Linear and Ultrasound Measurements in Crossbred Goats as a Predictor of Live and Hot Carcass Weights

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Abstract

This study was conducted to examine correlations between live linear and real-time ultrasound measurements and carcass characteristics in Spanish x Boer goats. Goats were housed at the University of Tennessee-Martin Sheep and Goat Research and Teaching Farm and grazed on pasture in late summer and fall, 2008. Body weight, ultrasound and linear measurements were recorded three times during the study. Body weight (BW) was determined using a Gallagher scale. Ultrasound measurements included: body wall thickness (BWT), hide thickness (HT), fat layer thickness (FLT) and Loin Depth (LD). Linear measurements included: cannon length (CL), cannon circumference (CC), shoulder height (SH), heart girth (HG), last rib girth (LR), and circumference of neck (NECK). Goats were transported to Meacham Packing Company (Batesville, AR) and were kosher slaughtered by exsanguination under the inspection of the United States Department of Agriculture. Immediately following slaughter, hot carcass weight (HCW) was recorded. Pearson correlation coefficients were calculated using Proc Corr in SAS; Proc Reg was used to determine regression equations for predicting BW and HCW. Regression using linear measurements and ultrasonography as input variables produced models to predict BW and HCW with R^2 values of 0.73 and 0.38, respectively. The data suggest that reasonable predictions of BW can be made using only linear measurements, especially CC, SH and LR. This finding is important for small goat producers who lack resources to purchase and maintain digital scales and ultrasound equipment.

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Introduction

Livestock operations in Tennessee and the Southeast are typically operated as part-time entities that provide supplemental income to the producer. Goats are commonly found on such farms, especially in Tennessee, which is the second largest goat producing state in the U.S. (NASS, 2007). Compared with cattle, goats have a greater stocking rate, do not require additional feed inputs, may be sustained on low quality forages, and can browse weeds, saplings and overly mature plants. Additionally, the demand for chevon, or goat meat, has greatly increased over the past several years in the U.S. This is due, in some part, to cultural diversification, especially on both the east and west coasts. Therefore, due to lower production inputs compared to cattle, increased demand for chevon, and Tennessee's proximity to the east coast market, the goat population in Tennessee has flourished. This gives part-time producers an additional source of diversified income for their farms.

In any livestock operation, body weight (BW) is a crucial piece of information that a producer needs to know to make proper management decisions. However, purchasing scales to accurately measure BW can be a costly endeavor for the producer and many part-time producers are not willing to make this investment. However, without an accurate BW, making sound management decisions is daunting, if not impossible. This is true pertaining to animal health and pharmaceutical administration, due to: (1) the public's negative opinion about overuse of antibiotics and (2) the potential for anthelmintic resistant strains of *Haemonchus contortus*. The importance of

BW is amplified because pharmaceuticals are given on a per pound basis. If the producer improperly administers antibiotics or de-wormers, profits may decrease, and pharmaceutical resistance in certain microorganisms may be accelerated.

In the past, goat research has been a low priority in the U.S. compared with cattle, swine, and sheep. Most research conducted on goats has occurred in countries such as India, where chevon and goat dairy products are commonly consumed.

Objectives

The objective of this research project was to develop a predictive formula for body weight (BW) and hot carcass weight (HCW) based on correlations and stepwise regressions from linear and/or ultrasound measurements on Spanish x Boer goats.

Literature Review

History of Goats

Goats were one of the earliest animals to be domesticated. Many experts argue whether the sheep or the goat was domesticated first. The domestication of both species has been traced back to long before the writings of the New Testament. Most scholars agree that domestication for both sheep and goats occurred at about the same time, because archeological sites dating back to 7,000 B. C. contained remains of both species (Ensminger, 2002).

The human race has relied on goats since their domestication and their utility has proved to be indispensable. Goats gave early man meat, fiber, cloth, shelter, tools, and milk. The meat of the animal was used for food, while fiber and leather from goat hides were used for clothing and shelter. Even after the development of more permanent housing, the goat has still maintained its place in many cultures. Its milk was consumed by man and animal alike, and was used to make cheese and other dairy products. Older does and bucks were slaughtered for their meat, called chevon, normally after they had served in these other useful ways. Over time, dual-purpose goat breeds were developed to provide adequate amounts of milk as well as high quality meat.

Today, goats are found in small numbers on many farms. Due to their browsing habits, goats are often used to keep land clear of brush and weeds. There is a niche market for dairy products from goats, as it is used to make many different cheeses. Worldwide, more people drink and consume dairy products from goats than from cattle (Belanger, 1974). Chevon is not readily consumed in the U.S., but as cultural markets have opened up and expanded, the demand for chevon has increased.

National and State Goat Statistics

According to the USDA's Agriculture Census (NASS, 2007), there were nearly 150,000 farms with goats and just over 3.1 million goats in the U.S. in 2007. This equates to an average of 20.6 goats per farm. These numbers have increased from 2002, when there were 91,000 farms with goats and 2.5 million goats in the U.S. (NASS, 2002). Texas has the largest number of goats with over 1.1 million head. Tennessee, Oklahoma, and California are the states with the next largest goat populations, totaling over 100,000 goats (NASS, 2007).

The USDA Agriculture Census divides the U. S. goat population into three segments: dairy, angora, and meat. Currently about 350,000 dairy goats are found on 27,000 farms in the U.S. California leads the country in dairy goat production with 39,000 dairy goats. The number of angora goats, which produce mohair fiber, has decreased since the 2002 census from 300,000 to 200,000. Production of mohair has decreased to about 1.4 million pounds because the U.S. lacks the infrastructure to process the mohair fiber. Most fiber is exported for processing and then imported as a finished product. Texas leads the U.S. with 130,000 angora goats producing nearly one million pounds of mohair. Meat type goats make up about 84% of the national goat population with over 2.6 million head. This figure has increased by over a half a million head since last documented in 2002. Texas has a meat goat population of nearly one million animals followed by Tennessee and Oklahoma with over 100,000 head each (NASS, 2007).

According to NASS (2007), Tennessee has an overall goat population of approximately 131,000 head, on 7,000 farms. This equates to an average of 18.7 goats per farm. The state ranks as the second highest in total goat numbers in the country. Tennessee ranks as the nineteenth state in the U.S. for number of dairy goats with roughly 6,000 goats, and thirty-seventh for number of Angora goats with only 250 head producing 1,100 pounds of mohair annually. In meat goat production, however, the state ranked second with 125,000 meat goats that produced revenue of 6.7 million dollars in 2007.

Meat Goat Production

Meat goat production, as in other species, begins with the breeding season. The crossbred goats that are used for meat production are not seasonal breeders like some purebred goats. The gestation period of a goat is about five months (Ensminger, 2002), which allows for two breeding seasons per year, thus conceivably doubling the producer’s annual output. While mature animals may be sold for consumption, most goat meat comes from kids. These animals are normally sold at an age of four to five months. This age coincides with the weaning age of the kids. When marketing kids, the producer, typically chooses from three options: (1) sell their animals through a sale barn, (2) sell the meat directly to the consumer, but the animal has to be slaughtered at a USDA inspected facility, or (3) sell animals directly from the farm for individual slaughter. However, to get the best price, using a barn that regularly has goat sales is preferred.

Use of Weights

The body weight (BW) of goats represents an important piece of information that is needed to manage the stock properly. Unfortunately, livestock scales are quite expensive and not economically feasible for small producers. However, if producers could estimate BW it would allow them to provide adequate nutrition, correctly administer medication and better estimate potential profit. For instance, most medication and de-wormers are given on a per-unit of BW basis and either a sub therapeutic dose or an overdose, can be harmful to the animal and greatly affect profitability. The BW is also important nutritionally, especially in breeding stock, as the producer usually makes feeding decisions based on percent of BW. Knowing the approximate BW of goats, therefore, would allow the producer to make more sound management decisions.

Predicting Body Weight Using Linear Measurements

Ensminger (2002), developed a BW equation where the heart girth is squared, multiplied by body length and then divided by 300. Three studies, conducted outside the U.S., have examined the relationships between linear measurements and the prediction of BW.

Attah et al. (2004) looked at two goat breeds found in West Africa, the Red Sokoto and West African Dwarf. They wanted to determine if animals slaughtered at a predetermined BW had similar body measurements. In their research, they used bucks and does from each breed. The animals were slaughtered at 10, 15, or 20 kilograms. Seventeen measurements were taken on each goat both pre- and post-slaughter. The live measurements included: height at withers, height at pelvis, width at pelvis, depth of chest, chest girth, width of chest, and carcass length. For Red Sokoto goats, there were no significant differences among slaughter weights for height at the withers, depth of chest, or carcass length. For the other measurements, at least two of the slaughter weights had means that were not significantly different. The West African dwarf goats had similar means for the larger two slaughter weights in every measurement except the width of pelvis. The researchers cite the small frame of the dwarf goat as the cause of the discrepancy in the means at the smaller slaughter weight versus those in the larger two. The researchers also compared males to females and found that few of the means were similar. Chest girth and width of chest were significantly correlated to dressing percentage at all three slaughter weights. No body measurements had similar correlation coefficients across all three slaughter weights.

In another study, 122 Black Bengal wethers were subdivided into three groups based on their locations in Bangladesh (Rahman, 2007). Group A had significant correlations between live weight and each of heart girth, body length, and wither height. Group B had significant correlations between the live weight and body length, wither height, heart girth, rib-saddle joint length, and hip width. Only BW and HCW were correlated ($P < 0.1$) in Group C. Rahman, used these correlated measurements, to develop several models for the prediction of live weight.

The third study conducted by Thiruvenkadan and Panneerselvamused (2009) used Kanni Adu goats in India. The animals were between one and six years old; 257 were females while the remaining 47 were males. The researchers took four measurements: body weight, height at withers, chest girth, and body length. All three of the body measurements were significantly correlated ($P < 0.01$) with BW.

Linear measurements are used to find the volume, i.e., the height, width, and length, of the goat, which should be directly related to weight. Now that the relationships between linear measurements and weight are better understood, researchers should be able to streamline the number of measurements needed to predict BW in goats.

Materials and Methods

Animals

Twenty-six male and female Spanish x Boer cross goats were obtained from the Tennessee Livestock Producer's sale barn in Columbia, TN. Handling procedures were done in accordance with UT Martin Agricultural Animal Care and Use Committee. The animals were placed in a quarantine pen at the University of Tennessee at Martin (UTM) Teaching Farm. Fecal egg counts were performed by the on-staff veterinarian, and it was determined that the animals had a large number of internal parasites that included hook, round, and tape worms as well as *Haemonchus contortus* and coccidia. They were subsequently de-wormed by oral drench with 11.36% Albendazole (Valbazen; Pfizer Animal Health) and Moxidectin (Cydectin; Fort Dodge/Pfizer Animal Health), and placed on amprolium 9.6% (Corrid; Merial) regiment for five days. All de-wormers were administered as oral drenches according to the label. During this time, three goats died from the heavy parasite load, which was confirmed via necropsies at the West Tennessee Diagnostics Lab (Martin, TN). The animals were then transported to the UTM Sheep and Goat Research Facility, where the remaining 23 were sorted into four groups and rotationally grazed on mixed grass pastures. Each group of animals was placed in a 0.2 hectare (0.5 ac) pen. Goats in this research project were fed no supplemental grain or roughage.

Data Collection

On August 18, 2008 all goats were caught and placed in a dry lot for a 12 hour shrink. The following day (Date 1) they were weighed and linear and ultrasound measurements were taken with the help of researchers at UTM. Each group of animals was then moved to a new 0.2 hectare (0.5 ac) paddock. Measurements were obtained with a Gallagher Scale (130 West 23rd Av. North Kansas City, MO.), an Ultrasound Scanner (Pie Medical 200 SLC, the Netherlands), and a tailor's measuring tape. Ultrasound measurements were taken at the last rib for hide thickness (HT), fat thickness (FT), body wall thickness (BWT), and depth of loin (LD). The linear measurements were cannon length (CL), cannon circumference (CC), heart girth (HG), shoulder height (SH), neck girth (NECK), and girth at the last rib (LR). This procedure was repeated two weeks later (Date 2). Due to equipment problems, goats were not measured again for nine weeks. During this time one goat died. The third time (Date 3) the animals were measured, all ultrasound measurements were taken but only CL, HG, and NECK were measured. Following data collection, goats were transported to a Meacham Packing Company (Batesville, AR). After slaughter, the HCW was obtained from the employees of the packing plant.

Data Analysis

The data were analyzed using Proc Corr and Proc Reg Procedures of SAS. Correlations and multiple regression were conducted separately for each of the three sampling dates. For the first two sampling events (Date 1 and Date 2), all linear measurements were combined and analyzed together. The CL, HG, and SH data were combined for all three data collection dates and analyzed for correlation and regression. Finally, data on CL, HG, SH and all ultrasound measurements were combined for analysis. Multiple regression and stepwise regression analysis was used to determine which linear and ultrasound measurements could be used to predict BW and HCW.

Results

Linear Measurements

Linear measurement data were initially analyzed as three individual groups with HCW included. Subsequently, data from the first sampling event (Date 1) were combined with data from the second sampling event (Date 2) and analyzed together (more linear measure categories were taken for Date 1 and Date 2 sampling events). For the third sampling event (Date 3), CC, LR, and SH linear measures were inadvertently omitted due to a miscommunication with the sampling team.

For Date 1, five of the six linear measurements were correlated with BW (Table 1). The CC (r = 0.58), HG (r = 0.66), and LR (r = 0.82) were highly correlated ($P \leq 0.01$) with BW. Both CL and SH were also correlated with BW at $P \leq 0.05$ (Table 1). Multiple regression analysis for BW as a function of all six linear measurements yielded the following equation:

$$BW = -120.65 + (CL*0.02) + (CC*-1.16) + (SH*0.78) + (HG*0.37) + (LR*1.34) + (NECK*0.16),$$

with an $R^2 = 0.72$ and $P = 0.0015$. (Equation 1)

Stepwise regression analysis yielded a reduced model which included only LR and SH:

$$BW = -113.08 + (SH*0.79) + (LR*1.49),$$

with an $R^2 = 0.72$ and $P \leq 0.0001$. (Equation 2)

The R^2 value for the reduced model (Equation 2) was almost identical to that of the full model (Equation 1). Therefore, of the linear measurements recorded on Date 1, LR and SH account for most of the variation in BW.

When the linear measurements from Date 1 were correlated with HCW of the animals, only HG (r = 0.59) and LR (r = 0.68) were correlated ($P \leq 0.01$) with HCW (Table 1). For both the full model and reduced model (stepwise regression) of HCW as a function of linear measurements, the R^2 values were low at 0.55 and 0.46 respectively.

For Date 2, again five of the six measurements were correlated with BW (Table 2). However, this time four of the measurements were highly correlated ($P \leq 0.01$): CC, SH, HG, and LR. The NECK was also correlated at $P \leq 0.05$ (Table 2). Multiple regression analysis for BW as a function of all six linear measurements yielded the following equation:

$$BW = -92.27 + (CL*0.32) + (CC*-0.07) + (SH*0.61) + (HG*0.56) + (LR*0.89) + (NECK*0.09),$$

with an $R^2 = 0.95$ and $P \leq 0.0001$. (Equation 3)

Stepwise regression analysis yielded a reduced model that included only SH, HG, and LR:

$$BW = -93.42 + (SH*0.67) + (HG*0.58) + (LR*0.90),$$

with an $R^2 = 0.95$ and $P \leq 0.0001$. (Equation 4)

The R^2 value for the reduced model (Equation 4) was identical to that of the full model (Equation 3). Therefore, of the linear measurements recorded on Date 2 of this study, SH, HG, and LR account for most of the variation in BW. The R^2 value (0.95) for Equation 4 was higher than that of Equation 2 ($R^2 = 0.72$), the reduced model from Date 1, possibly because of the inclusion of an additional variable, (HG) in the model.

Correlation analysis for data from Date 2 revealed that, CC (r = 0.50), SH (r = 0.47), and HG (r = 0.61) were correlated ($P \leq 0.05$) with HCW (Table 2). Only LR (r = 0.68) was correlated at $P \leq 0.01$. For both the full model and reduced model (stepwise regression) of HCW as a function of linear measurements, the R^2 values were again 0.55 and 0.46, respectively.

Only three linear measurements were taken on data collection Date 3, as opposed to six measurements on the previous data collection events. Two of the three measurements were highly correlated ($P \leq 0.01$) with BW: NECK (r = 0.62) and HG (r = 0.83). Cannon length was also correlated ($P \leq 0.05$) with BW (Table 3). Multiple regression analysis for BW as a function of all three linear measurements yielded the following equation:

$$BW = -54.58 + (CL*1.26) + (HG*1.27) + (NECK*0.37),$$

with an $R^2 = 0.74$ and $P \leq 0.0001$. (Equation 5)

Stepwise regression analysis yielded a reduced model that included only CL and HG:

$$BW = -53.55 + (CL*1.61) + (HG*1.38),$$

with an $R^2 = 0.73$ and $P \leq 0.0001$. (Equation 6)

When the linear measurements from Date 3 were correlated with HCW of the animals, only NECK (r = 0.45, $P \leq 0.05$) and HG (r = 0.65, $P \leq 0.01$) were correlated with HCW (Table 3). For both the full model and reduced model (stepwise regression) of HCW as a function of linear measurements, the R^2 values were low at 0.44 and 0.42, respectively.

The data from the Date 1 and Date 2 were combined and analyzed together to increase sample size. Data collected for Date 3 was excluded due to the fewer number of linear measurements taken. For this combined data set (Date 1 and Date 2), all six linear measurements were correlated to BW. Cannon length was correlated at $P \leq 0.05$, while CC, SH, HG, LR, and NECK were all correlated at $P \leq 0.01$ (Table 4). The full multiple regression model for BW as a function of all six linear measurements was:

$$BW = -99.97 + (CL*0.49) + (CC*3.04) + (SH*0.42) + (HG*0.30) + (LR*1.00) + (NECK*0.03),$$

with an $R^2 = 0.73$ and $P \leq 0.0001$. (Equation 7)

Stepwise regression analysis yielded a reduced model that included CC, SH, and LR:

$$BW = -96.72 + (CC*3.63) + (SH*0.49) + (LR*1.15),$$

with an $R^2 = 0.72$, $P \leq 0.0001$ (Equation 8)

This reduced model included both SH and LR, as had the reduced models (Equations 2 and 4) from the analysis of the individual data sets from each data collection date. However, the reduced model for the combined data set included CC as well, which was not found in either of the other two reduced models.

When the linear measurements from combined Date 1 and Date 2 were correlated with HCW of the animals, five of the six measurements were correlated. Four of these measurements, CC (r = 0.44), SH (r = 0.44), HG (r = 0.60), and LR (r = 0.68), were correlated at $P \leq 0.01$. Only CL (r = 0.35) was correlated at $P \leq 0.05$ (Table 4). For both the full model and reduced model (stepwise regression) of HCW as a function of linear measurements, the R^2 values were 0.54 and 0.50, respectively.

Due to the miscommunication that led to only three linear measurements being taken on Date 3, the data were analyzed again using the three consistent measurements from Date 1, Date 2, and Date 3. The three consistent measurements were CL, HG, and NECK. Correlation analysis for data from Date1, Date 2, and Date 3 revealed that, CL (r = 0.43) and HG (r = 0.79) were correlated ($P \leq 0.01$) with BW (Table 5). Only NECK (r = 0.28) was correlated at $P \leq 0.05$. For both the full model and reduced model (stepwise regression) of BW as a function of linear measurements, the R^2 values were lower then the R^2 derived from the six linear measurements from the combined data from Date 1 and Date 2. The full multiple regression model for BW as a function of the three linear measurements was:

$$BW = -68.77 + (CL*0.84) + (HG*1.43) + (NECK*0.53)$$

with an $R^2 = 0.66$ and $P \leq 0.0001$. (Equation 9)

Stepwise regression analysis yielded a reduced model that included HG and NECK:

$$BW = -68.05 + (HG*1.50) + (NECK*0.54)$$

with an $R^2 = 0.66$ and $P \leq 0.0001$. (Equation 10)

For HCW both CL and HG are correlated with BW at $P \leq 0.01$, with NECK correlated at $P \leq 0.05$. The R^2 values for both the full and stepwise models were low at 0.33 and 0.31 respectively.

Ultrasound Measurements

The ultrasound data and data on BW, HCW, NECK, CL, and HG from Date 1, Date 2, and Date 3 were combined and analyzed for correlation and regression. Five of the seven measurements were correlated with BW. NECK was the only measurement correlated at $P \leq 0.05$. The CL, HG, LD, and BWT were all highly correlated ($P \leq 0.01$) with BW (Table 5). Multiple regression analysis for BW as a function of linear and ultrasound measurements yielded the following equation:

$$BW = -59.95 + (CL*0.13) + (HG*1.19) + (NECK*0.62) + (HT*-1.94)$$

$$+ (FT*-1.99) +(LD*0.55) + (BWT*0.35),$$

with an $R^2 = 0.74$ and $P \leq 0.0001$. (Equation 11)

Stepwise regression analysis yielded a reduced model that included HG, NECK, FT, and LD:

$$BW = -60.94 + (HG*1.20) + (NECK*0.65) + (FT*-2.08) + (LD*0.64),$$

with an $R^2 = 0.73$ and $P \leq 0.001$. (Equation 12)

Within this combined data set, five of the seven measurements were correlated with HCW of the animals. Three of these measurements, CL (r = 0.37), HG (r = 0.52), and LD (r = 0.45), were correlated at $P \leq 0.01$. NECK (r = 0.27) and BWT (r = 0.26) were correlated at $P \leq 0.05$ (Table 5). For both the full model and reduced model (stepwise regression) of HCW as a function of linear and ultrasound measurements, the R^2 values were low at 0.39 and 0.38, respectively.

Discussion

This research indicates prediction of BW using linear measurements in conjunction with ultrasound measurements has potential. The analysis of the linear measurements from Date 2 provided the highest coefficient of determination with an R^2 of 0.95. However, this single set of data was small (n = 23) and results varied from the R^2 derived from Date 1 and Date 3. Equation 7 provides a more accurate prediction (R^2 = 0.73) by using a larger data set from combining sampling Date 1 and Date 2. The stepwise procedure reduced the model to CC, SH, and LR with an R^2 of 0.72 (Equation 8). Combining the linear measurements in common (CL, HG, and NECK) for all three sampling dates did not improve the R^2 value (R^2 = 0.66) for either the full or the reduced regression model. Similarly when the linear data were combined with the ultrasound measurements, Equation 11 (full model) was produced with an R^2 of 0.74. When this data set was analyzed using a stepwise regression, the model included HG, NECK, FT and LD (Equation 12) with an R^2 of 0.73. Although the R^2 value was similar to that obtained from stepwise regression of the combined data set from Date 1 and Date 2, the linear variables included in the equation were different, due to fewer linear measurements being taken during the Date 3 sampling event.

Of the regression models derived from the data in this study, Equations 8 and 12 are the two best equations for predicting BW, with R^2 values of 0.72 and 0.73, respectively. Since both of the equations are derived by stepwise regressions, they limit the number of measurements required to predict BW. However, Equation 8 is the most logical choice for a model to predict BW in goats because it includes only linear measurements (CC, SH, and LR). The small increase in the R^2 value for Equation 12 does not justify the use of an ultrasound scanner in the prediction of BW.

Ensminger (2002) developed a model to predict BW in goats using HG and body length. Although HG was not included in Equation 8 (combined data from Date 1 and Date 2), HG was correlated with BW and was part of the reduced models for predicting BW from the individual data sets from Date 2 and Date 3. Therefore, HG cannot be ruled out when considering future research on models to predict BW of goats based on linear measurements. Rahman (2007), Attah et al. (2004), and Thiruvenkadan et al. (2009) all found that body length was significantly correlated with BW. Future research should consider body length as linear measurement for the prediction of BW.

Although this research showed that it is possible to predict BW in goats using linear measurements, the analysis of linear and ultrasound measurements did not produce an acceptable formula for predicting HCW. In both individual and combined data sets of linear measurements and/or ultrasound measurements, R^2 values for the regression models were low (≤ 0.55), indicating that there is much variation in HCW that cannot be explained by the variables included in the models.

Conclusion

Goat producers need an accurate, inexpensive method of predicting the body weight of goats. Proper goat management depends on knowing the body weight of the animals so that producers can provide proper nutrition and administer medication using the correct dosage. Because many goat producers do not own livestock scales, this study examined the possibility of using linear and ultrasound measurements of goats to estimate body weight.

Of the models derived from the variables measured in this study, Equation 8 is the most suitable equation for predicting BW. Equation 8 (with an R^2 of 0.72) can be used to predict BW in goats using CC, SH, and LR. Although other models yielded higher R^2 values, Equation 8 was derived from a combined data set, with a larger sample size. Therefore, it is expected to give a better estimate of BW over a larger range of linear measurements. Equation 12 was also derived from a combined data set and may be used to predict BW, but it is does not improve R^2 by much ($R^2 = 0.73$). In addition, Equation 12 includes ultrasound measurements, which are not cost-effective for many small producers. Thus Equation 8 is best for predicting BW at the lowest cost to the producer.

Although this is a preliminary study with a small sample size (n = 23), the results show that it is possible to derive models to predict BW in goats. Sub-dividing the animals by sex could improve the R^2 value and predictability as well, since it would take into account the variations in size and weight between males and females. Further research on this topic should increase the accuracy of predicting BW in goats using only linear measurements.

Table 1: Correlations among body weight (BW), cannon length (CL), cannon circumference (CC), shoulder height (SH), heart girth(HG), girth at the last rib (LR), neck girth (NECK) and hot carcass weight (HCW) of goats measured on Date 1.

	BW	CL	CC	SH	HG	LR	NECK
CL	0.418*						
CC	0.581**	0.242					
SH	0.462*	0.473*	0.330				
HG	0.665**	0.578**	0.606**	0.260			
LR	0.820**	0.371	0.681**	0.327	0.730**		
NECK	0.348	-0.034	0.625**	0.273	0.300	0.362	
HCW	0.738**	0.391	0.413	0.419	0.590**	0.678*	0.158

* P ≤ 0.05; ** P ≤ 0.01

Table 2: Correlations among body weight (BW), cannon length (CL), cannon circumference (CC), shoulder height (SH), heart girth(HG), girth at the last rib (LR), neck girth (NECK) and hot carcass weight (HCW) of goats measured on Date 2.

	BW	CL	CC	SH	HG	LR	NECK
CL	0.312						
CC	0.736**	0.318					
SH	0.602**	0.388	0.560**				
HG	0.875**	0.320	0.670**	0.425*			
LR	0.926**	0.167	0.673**	0.411	0.805**		
NECK	0.561**	0.099	0.606**	0.439*	0.420	0.527*	
HCW	0.716**	0.329	0.499*	0.472*	0.607**	0.679**	0.279

* P ≤ 0.05; ** P ≤ 0.01

Table 3: Correlations among body weight (BW), cannon length (CL), heart girth(HG), neck girth (NECK) and hot carcass weight (HCW) of goats measured on Date 3.

	BW	CL	HG	NECK
CL	0.457*			
HG	0.835**	0.344		
NECK	0.625**	0.510*	0.600**	
HCW	0.719**	0.357	0.647**	0.446*

* P ≤ 0.05; ** P ≤ 0.01

Table 4: Combined correlations among body weight (BW), cannon length (CL), cannon circumference (CC), shoulder height (SH), heart girth(HG), girth at the last rib (LR), neck girth (NECK) and hot carcass weight (HCW) of goats measured on Date 1 and Date 2.

	BW	CL	CC	SH	HG	LR	NECK
CL	0.325*						
CC	0.676**	0.275					
SH	0.464**	0.413**	0.406**				
HG	0.721**	0.410**	0.616**	0.350*			
LR	0.819**	0.241	0.647**	0.373*	0.772**		
NECK	0.459**	0.055	0.614**	0.352*	0.368*	0.453**	
HCW	0.694**	0.346*	0.442**	0.443**	0.597**	0.678**	0.224

* P ≤ 0.05; ** P ≤ 0.01

Table 5: Combined correlations among body weight (BW), cannon length (CL), heart girth(HG), neck girth (NECK) and hot carcass weight (HCW) of goats measured on Date 1, Date 2, and Date 3.

	BW	CL	HG	NECK
CL	0.425**			
HG	0.793**	0.455**		
NECK	0.277*	0.088	0.131	
HCW	0.616**	0.372**	0.522**	0.269*

Table 6: Combined correlations among body weight (BW), cannon length (CL), heart girth(HG), neck girth (NECK), hide thickness (HT), fat thickness (FT), loin depth (LD), body wall thickness (BWT), and hot carcass weight (HCW) of goats measured on Date 1, Date 2, and Date 3.

	BW	CL	HG	NECK	HT	FT	LD	BWT
CL	0.42**							
HG	0.79**	0.45**						
NECK	0.27*	0.08	0.13					
HT	0.04	-0.13	0.26*	-0.27*				
FT	0.04	0.24	0.16	0.21	0.06			
LD	0.65**	0.42**	0.58**	0.02	0.04	0.02		
BWT	0.52**	0.32**	0.58**	-0.18	0.23	0.02	0.54**	
HCW	0.62**	0.37**	0.52**	0.27*	-0.10	0.17	0.45**	0.26*

* P ≤ 0.05; ** P ≤ 0.01

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Appendix

Table A.1: Stepwise Regression for BW Using Linear Measurements from Date 1 and Date 2.

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	LR	0.6493	0.6493	6.9261	81.47	< 0.0001
2	CC	0.0480	0.6974	2.2230	6.83	0.0123
3	SH	0.0148	0.7121	2.1613	2.16	0.1494

Table A.2: Stepwise Regression for HCW Using Linear Measurements from Date 1 and Date 2.

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	LR	0.4591	0.4591	3.1508	35.65	<0.0001
2	SH	0.0422	0.5013	1.7855	3.47	0.0697

Table A.3: Stepwise Regression for BW Using Three Linear Measurements from Date 1, Date 2, and Date 3.

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	HG	0.6292	0.6292	6.4687	108.59	< 0.0001
2	NECK	0.0306	0.6598	2.8163	5.67	0.0203

Table A.4: Stepwise Regression for HCW Using Three Linear Measurements from Date 1, Date 2, and Date 3.

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	HG	0.2723	0.2723	5.7404	23.95	< 0.0001
2	NECK	0.0408	0.3131	3.9377	3.75	0.0574

Table A.5: Stepwise Regression for BW Using Linear and Ultrasound Measurements

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	HG	0.6147	0.6147	21.0907	105.30	< 0.0001
2	LD	0.0631	0.6778	9.1599	12.72	0.0007
3	NECK	0.0299	0.7076	4.5652	6.54	0.0129
4	FT	0.0097	0.7173	4.4235	2.16	0.1465

Table A.6: Stepwise Regression for HCW Using Linear and Ultrasound Measurements

Step	Variable	Partial R^2	R^2	C(p)	F-value	Pr > F
1	HG	0.2723	0.2723	7.2533	23.95	< 0.0001
2	HT	0.0621	0.3344	3.3474	5.87	0.0183
3	LD	0.0235	0.3578	3.1154	2.26	0.1375
4	NECK	0.0218	0.3796	3.0378	2.15	0.1480