Songklanakarin J. Sci. Technol.
43 (6), 1635-1640, Nov. - Dec. 2021

http://www.sjst.psu.ac.th

Original Article

Body measurements of beef cows by using mobile phone application and prediction of body weight with regression model

Peerayut Nilchuen*, Tipmon Yaigate, and Wirat Sumon

Tubkwang Research Station, Department of Animal Science, Faculty of Agriculture, Kasetsart University, Kaeng Khoi, Saraburi, 18260 Thailand

Received: 3 February 2020; Revised: 5 July 2020; Accepted: 13 January 2021

Abstract

The objective of this experiment was to measure beef cows body parts by using mobile phone application and prediction of body weight (BW) with regression model. A total of 160 crossbred beef cows with 50% Charolais breed in Thailand were weighed using a digital weighing scale and estimated body condition score (BCS) of cows. All cows were photographed with a mobile phone camera and images analyzed for chest depth (CD) by using ImageMeter® application. An average of body weight was 423.99±84.66 kg. The best model to predict BW from CD and BCS for the overall data was as follows thin: BW= -232.34 + 11.17 (CD), moderate: BW= -609.26 + 18.76 (CD) and fat: BW= -232.69 + 12.12 (CD), with an adjusted R^2 of 0.824 and a RMSE of 35.52 corresponding to 8.37 % of the mean actual BW. When compared between the actual BW and BW predicted from the simple linear regression model were not significant (p > 0.05). Correlation coefficient was 0.911. Results of this study suggested that beef cows body measurements by ImageMeter® application and being used in regression equations based on CD and BCS were accurately predicted body weight of crossbred beef cows with 50% Charolais breed.

Keywords: chest depth, body condition score, body weight, crossbred beef cows, mobile application

1. Introduction

Body weight of beef cows is the basis practically used for several management purposes including assessment of feed efficiency, evaluation of nutritional requirements, calculation of dosages of medicines, and determination of growth rate and general health condition (Tariq, Younas, Khan, & Schlecht, 2013). Body weight is also used for determining ration amounts and sale prices of animals (Wangchuk, Wangdi, & Mindu, 2017). Therefore, the accurate estimate of live body weight is of fundamental importance to any livestock production (Wangchuk *et al.*, 2017). The most widely accepted method globally, of measuring body weight is using a calibrated electronic or mechanical scale. However, such equipment is not readily available in a smallholder farming because it is expensive (Dingwell, Wallace, McLaren, Leslie, & Leslie, 2006; Kashoma, Luziga, Werema, Shirima, & Ndossi, 2011; Musa, Elamin, Mohammed, & Abdalla, 2011).

The estimation of body weight by using body measurements has been practiced for a long time. Body weight is closely related to body measurements in cattle (Gilbert, Bailey, & Shannon, 1993; Isik, Topcu, & Guler, 2009; Yan, Mayne, Patterson, & Agnew, 2009; Lesosky *et al.*, 2012; Lukuyu *et al.*, 2016; Wangchuk *et al.*, 2017). Among body measurements, heart girth can be used with great accuracy in estimating live body weight in dairy cows (Lukuyu *et al.*, 2016; Tebug *et al.*, 2018) and beef cows (Mekonnen & Biruk, 2004; Rashid, Hoque, Huque, & Bhuiyan, 2016; Comlan, Steve, & Ibrahim, 2017; Paputungan, Hendrik, & Utiah, 2018; Vanvanhossou, Diogo, & Dossa, 2018)

The body measurements made on cows may result in dangerous events due to the animals being under stress during the process of forcing the animals to position them for an accurate body measurement. Additionally; the possibility of having wrong measurements is also very high. Therefore, due to such unfavorable reasons, the farmers accept not keeping abreast of having body weight information or perform the weighing process rarely (Enevoldsen & Kristensen, 1997; Wilson, Egan, & Terosky, 1997; Tasdemir, Yakar, Urkmez, &

*Corresponding author
Email address: fagrpyn@ku.ac.th

Inal, 2008). Currently, researchers are attempting to using digital image analysis by computer software have been applied to determine and follow the body measurements, live weights and growths of beef cattle (Bozkurt, Aktan, & Ozkaya, 2007; Ozkaya & Yalcin, 2008; Ozkaya, Neja, Krezel-Czopek, & Oler, 2015; Gomes *et al.*, 2016) and dairy cattle (Tasdemir, Urkmez, & Inal, 2011). There are reports of used application on smartphone for estimation of body weight of pig (Wuggl from Allibra, Austria) and for beef (Beefie from Agroninja, Hungary) are now available. However, both applications need to pay for the purchase of accessories and still have a high price which is not yet suitable for use for small-scale farmers. Therefore, the objective of this experiment was to measure beef cows body parts by using mobile phone application and the possibility of applying to prediction of body weight with regression model as basic data which will be developed into a one stop service application in mobile phone.

2. Materials and Methods

2.1 Animals

This study was carried out in beef cattle farm at Tubkwang Research Station, Department of Animal Science, Faculty of Agriculture, Kasetsart University, Saraburi, Thailand. Beef cows (n = 160) of Kamphaeng Saen beef cattle breed, a crossbred cattle (25% Thai native cattle, 25% Brahman breed and 50% Charolais breed) with the a ages of beef cows in postpartum period (90 day) are between 3-10 years, which were kept off feed and water for 12 hours before processes of body measurements, body weighing and taking photographs.

2.2 Body measurements

Body measurements were taken by using measuring tape and measured body values of animal and recorded in centimeters (cm). Heart girth (HG) was measured as the minimal circumference around the body immediately behind the front shoulder of the animal. Body condition scoring (BCS) was performed (1-9 point scale) where 1 point scale was emaciated, 5 point scale was moderate and 9 point scale was extremely fat (Rae, Kunkle, Chenoweth, Sand, & Tran, 1993). The BCS are groups and category as follows; thin: 1-4 point, moderate: 5-7, and fat: 8-9.

2.3 Live body weighing

All animals were weighed using a digital cattle weighing scale mounted on a steel platform and recorded in kilogram (kg). The weighing scale was calibrated prior to the data collection.

2.4 Photographs of animals

All animals were photographed with a mobile phone camera (Zenphone, Asus®) at a distance of 1.3 m above the ground and distance of 2.5 m from the animal and size of image aspect ratio to 16:9. Before each photograph was taken, a 73 cm ruler was used as a dimensional reference.

2.5 Image analysis

All images were analyzed using ImageMeter® mobile application (Algorithmic Research, Germany) and Adobe Photoshop® CS6 computer program (Adobe Systems Inc., San Jose, CA). The analysis of images was carried out as follows: the number of pixels contained in the body dimensions and reference ruler and a pixel:cm ratio was calculated for each photograph by measuring the numbers of pixels contained in the ruler. This pixel:cm ratio was used to transform all the measurements taken on the photographs of the animals into cm. Chest depth (CD) was measured as distance between top of back just behind shoulder and bottom of barrel behind the front leg (Figure 1).

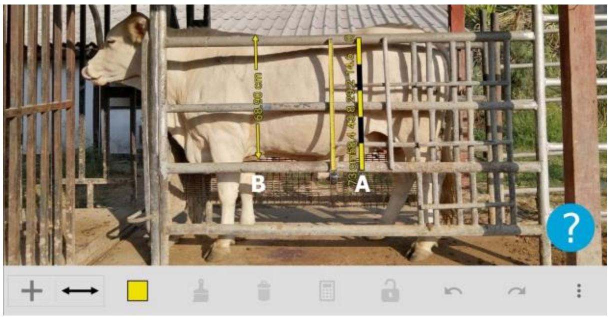

Figure 1. Typical digital body measurements in ImageMeter® mobile application (A: dimensional reference and B: chest depth)

2.6 Statistical analysis

All statistical analyses were performed using R version 3.2.2. (R Core Team, 2019). The recorded data was subjected to statistical analysis to find the correlation coefficients and regression analysis of BW as dependent body measurements and converted ordinal data (BCS are 3 levels :thin, moderate and fat) into dummy variables were performed using simple linear regressions analysis. The model used was:

$$Y_i = b_0 + b_1X_1 + \varepsilon_i$$

where, Y_i is the live weight observation of i^{th} animals; b_0 is the intercept; b_1 are the regression coefficient; X_1 is HG or CD and ε_i is residual error term. The adjusted coefficient of determination (adjusted R^2) was also given for the models, as an indicator of the amount of variance in BW explained by the model. The root mean square error (RMSE; the same as the standard deviation of the residuals), and also the RMSE expressed as a percent of the actual BW, was used an indicator of accuracy of the regression estimates (Yan *et al.*, 2009; Lukuyu *et al.*, 2016). The fit of the regression models were also tested for homogeneity of variances and normality using Bartlett' test and Shapiro-Wilk test, respectively.

The comparison between the actual BW and BW predicted from the regression model were determined by paired t-test. The correlation of the actual BW and BW predicted were calculated by Pearson's correlation coefficients. A probability of $p \leq 0.05$ was considered as significant.

3. Results

3.1 Body measurements

The correlation coefficient between BW and HG obtained in this study was high (r = 0.952). When regression analysis, found that simple linear regression model was used to construct a prediction equation based on a single body measurement by using measuring tape, regressing BW on HG measurements gave statistically significant ($p < 0.001$), which had an adjusted R^2 of 0.9047 and a RMSE of 26.22 corresponding to 6.18 % of the mean actual BW. Combination of HG and BCS was found regressing BW on HG and BCS measurements gave statistically significant ($p < 0.001$), which had an adjusted R^2 of 0.9197 and a RMSE of 24.06 corresponding to 5.67 % of the mean actual BW (Table 1).

When compared between the actual BW and BW predicted from all simple linear regression models were not significant ($p > 0.05$). The correlation coefficients were 0.952 for HG regression model, 0.962 for HG and BCS regression model.

3.2 Images analysis

Firstly, a comparison of accuracy CD measurement of cow images between images analyzed using Adobe Photoshop® CS6 computer program and ImageMeter® mobile application by paired t-test found that CD measured were insignificant statistically ($p > 0.05$). Therefore, ImageMeter® mobile application can be used to body measurements of images in cattle (Figure 2).

When analyzing the image, found that simple linear regression model was used to construct a prediction equation based on a single body measurement by images analyzed using ImageMeter® mobile application, regressing BW on CD measurements gave statistically significant ($p < 0.001$), which had an adjusted R^2 of 0.7260 and a RMSE of 44.31 corresponding to 10.45% of the mean actual BW. Combination of CD and BCS was found regressing BW on CD and BCS measurements gave statistically significant ($p < 0.001$), which had an adjusted R^2 of 0.8240 and a RMSE of 35.52 corresponding to 8.37% of the mean actual BW (Table 2).

When compared between the actual BW and BW predicted from all simple linear regression models were not significant ($p > 0.05$). The correlation coefficients were 0.853 for CD regression model, 0.911 for CD and BCS regression model (Figure 3).

4. Discussion

The aim of this experiment was to develop an easy-

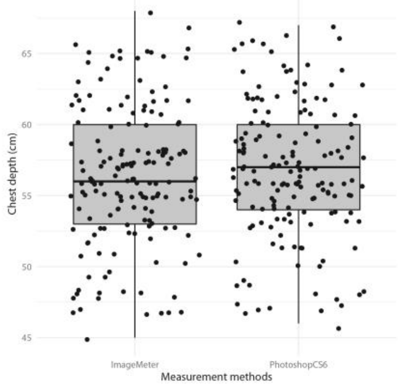

Figure 2. Boxplot of a comparison of accuracy CD measurement of cow images between images analyzed using ImageMeter® mobile application and Adobe Photoshop® CS6 computer program by paired t-test

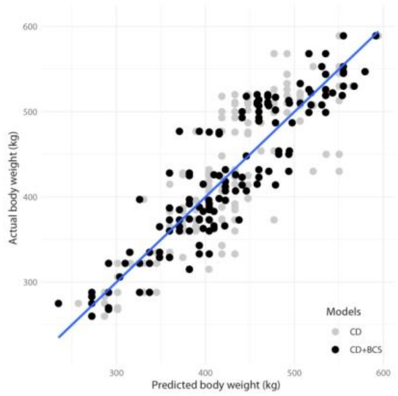

Figure 3. Scatterplot of relationship between the actual body weight and predicted body weight using regression models derived an independent variable from Image Meter® mobile application

to-use tool to predict BW of cows from body measurements by using mobile phone image analysis application. We were interested in a model with a single explanatory variable and that could be used across the range of cattle types present in the study sites. The single explanatory variable that explained the most variation was HG, consistent with previous studies in beef cows (Mekonnen & Biruk, 2004; Rashid *et al.*, 2016; Comlan *et al.*, 2017; Paputungan *et al.*, 2018; Vanvanhossou *et al.*, 2018). The correlation was high (r = 0.952) between BW and HG obtained in this study. The body weight was highly correlated with heart girth in cattle as reported by Mekonnen and Biruk (2004) demonstrate that the existence of a strong relationship between HG and BW (r = 0.970) in zebu

Table 1. Simple linear regression of body weight (BW) and body condition scores (BCS) on independent variables by body measurements were using measuring tape

Parameter	BCS[a]	Regression model	Adjusted R^2	RMSE[b]	RMSE as % actual BW
HG	-	BW= -690.80 + 6.62 (HG)	0.9047	26.22	6.18
HG	Thin	BW= -745.02 + 6.88 (HG)	0.9197	24.06	5.67
	Moderate	BW= -630.64 + 6.35 (HG)			
	Fat	BW= -760.67 + 7.03 (HG)			

[a]BCS are groups and category as follows; thin: 1-4 point, moderate: 5-7 and fat: 8-9. [b]Root mean square error

Table 2. Simple linear regression of body weight (BW) and Body condition scores (BCS) on independent variables by images analyzed using ImageMeter® mobile application

Parameter	BCS[a]	Regression model	Adjusted R^2	RMSE[b]	RMSE as % actual BW
CD	-	BW= -401.84 + 14.65 (CD)	0.7260	44.31	10.45
CD	Thin	BW= -232.34 + 11.17 (CD)	0.8240	35.52	8.37
	Moderate	BW= -609.26 + 18.76 (CD)			
	Fat	BW= -232.69 + 12.12 (CD)			

[a]BCS are groups and category as follows; thin: 1-4 point, moderate: 5-7 and fat: 8-9. [b]Root mean square error

cows. Similar, report of Rashid *et al.* (2016) found that the body weight had highest correlation coefficient with HG around the chest (r = 0.973) in Brahman crossbred cows. Comlan *et al.* (2017) described that the greatest correlation was observed between BW and HG (r = 0.970) in Lagune crossbred cows.

In the present study, predicting BW from HG alone by using measuring tape, the model had that R^2 value and accuracy of the regression BW estimates were high. Findings of this study were supported by Mekonnen and Biruk (2004), Rashid *et al.* (2016), Comlan *et al.* (2017), Paputungan *et al.* (2018) and Vanvanhossou *et al.* (2018) described that R^2 value of HG were significantly higher and most suitable predictor for BW estimation in crossbred beef cattle. Musa *et al.* (2011) found a similar trend in beef cattle, that high HG circumference measurement meant more muscle in the meat.

However, when analyzing BCS together with body measurements, it was found that the model had greater an accuracy of the regression BW estimates (5.67%) than model that measured HG alone. Supported the recommendation made by Enevoldsen and Kristensen (1997) to use BCS along with body measurements as a predictor of BW. Several authors have demonstrated that, there is a relationship between body measurements especially BCS and HG with live weight of animals (Nicholson & Sayers, 1987; Nesamvuni, Mulaudzi, Ramanyimi, & Taylor, 2000; Abdelhadi & Babiker 2009). The body condition scoring being a subjective technique is used at regular intervals for assessing the condition of livestock. It is particularly helpful in assessing the body fat reserves of farm animals by visual and manual inspection of the thickness of fat cover and prominence of the bone at the tail head and loin region (Vasseur, Gibbons, Rushen, & Passillé, 2013; Roche, Berry, & Kolver, 2006; Roche, Berry, Lee, Macdonald, & Boston, 2007; Roche *et al.*, 2008). Singh, Randhawa, and Randhawa (2015) studied the relationship between BCS and back fat thickness using real-time ultrasonographic in transition crossbred cows and found that the correlation coefficient between BCS and back fat thickness for different transition stages was 84%, 79% and 75% for far off dry, close up dry and fresh period, respectively. Therefore, evaluating BCS along with HG measurements makes the body weight predictions more accurate.

Adobe Photoshop® CS6 computer program and ImageMeter® mobile application were used to body measurement of cow photos found that not significantly different. There are several reports indicating that using Adobe Photoshop® program in computer for size and length measurement of items in a photograph. (Bruckmaier, Lehmann, Hugi, Hammon, & Blum, 1998; Santo *et al.*, 2001; Kapetch, Pakdeethai, & Sarawat, *2011*; Stojkov, von Keyserlingk, Marchant-Forde, & Weary, 2015). Kapetch *et al.* (*2011*) found that the area of paper in digital image were measured by using Adobe Photoshop® CS*3* have the closest to real area ($R^2 = 0.9999$). Santo *et al.* (2001) demonstrated that Adobe Photoshop® CS6 was effective for breast measurement in women by using a computer and Raw files, with a specific software, without the need for specific training. The direct breast measurements were different from the ones obtained using Adobe Photoshop® CS6.

The results from body measurements of cows by images analyzed using ImageMeter® mobile application are in the same direction as body measurements by using measuring tape, found that predicting BW from CD alone, the model had lower an accuracy of the regression BW estimates (10.45%) than model that measured HG by using measuring tape. However, when analyzing BCS together, it was found that the model had greater an accuracy of the regression BW estimates (8.37%) than model that measured CD alone. Similar, Bozkurt *et al.* (2007) reported that the prediction ability of body measurements (body length, wither height, hip height, hip width and chest depth) by digital image analysis system was very promising to predict BW in slaughtered beef cattle. HG measurement by using measuring tape can be measured in *3*D, which can measure the total length of the chest that is curved or concave and can achieve accurate length. As for CD measurement from the photograph, the body size can be measured only in *2*D. When CD measured, it is not possible to measure all curves or concave, resulting in less accuracy than body measurement from using measuring tape.

A comparison of predicted BW to real BW via the model showed no significant difference. In accordance with the report of Tasdemir *et al.* (2011) found that BW estimation using body measurements was then performed by the aid of the regression equations, and the correlation coefficient between the estimated and real body weight values obtained by weighing was calculated as 0.9787, which indicates the digital image analysis (IA) method is appropriate for BW estimation of Holstein cows.

Although, predicting BW from models by images analyzed using ImageMeter® mobile application had lower an accuracy of the regression BW estimates than model that body measurements by using measuring tape. But, the advantage of this type of image analysis is that save on the time, labor required and most importantly not touch the animal's body which can reduce stress and reduce accidents caused by work. However, the body weight estimates are within ±20% of true weight, which is acceptable for dosing with veterinary drugs (Machila, Fèvre, Maudlin, & Eisler, 2008; Lesosky *et al.*, 2012) whereas such a range may be inappropriate where animals are sold per kg live weight as it may have implications on profitability of the enterprise (Machila *et al.*, 2008). The magnitude of errors observed in this study is nevertheless, within the safe limits for drug.

5. Conclusions

It is concluded that the prediction ability of digital image analysis system by using ImageMeter® mobile application was very promising to predict BW in crossbred beef cows with 50% Charolais breed. Moreover, this method is viable, quick, effective and very practical on animals to obtain their body measurements. Additionally, this approach can be used other brands of mobile phones that can download this mobile application. In the future, this research results will be further developed to be programmed and built into a one stop service application mobile phone by analyzing digital photos from mobile phone and calculate to be body weight.

Acknowledgements

Authors would like to thank all technicians and staff at Tubkwang Research Station, Department of Animal Science, Faculty of Agriculture, Kasetsart University, Saraburi, Thailand for field study.

References

Abdelhadi, O. M. A., & Babiker S.A. (2009). Prediction of zebu cattle live weight using live animal measurements. *Livestock Research for Rural Development, 21*, 133, Retrieved from http://www.lrrd.org/lrrd21/8/abde21133.htm

Bruckmaier, R. M., Lehmann, E., Hugi, D., Hammon, H. M., & Blum, J. W. (1998). Ultrasonic measurement of longissimus dorsi muscle and backfat, associated with metabolic and endocrine traits, during fattening of intact and castrated male cattle. *Livestock Production Science, 53*, 123-134. doi:10.1016/S0301-6226(97)00162-0

Bozkurt, Y., Aktan, S. & Ozkaya, S. (2007). Body weight prediction using digitalimage analysis for slaughtered beef cattle. *Journal of Applied Animal Research, 32*(2), 195-198. doi:10.1080/09712119.2007.9706877

Comlan, A. B. G., Steve, A. J., & Ibrahim, A. T. (2017). Use of body measurements to estimate live weight of Lagune cattle in southern Benin. *The Saudi Journal of Life Sciences, 2*(2), 23-32. doi:10.21276/haya.2017.2.2.1

Dingwell, R. T., Wallace, M. M., McLaren, C. J., Leslie, C. F., & Leslie K.E. (2006). An evaluation of two indirect methods of estimating body weight in Holstein calves and heifers. *Journal of Dairy Science*, 89(10), 3992-3998. doi:10.3168/jds.S0022-0302(06)72442-0

Enevoldsen, C. & Kristensen, T. (1997). Estimation of body weight from body size measurements and body condition scores in dairy cows. *Journal of Dairy Science, 80*, 1988-1995. doi:10.3168/jds.S0022-0302(97)76142-3

Gilbert, R. P., Bailey, D. R. C., & Shannon, N. H. (1993). Linear body measurements of cattle before and after 20 years of selection for post weaning gain when fed two different diets. *Journal of Animal Science, 71*, 1712-1720. doi:10.2527/1993.7171712x

Gomes, R. A., Monteiro, G. R., Assis, G. J. F., Busato, K. C., Ladeira, M. M., & Chizzotti, M. L. (2016). Estimating body weight and body composition of beef cattle trough digital image analysis. *Journal of Animal Acience, 94*(12), 5414-5422. doi:10.2527/jas.2016-0797

Isik, H. B., Topcu, Y., & Guler, O. (2009). Determination of the factors affecting live weight gain using factor analysis and stepwise regression model. *Journal of Applied Animal Research, 35*, 161-164. doi:10.1080/09712119.2009.9707008

Kapetch, P., Pakdeethai, C., & Sarawat V. (2011). Estimation of leaf area using digital image. *Khon Kaen Agriculture Journal, 39*, 392-397. Retrieved from https://ag2.kku.ac.th/kaj/PDF.cfm?filename=70.pdf&id=538&keeptrack=8

Kashoma, I. P. B., Luziga, C., Werema, C. W., Shirima, G. A., & Ndossi, D. (2011). Predicting body weight of Tanzania shorthorn zebu cattle using heart girth measurements. *Livestock Research for Rural Development*, *23*(4) (Abstract). Retrieved from http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/2407

Lesosky, M., Dumas, S., Conradie, I., Handel, I. G., Jennings, A., Thumb, S., & de Clare Bronsvoort, B.M. (2012). A live weight–heart girth relationship for accurate dosing of east African shorthorn zebu cattle. *Tropical Animal Health and Production, 45*(1), 311-316. doi:10.1007/s11250-012-0220-3

Lukuyu, M. N., Gibson, J. P., Savage, D. B., Duncan, A. J., Mujibi, F. D. N., & Okeyo, A. M. (2016). Use of body linear measurements to estimate liveweight of crossbred dairy cattle in smallholder farms in Kenya. *SpringerPlus, 63*(5), 1-14. doi:10.1186/s40064-016-1698-3

Mekonnen, H. M., & Biruk. T. (2004). Heart girth-body weight relationship in two Ethiopian zebu breeds. *Revue de Medecine Veterinaire, 155*, (Abstract). Retrieved from https://www.revmedvet.com/artdes-us.php?id=1266

Machila, N., Fèvre, E. M., Maudlin, I., & Eisler, M. C. (2008). Farmer estimation of live bodyweight of cattle: implications for veterinary drug dosing in East Africa. *Preventive Veterinary Medicine, 87*(3-4), 394-403. doi:10.1016/j.prevetmed.2008.06.001

Musa, A. M., Elamin, K. M., Mohammed, S. A., & Abdalla, H. O. (2011). Morphometric traits as indicators for body weight in Sudanese Kenana cattle. *Online Journal of Animal and Feed Research, 1*(5), 218-222. Retrieved from http://ojafr.ir/main/attachments/article/78/OJAFR-%20A36.pdf

Nicholson, M. J., & Sayers, A. R. (1987). Relationships between body weight, condition score and heart girth changes in Boran cattle. *Tropical Animal Health Production, 19*, 115-120. doi:10.1007/BF02297329

Nesamvuni, A. E., Mulaudzi, J., Ramanyimi, N. D., & Taylor, G. J. (2000). Estimation of body weight in Nguni-type cattle under communal management conditions. *South African Journal of Animal Science, 30*(4), 97-98. doi:10.4314/sajas.v30i4.3927

Ozkaya, S., & Yalcin, B. (2008). The relationship of parameters of body measures and body weight by using digital image analysis in pre-slaughter cattle. *Archiv Fur Tierzucht-Archives of Animal Breeding, 51*, 120-128. doi:10.5194/aab-51-120-2008

Ozkaya, S., Neja, W., Krezel-Czopek, S., & Oler, A. (2015). Estimation of bodyweight from body measurements and determination of body measurements on Limousin cattle using digital image analysis. *Animal Production Science, 56*(12), 2060-2063. doi:10.1071/AN14943

Paputungan, U., Hendrik, M. J., & Utiah, W. (2018). Predicting live weight of Indonesian Local-Bali cattle using body volume formula. *Livestock Research for Rural Development, 30*(8), Retrieved from http://www.lrrd.cipav.org.co/lrrd30/8/umarf30144.html

Rae, D. O., Kunkle, W. E., Chenoweth, P. J., Sand, R. S., & Tran, T. (1993). Relationship of parity and body condition score to pregnancy rates in Florida beef cattle. *Theriogenology, 39*(5), 1143-1152. doi:10.1016/0093-691X(93)90013-U

Roche, J. R., Berry, D. P., & Kolver, E. S. (2006). HolsteinFriesian strain and feed effects on milk production, body weight, and body condition score profiles in grazing dairy cows. *Journal of Dairy Science, 89*, 3532-3543. doi:10.3168/jds.S0022-0302(06)72393-1

Roche, J. R., Berry, D. P., Lee, J. M., Macdonald, K. A., & Boston, R. C. (2007). Describing the body condition score change between successive calvings: A novel strategy generalizable to diverse cohorts. *Journal of Dairy Science, 90*, 4378-4396. doi:10.3168/jds.2006-729

Roche, J. R., Blache, D., Kay, J. K., Miller, D. R., Sheahan, A. J., & Miller, D.W. (2008). Neuroendocrine and physiological regulation of intake, with particular reference to domesticated ruminant animals. *Nutrition Research Reviews, 21*, 207-234. doi:10.1017/S0954422408138744

Rashid, M. M., Hoque, M. A., Huque, K. S., & Bhuiyan, A. K. F. H. (2016). Prediction of live weight for Brahman crossbred cattle using linear body measurements in rural area. *Advances in Animal and Veterinary Sciences, 4*(2), 99-106. doi:10.14737/journal.aavs/2016/4.2.99.106

R Core Team. (2019, August 27). *R*: *A language and environment for statistical computing.* R Foundation for Statistical Computing. Vienna, Austria. Retrieved from http://www.R-project.org/

Stojkov, J., von Keyserlingk, M. A. G., Marchant-Forde, J. N., & Weary, D.M. (2015). Assessment of visceral pain associated with metritis in dairy cows. *Journal of Dairy Science, 98*(8), 5352-5361. doi:10.3168/jds.2014-9296

Singh, R., Randhawa, S. N. S., & Randhawa, C. S. (2015). Body condition score and its correlation with ultrasonographic back fat thickness in transition crossbred cows. *Veterinary World, 8*(3), 290-294. doi:10.14202/vetworld.2015.290-294

Santo, P., Neto, M., Furtado, F., Trigo, T., Santo, A., Nonato, F., Tumeh, R., & Ferreira, L. (2018). Breast measurement using Adobe Photoshop®. *Brazilian Journal of Plastic Surgery, 33*(1), 96-103. doi:10.5935/2177-1235.2018RBCP0014

Tasdemir, S., Yakar, M., Urkmez ,A., & Inal, S. (2008). Determination of body measurements of a cow by image analysis. *Proceedings of the 9th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing*, 1-7. doi:10.1145/1500879.1500956

Tasdemir, S., Urkmez, A., & Inal, S. (2011). Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis. *Computers and Electronics in Agriculture, 76*(2), 189-197. doi:10.1016/j.compag.2011.02.001

Tariq, M., Younas, M., Khan, A. B., & Schlecht, E. (2013). Body measurements and body condition scoring as basis for estimation of live weight in Nili-Ravi buffaloes. *Pakistan Veterinary Journal, 33*, 325-329. Retrieved from http://pvj.com.pk/pdf-files/33_3/325-329.pdf

Tebug, S. F., Missohou, A., Sourokou Sabi, S., Juga, J., Poole, E. J., Tapio, M., & Marshall, K. (2018). Using body measurements to estimate live weight of dairy cattle in low-input systems in Senegal. *Journal of Applied Animal Research, 46*(1), 87-93. doi:10.1080/09712119.2016.1262265

Vasseur, E., Gibbons, J., Rushen, J., & Passillé, A. M. D. (2013). Development and implementation of a training program to ensure high repeatability of body condition scoring of dairy cows. *Journal of Dairy Science, 96*(7), 4725-4737. doi:10.3168/jds.2012-6359

Vanvanhossou, S. F. U., Diogo R. V. C., & Dossa L. H. (2018). Estimation of live bodyweight from linear body measurements and body condition score in the West African Savannah Shorthorn cattle in North-West Benin. *Cogent Food & Agriculture, 4*(1), 1-12. doi:10.1080/23311932.2018.1549767

Wilson, L. L., Egan, C. L., & Terosky, T. L. (1997). Body measurements and body weights of special-fed Holstein veal calves. *Journal of Dairy Science, 80*, 3077-3082. doi:10.3168/jds.S0022-0302(97)76277-5

Wangchuk, K., Wangdi, J., & Mindu, M. (2017). Comparison and reliability of techniques to estimate live cattle body weight. *Journal of Applied Animal Research, 46*(1), 349-352. doi:10.1080/09712119.2017.1302876

Yan, T., Mayne, C. S., Patterson, D. C., & Agnew R. E. (2009). Prediction of body weight and empty body composition using body size measurements in lactating dairy cows. *Livestock Science, 124*(1-3), 233-241. doi:10.1016/j.livsci.2009.02.003