rams	60.2721+1.9411-0.5775*Carcass Backfat
	Maternal Ewes	60.2721+1.9411-0.8428-0.5775*Carcass Backfat
4.7.8	**Factors**	**Equations**
	Terminal	SMY = 63.4043 - 0.4361 * GR
	Maternal	SMY = 63.4043 + 2.2337 - 0.4361 * GR

[z] Animal factors included Breed Type (Maternal vs. Terminal) and Gender (Ewes vs. Rams).

4.7 Figures

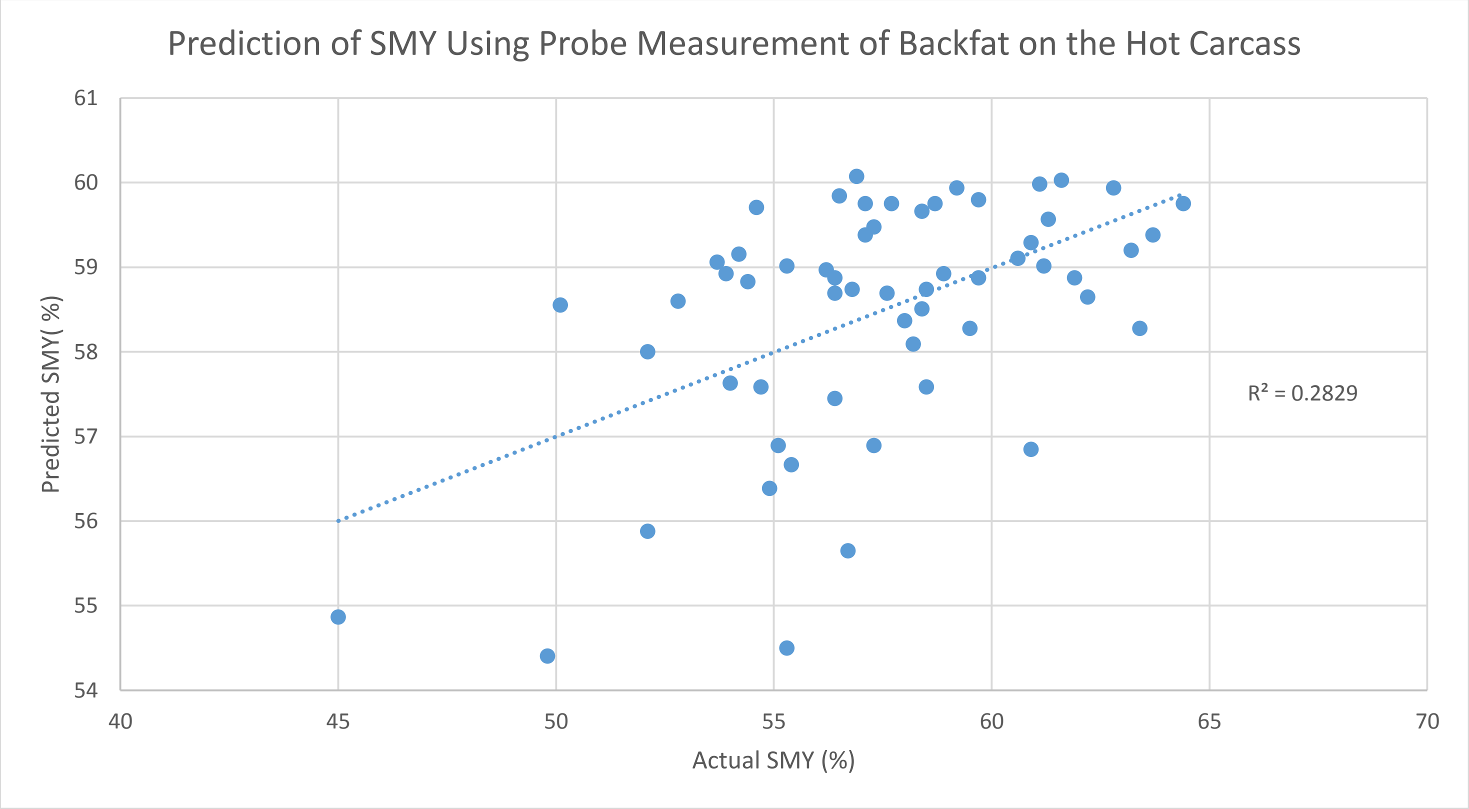

Figure 4.7.1. Relationship between predicted vs. actual SMY for model with electronic probe measurement of subcutaneous backfat on the hot carcass between 3 and 4 cm from the midline.

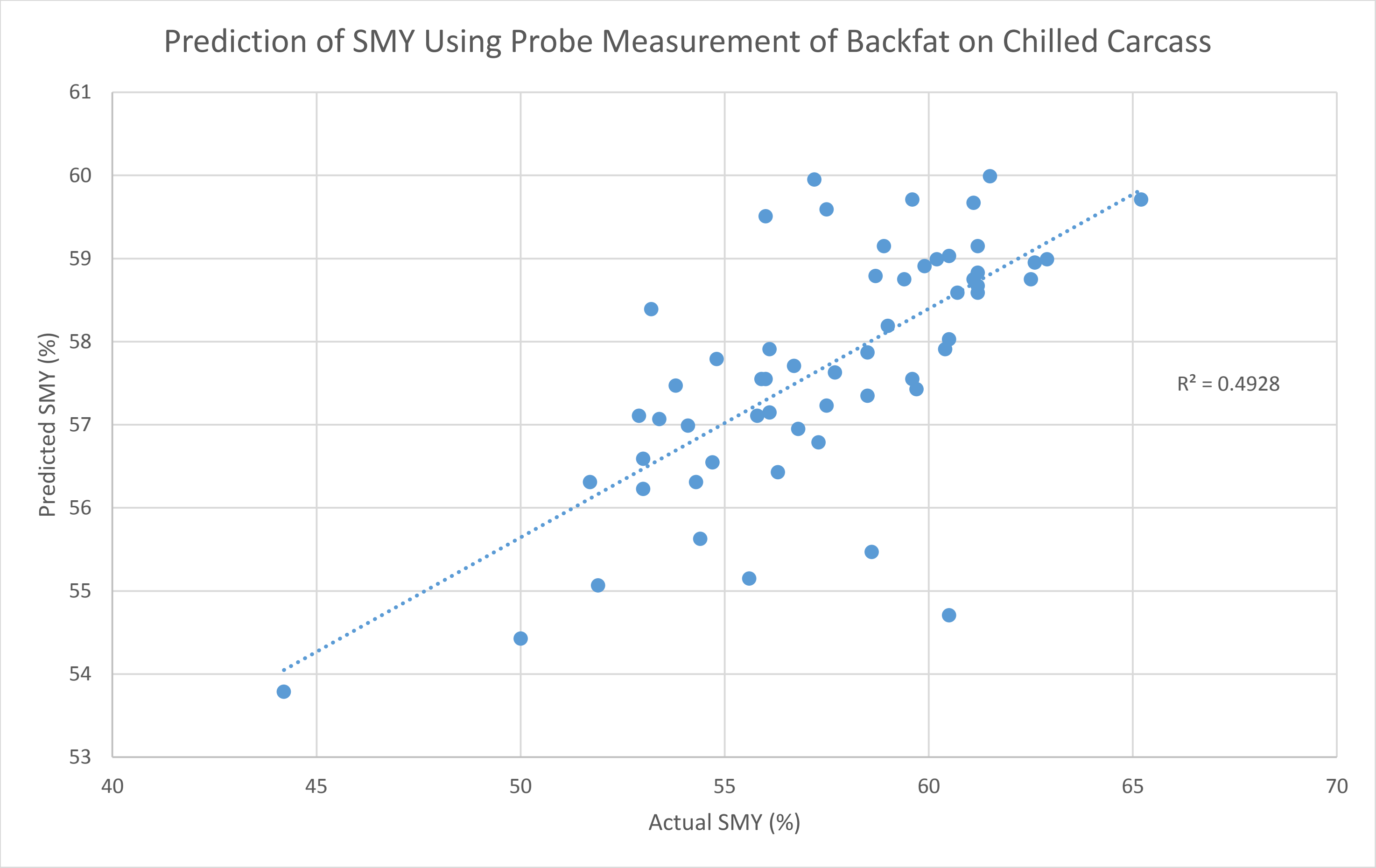

Figure 4.7.2. Relationship between predicted vs. actual SMY for model with electronic probe measurement of subcutaneous backfat taken on the chilled carcass between 3 and 4 cm from the midline.

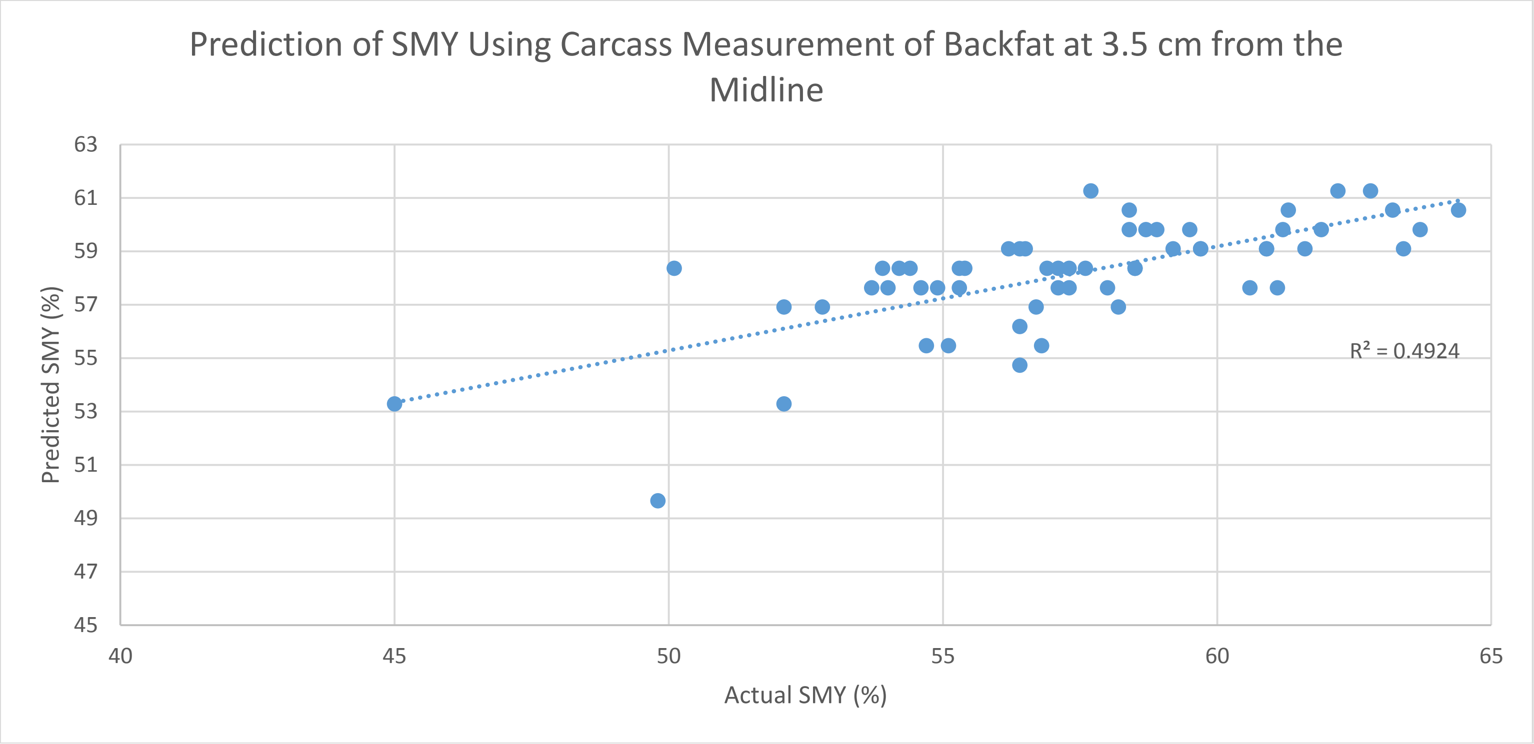

Figure 4.7.3. Relationship between predicted vs. actual SMY for model containing a ruler measurement of carcass subcutaneous backfat at 3.5 cm from the midline.

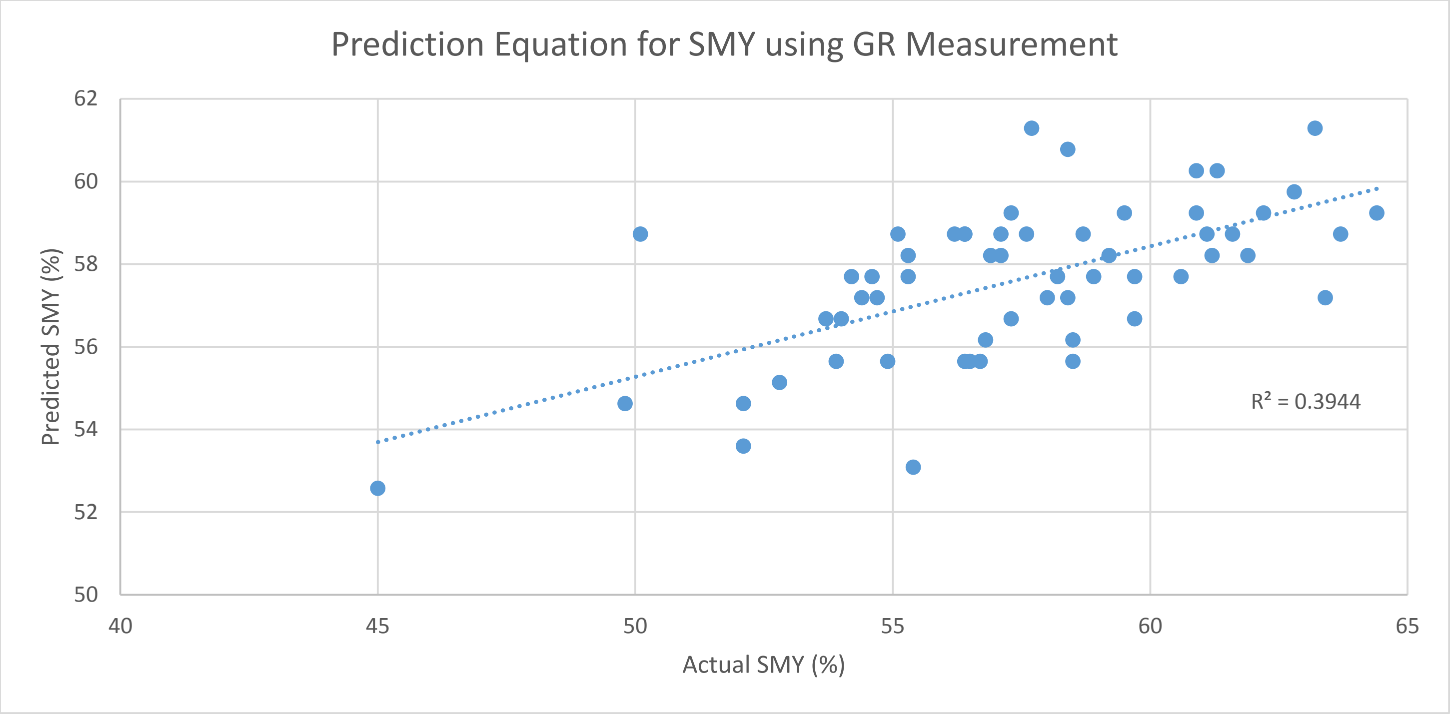

Figure 4.7.4. Relationship between predicted vs. actual SMY for model containing a ruler measurement of GR.

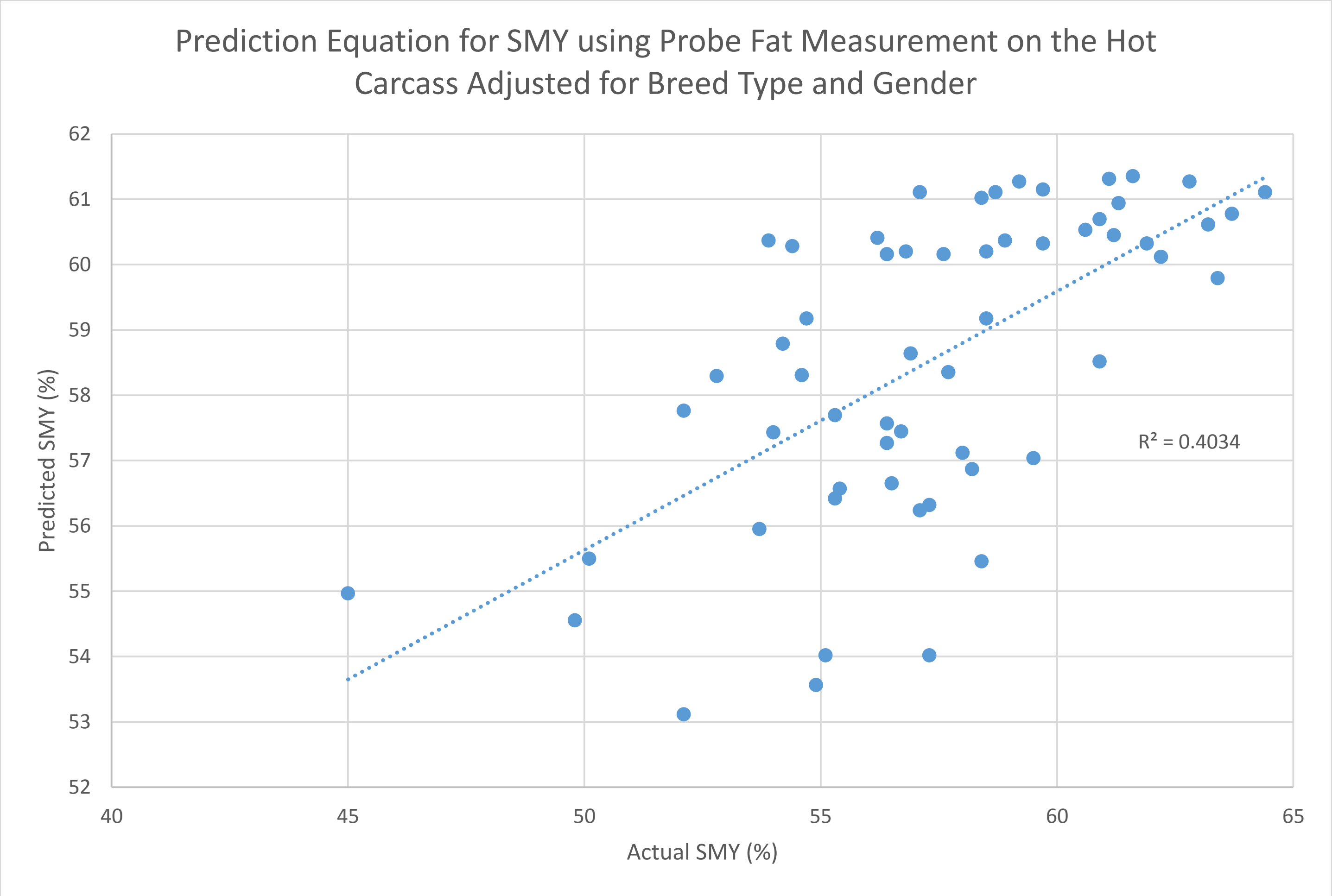

Figure 4.7.5. Relationship between predicted vs. actual SMY with an electronic probe measurement of subcutaneous backfat on hot carcass with breed type and gender factored into the model.

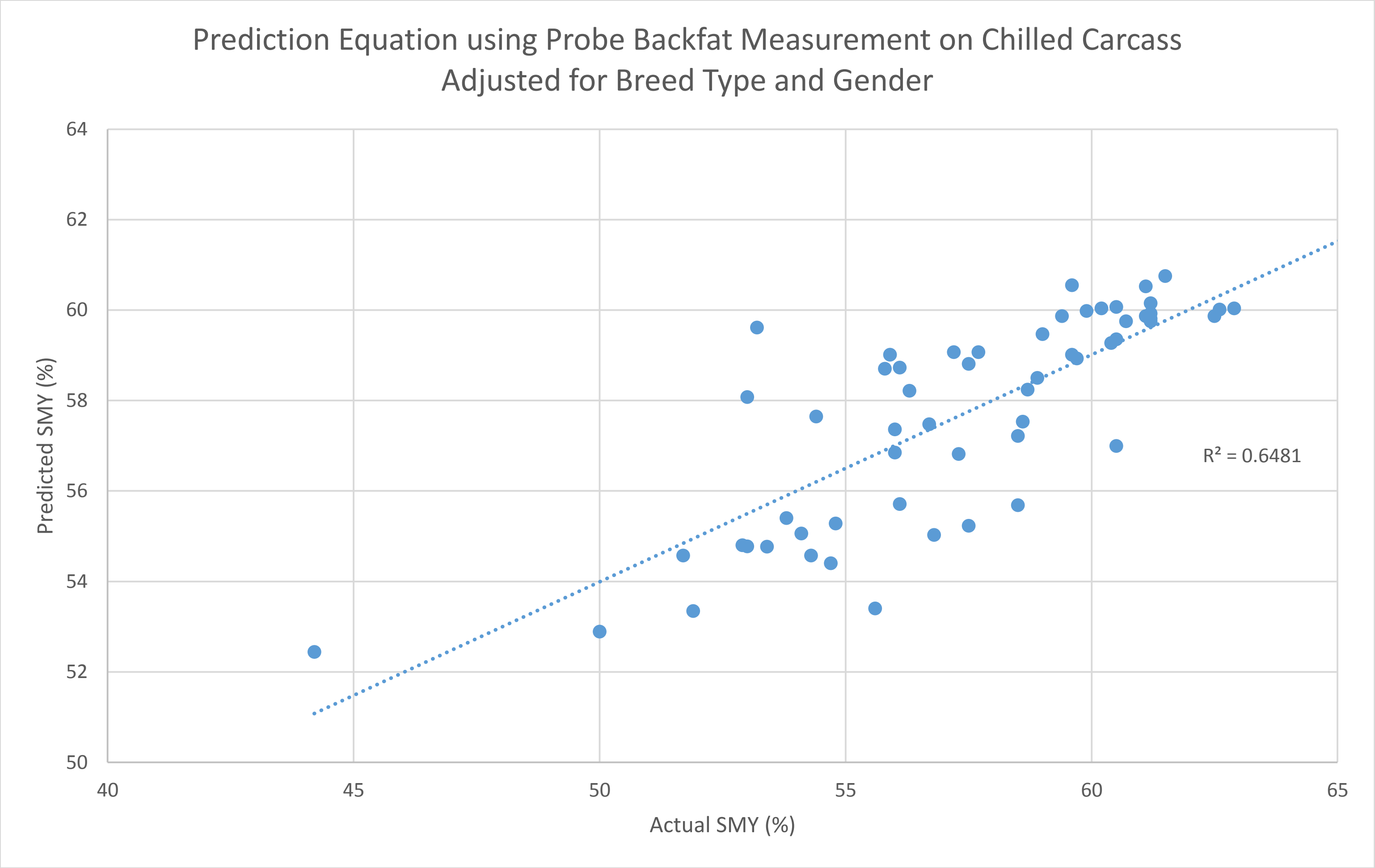

Figure 4.7.6. Relationship between predicted vs. actual SMY for model with electronic probe measurement of subcutaneous backfat on chiiled carcass with breed type and gender factored into the model.

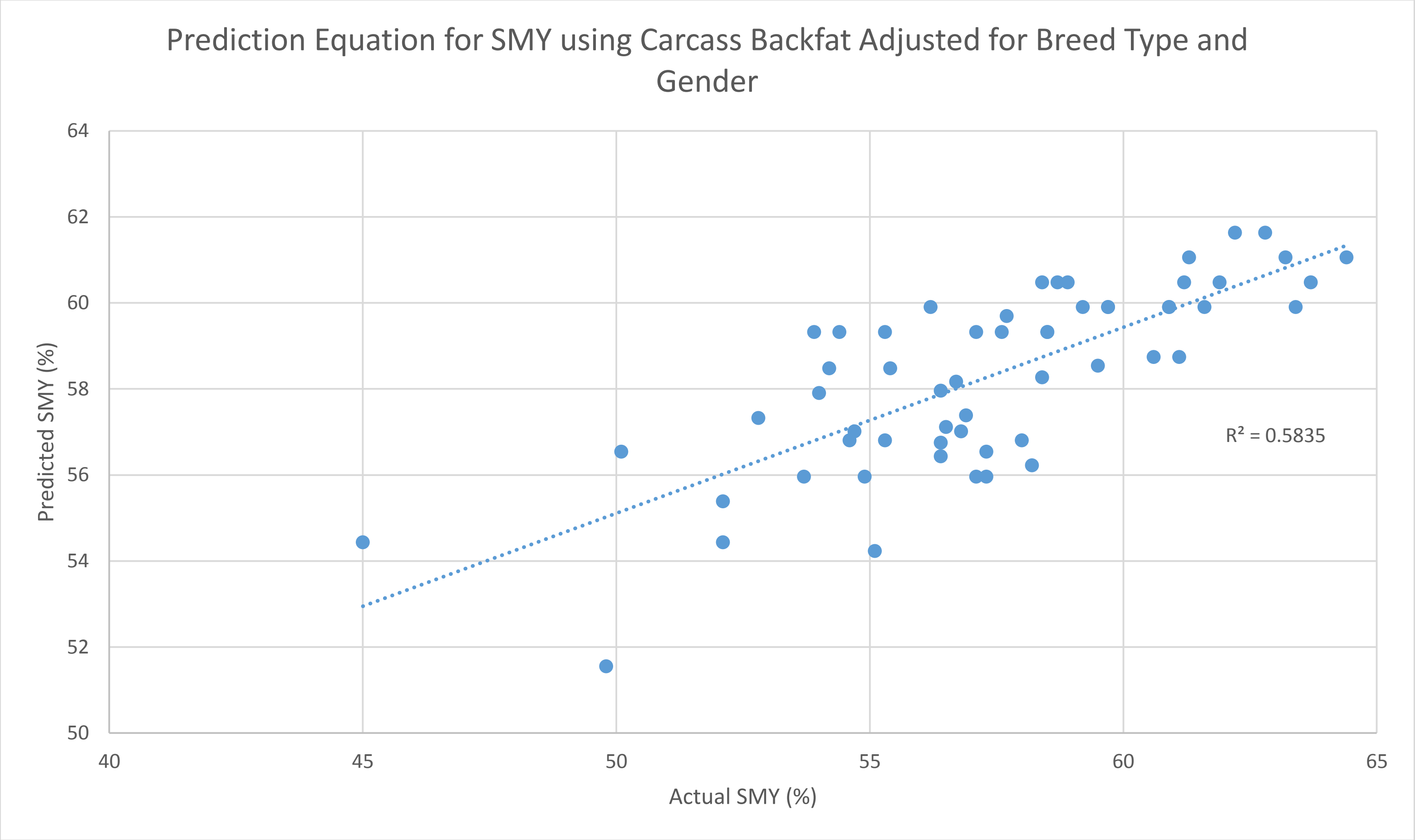

Figure 4.7.7. Relationship between predicted vs. actual SMY for model containing ruler measurement if subcutaneous backfat at 3.5 cm from the midline with breed type and gender factored into model.

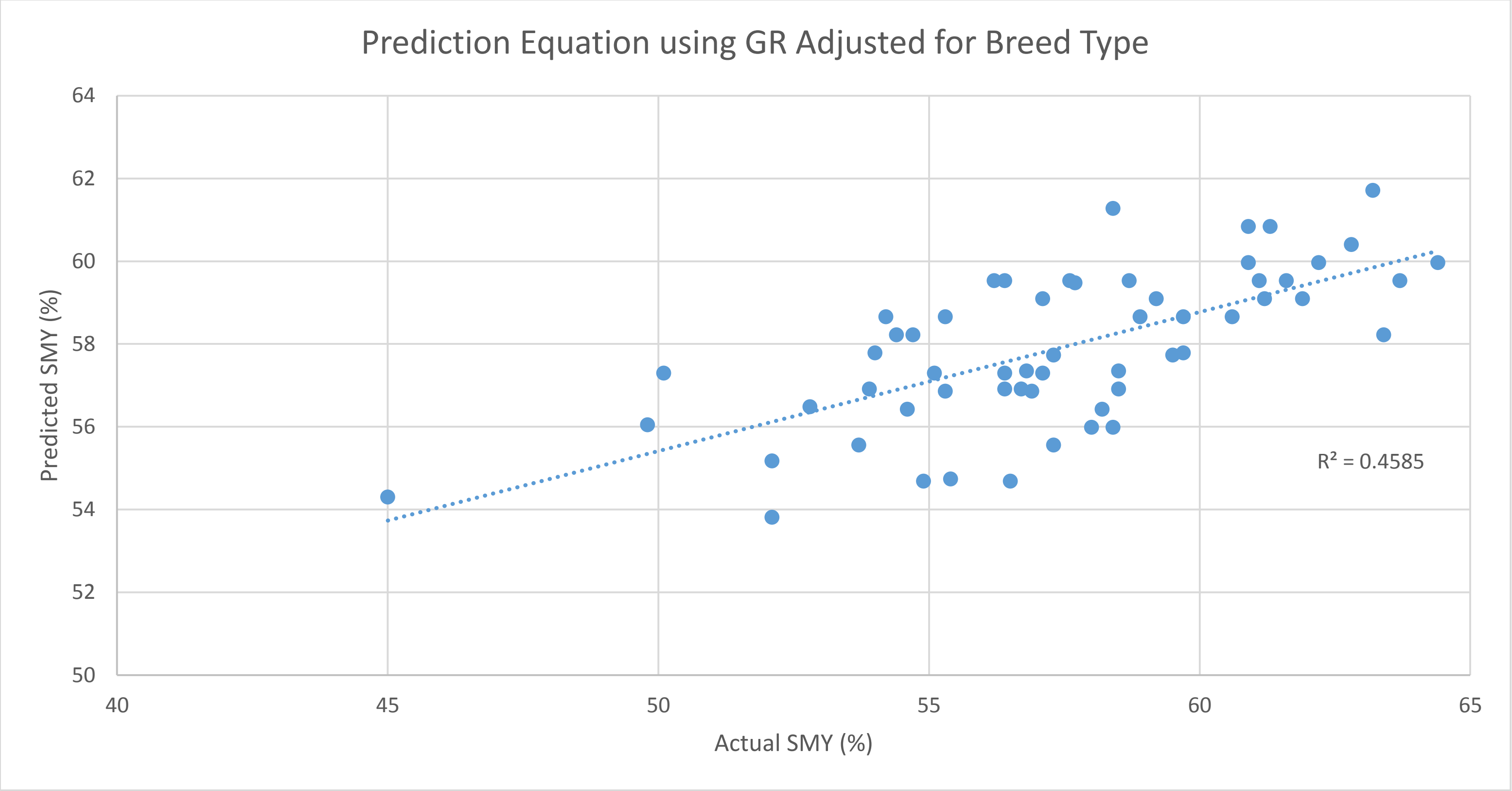

Figure 4.7.8. Relationship between predicted vs. actual SMY for model containing ruler measurement of GR with breed type factored into the model.

5.0 Conclusions

The first objective of this study was to determine the accuracy of the Viewtrak PG-207 electronic probe in predicting SMY in lambs. The Viewtrak PG-207 did not accurately measure subcutaneous backfat depths between the 11th and 12th ribs in the lamb carcass weight classes evaluated in the present study. Pearson r values were variable depending on the gender/weight/fatness subclasses, but overall the probe could not provide a reliable measurement of subcutaneous backfat whether probed on the hot or chilled carcass. Pearson correlation coefficients would indicate that the probe only provided a marginal estimate of *longissimus* muscle depth. On average, the Pearson's correlations were higher when measuring chilled versus hot carcasses, whether measuring backfat or *longissimus* depths. Our findings agree with recent work by Hopkins et al. (2013) which found the Hennessey probe did not provide accurate estimates of backfat and *longissimus* muscle depths. Multiple regression analysis revealed that probe measurements on either the hot or chilled carcass did a poor job of explaining the variation of SMY in ewe lambs, while there was a small improvement in R^2 value when ewe lambs were probed. Even with this improvement, the models did poor job at explaining the variation in SMY. Probe models did a poor job at explaining the variation in fat content of lamb carcasses. Overall, the probe could not accurately measure subcutaneous backfat or *longissimus* muscle depths on lamb carcasses. Therefore, it is not surprising that probe measurement models (based on probing the hot or chilled carcass) could not accurately predict SMY or fat content in lamb carcasses. Equivalent carcass measures of backfat and *longissimus* depths while slightly better than those of the probe, were also poor at explaining the variation in SMY and fat content.

The second objective of the study was to evaluate the relationship between probe and carcass measures for predicting SMY. Analysis revealed that probe measurements on either the hot or chilled carcass were not highly correlated to either SMY or fat content of the carcass regardless of gender or fatness subclass. Carcass backfat measured at 3.5 cm from the midline had the highest correlation to SMY (-0.664, Table 4.6.6), whereas GR had the highest correlation to carcass fat content (0.737, Table 4.6.6). Use of multiple regression analysis found that equivalent carcass measures of backfat and *longissimus* depth only provided a moderate job at explaining the variation in SMY and carcass fat content. This could explain why probe measurements did not perform well in the present study when explaining the variation in SMY and carcass fat content. Probe fat measurements were found to be significant predictors ($P < 0.01$) of SMY whether the measurement was taken on the hot or chilled carcass; however, prediction equations created from these measurements could not provide accurate estimates of SMY. Carcass backfat and GR were also significant ($P < 0.01$) predictors of SMY for lamb carcasses. Yet, models containing these measurements could only provide a moderately accurate estimate of SMY. Models which included probe or carcass measures of subcutaneous backfat; *longissimus* muscle depth; LMA; and GR were not accurate predictors of variation in SMY.

Inclusion of covariates including breed type and gender improved the explanation of variation in SMY ($P < 0.01$) in models containing hot probe backfat measurements and carcass subcutaneous backfat measurements. For chilled probe backfat models, gender and breed type*gender interactions ($P < 0.01$) were significant predictors of SMY. For models including GR, only breed type ($P < 0.01$) enhanced the prediction of SMY vs. GR alone. When these factors were included in the various models, prediction did improve. However, the extent of improvement in prediction accuracy was not great enough to justify the extra labour required to incorporate this information in a practical setting at the packing plant.

In conclusion, the Viewtrak PG-207 did not accurately measure carcass subcutaneous backfat and *longissimus* muscle depths in lamb carcasses. Use of these probe measurements whether taken on the hot or chilled carcass could not provide a reliable estimate of carcass SMY or fat content. However, equivalent carcass measures were also limited in their ability to estimate carcass SMY. Animal factors such as breed type and gender should be included in prediction models in the future if probe technology is going to be investigated further for lamb carcasses.

6.0 Recommendations

While the research objectives were completed in the present study, the Viewtrak PG-207 probe could not be used to accurately determine saleable meat yield although information regarding individual lamb genotype and gender improves accuracy. Acquiring this extra information on lambs may be very impractical within a commercial packing plant setting. However, the prediction of saleable meat yield only moderately improved when actual carcass data was used to develop prediction equations. As the purpose of the probe is to provide similar electronic measures to mechanical measures, it is then not unexpected that the probe's performance is inadequate. The following recommendations should be considered for future studies.

- Ewe lambs were difficult to purchase for this study as producers tend to retain them as replacements. Purposive purchasing of females so as to increase the numbers evaluated would improve understanding of gender effects on probe and carcass traits. This is important as ewe lambs tend to deposit more backfat than ram lambs.
- There were limitations to producer information such that breed type and individual producer production practices were not well defined. For example, there was no mention if lambs were exclusively feed a high concentrate diet after weaning or if lambs were pastured before being finished by high concentrate diet or marketed as pasture finished lambs. Genotype information was lacking with limited information about breed crosses.

- More in-depth investigation is needed on site of probing, comparing probing between the 10 and 11th ribs, 11th and 12th ribs, and 12th and 13th ribs to determine if probe location significantly affects prediction of SMY.
- Examination of other carcass measures is needed for predicting SMY, since use of actual carcass measures only resulted in a marginal improvement in the prediction of saleable meat yield versus use of probe measures.
- A subsequent study would benefit from more detailed investigations into other grading technologies (i.e. ultrasound, VIA) for determining saleable meat yield as there is a need for additional information for both producers and packers.

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