Meat Production Potential and Prediction of Carcass Weight of Three Native Goat Breeds in Ethiopia

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Abstract

In this study, randomly selected bucks belonging to Abergelle, Afar and Central-Highlands (CH) goat breeds with their origin in the country and mostly reared under traditional (extensive) management system were used to record their age using dentition pattern, along with some linear body measurements (LBMs): heart girth (HG), height at withers (HAW), body length (BL), rump height (RH), pelvic width (PW) and neck circumference (NC), as well as body weight (BW) at slaughter and hot carcass weight (HCW) after evisceration whereas dressing percentage (DP) was computed using BW and HCW. The objectives were to assess the effect of breed, age and their interaction on LBMs, BW, HCW and DP and develop models for predicting HCW using LBMs and BW. Breed, age and their interaction had significant ($P < 0.05$) influence on LBMs, BW and HCW whereas DP was influenced ($P < 0.05$) by breed and age. Body weight, HG, HAW, BL and RH were the highest ($P < 0.001$) in CH; CH and Abergelle breed had comparable ($P > 0.05$) HCW, PW and NC and these were higher ($P < 0.05$) than values recorded for Afar whereas the highest ($P < 0.05$) DP was recorded in Abergelle. The association HCW had with LBMs and BW was the highest ($P < 0.001$) in CH. Models set for predicting HCW of Abergelle (Adj R^2= 0.69) and CH (Adj R^2= 0.84) at age of 2 PPI and Afar bucks at age of 1 PPI (Adj R^2= 0.76) explained the variation in HCW better than models set for the other age categories of their respective breed. In conclusion, Abergelle breed had better meat production potential. The models set for predicting HCW would be useful for selecting goats for meat production.

***Keywords**: indigenous goat breeds, live body attributes, carcass weight, prediction models, Ethiopia.*

INTRODUCTION

Ethiopia is endowed with large goat population estimated at 29.1 million heads (CSA, 2015). The goats are reared across diverse agro-ecologies, communities and production systems (Solomon Gizaw, 2008). Goat plays a vital role in the livelihood of subsistence and small-scale

farmers, agro-pastoralists and pastoralists of Ethiopia, contributing to food security directly through milk and meat production and indirectly as source of income (Dereje Tadesse *et al*., 2014). The demand for live goats and/or their meat (chevon) both for domestic consumption and national export earnings is increasing (Ameha Sebsibe, 2006). According to Ethiopia livestock master plan, the total increase in number of goats in all production zones of Ethiopia will be from 32 to 44 million in 2020 showing a 36% increase whereas the potential contribution of goats to meat in all production zones will grow from 97, 331 (in 2015) to 171,400 tons by 2020 showing a 43% increase (Shapiro *et al*., 2015), which requires efforts to improve the scale of goat production.

Ethiopian goats are grouped into 11 breeds/populations based on physical characteristics (FARM Africa, 1996) and into 8 breeds/populations on the basis of DNA or molecular characterization (Tesfaye Alemu, 2004). Abergelle, Afar and Central-Highlands (CH) goats are among the goat breeds which are common to north Ethiopia. Abergelle goat breed has developed specific adaptations to survive and produce under extremely adverse conditions where there is feed and water shortage, that make the breed suitable for use in traditional low input system (Nigatu Alemayehu, 1994).Abergelle goats are stocky, compact and well built, with straight to concave facial profile and in most cases males have much bigger, magnificent spiral horns directed backwards. The coat color is mostly reddish-brown with some individuals having plain or patchy colors. The hair coat is short and smooth in both sexes and males have ruff and beard (FARM-Africa, 1996). Afar goat breed is the other goat breed which is known for its adaptation to harsh environmental and climatic condition. The breed is characterized by physical characteristics of concave facial profile, narrow face, pricked ear, leggy body conformation, long and thin upward-pointing horns, variable coat color, patchy being common. Afar goats have fine and short hair coat, majority of the male goats have ruff, beard and wattles (FARM-Africa, 1996). Central-Highlands goat (CH) breed is a famous breed found widely distributed in the colder central highlands of Ethiopia. The breed is characterized by medium-body size, broad-face and variable coat color, the predominant color being reddish-brown. The breed is characterized by predominantly straight facial profile, all males have curved or straight horns which are oriented backwards (Yoseph Mekasha *et al*., 2008).

Body weight (BW), hot carcass weight (HCW) and dressing percentage (DP) are important parameters for assessing the meat production potential of animals (Dzakuma *et al*., 2004). Evaluation of performance in live animals is commonly done through determination of BW (Slippers *et al*., 2000) but other parameters such as linear body measurements (LBMs) are also in use (Attah *et al*., 2004). Body weight can be predicted using LBMs as predictor variables. Similarly, HCW can be predicted using LBMs and BW as predictors. Such relationship between parameters is also used as criteria for selection of goats for meat production (Rahman *et al*., 2008). Breed, sex and BW are known to influence body measurements to various degrees in goats (Attah *et al*., 2004). Age has also been reported to significantly affect different body parameters (Rahman, 2007) as weight and other measurements increase with age (Sebolai *et al.*, 2012).

Though Ethiopia is endowed with diverse goat genetic resources, the meat production potential of the goat breeds in relation to age and under farmer's management condition has not been adequately documented (Ameha Sebsibe, 2006) especially for Abergelle, Afar and CH goat breeds. In addition, so far models for predicting HCW of goats indigenous to Ethiopia are lacking. Knowledge on the meat production potential of indigenous goat breeds is useful to select for increased productivity and for designing appropriate breed-improvement plan. Thus, the objectives of this study were to assess the effect of breed, age and their interaction on LBMs, BW, HCW and DP and develop models for predicting HCW using LBMs and BW as predictor variables.

MATERIALS AND METHODS

Study location and animals

Data collection was conducted at Abergelle International Export Slaughterhouse, located at geographic coordinates of 13°33'N and 39°30'E, at a distance of 9 km north of Mekelle town, the capital of Tigray region, in north Ethiopia. Abergelle Slaughterhouse is a modern Slaughterhouse and uses many advanced slaughter techniques. It is equipped with large cold rooms, vacuum packing system and waste treatment facilities (AILD, 2010). More than 95% of the production is destined for export to the Middle East countries (AILD, 2010; FEMLE, 2010). At full production, the Slaughterhouse has a capacity of processing 30 tons of beef and 9 tons of goat and sheep meat per day (AILD, 2010; FEMLE, 2010).

The study animals were un-castrated bucks belonging to Abergelle, Afar and CH goat breeds, selected from a batch of bucks delivered for slaughter at Abergelle International Export Slaughterhouse. Bucks of the three goat breeds were selected purposively because of their abundance in the study area and the breeds represented the main slaughtered goats at Abergelle Slaughter house. A total of 1062 bucks, 354 each from the 3 goat breeds at equal proportion (118 bucks) of 3 age categories (0 PPI, 1 PPI and 2 PPI) were utilized (Table 1). Because the Slaughterhouse was dealing mainly with slaughter of younger goats, this study was limited to the three age categories indicated above.

Management of study goats within the prevailing livestock production systems

The goat breeds (from which the study bucks originated) are reared by farmers, pastoralists and agro-pastoralists in their breeding area under traditional (extensive) livestock management system. Abergelle goats are mainly reared under extensive system, in the mixed crop-livestock and agro-pastoral production systems, along River Tekeze and some parts of Alamata district in Tigray region and in Wag-Himra (Sekota) and East Gondar zones of Amhara region. Abergelle goats are grazed on native pasture on communal grazing lands and fallow plots, occasionally provided with straw, crop residue and stubble (aftermath) depending on season. During the cropping season, the goats are largely dependent on hillsides, field margins and roadside grazing (FARM-Africa, 1996).

Table 1. Mean ± SD for LBMs (cm), body weight (kg), HCW (kg) and DP of bucks of study goats by breed and age categories.

Age	N	HG [cm]	HAW [cm]	BL [cm]	RH [cm]	PW [cm]	NC [cm]	BW [kg]	HCW [kg]	DP (%)
Breed										
Ab	354	64.0±3.6	64.0±3.9	60.1±4.4	67.1±3.7	10.2±1.2	27.4±2.7	19.8±2.9	8.9±1.6	44.8±4.9
AF	354	61.5±3.9	61.7±3.5	59.5±4.2	64.5±4.1	9.9±1.3	26.6±2.8	19.0± 2.7	8.4±1.8	43.8±5.8
CH	354	64.8±4.5	65.6±4.6	61.3±4.5	69.3±5.1	10.3±1.2	27.5±3.1	20.7± 3.4	9.1±1.9	43.7±4.8
Breed by age categories										
Ab 0 PPI	118	62.8±3.3	62.9±3.9	58.9±4.7	66.7±3.8	10.0±1.2	26.8±2.7	19.2±2.3	8.6±1.2	45.1±4.5
1 PPI	118	63.8±3.4	63.9±3.5	59.9±4.0	66.7±3.8	10.1±1.1	26.9±2.4	19.5±2.8	8.6±1.5	44.2±4.9
2 PPI	118	65.5±3.5	65.2±3.3	61.6±4.1	67.9±3.4	10.6±1.3	28.6±2.7	20.9±3.2	9.4±1.9	45.1±5.3
AF 0 PPI	118	59.7±2.7	60.9±3.1	58.0±3.8	63.0±3.3	9.4±0.9	25.2±2.1	17.6±1.6	7.5±1.1	42.8±4.3
1 PPI	118	61.4±3.6	61.9±3.8	59.4±4.4	64.8±4.3	9.7±1.1	26.5±2.7	19.5±2.9	8.6±1.6	43.9±4.5
2 PPI	118	63.5±4.2	62.4±3.4	61.3±3.9	65.8±4.3	10.7±1.5	28.0±2.9	20.0±2.9	8.9±2.2	44.7±7.8
CH 0 PPI	118	63.6±3.7	64.9±3.8	60.4±4.4	67.9±4.2	9.8±1.0	26.2±2.6	19.9±2.6	8.6±1.5	43.5±4.2
1 PPI	118	64.8±3.4	64.9±4.1	60.9±4.2	69.5±4.2	10.2±1.1	27.1±2.5	20.4±3.1	8.8±1.6	42.9±4.8
2 PPI	118	66.2±5.7	67.0±5.3	62.7±4.6	70.4±6.2	10.7±1.2	29.2±3.4	21.9±3.9	9.8±2.3	44.7±5.2

Ab: Abergelle goat; AF: Afar goat; BL: body length; BW: body weight; CH: Central-Highlands goat; DP: dressing percentage; HAW: height at withers; HG: heart girth; HCW: hot carcass weight; N = sample size; NC: neck circumference; PPI: pairs of permanent incisors; PW: pelvic width; RH: rump height; SD: standard deviation;

Afar goat breed is a predominant breed found in the pastoral and agro-pastoral areas of Afar region, where livestock including goats graze freely on the arid and semi-arid rangelands of Afar region. Afar goats are managed together with sheep in a mixed flock under traditional (extensive) management system (Theodros Tekle, 2014). According to Anwar Seid and Yayneshet Tesfaye (2014), during the dry season, the major feed resources for Afar goats (and sheep) kept under pastoral condition are hill side grazing and indigenous bush whereas under agro-pastoral condition, both swampy and aftermath grazing, hay and roadside grazing are the major feed sources. Central-Highland (CH) goats are adapted to humid and sub-humid highlands under mixed crop-livestock farming system. Livestock including goats are grazed freely on hill side and communal grazing land during the dry season but tethered during the crop-growing season (Yoseph Mekasha *et al*., 2008; Belay Deribe and MengistieTaye, 2013).

Animal handling practices at the slaughterhouse

Flock owners and/or traders in the rural areas (rural traders) were the major suppliers of goats to Abergelle Slaughterhouse. The goats are transported by any possible means of transport including trekking and trucks to reach animal collection and quarantine sites of Abergelle Slaughterhouse at Beri Teklay/Alamata or Agbe. At times purchasers of the Slaughterhouse reach those remote areas.

Beri Teklay/Alamata Animal Collection and Quarantine Site is located at distance of 150km from Mekelle whereas Agbe site is located at distance of 100km from Mekelle. Clinical examination and screening of the bucks was undertaken by experts of the Slaughterhouse at the Animal Collection and Quarantine Sites focusing mainly on the health, BW and condition of the bucks for accepting (purchasing) the bucks. Upon acceptance, the bucks were rested for a period of 21-30 days at the Animal Collection and Quarantine Sites, and grazed on fenced natural grazing lands.

After such resting period, the bucks were re-examined for health, body weight and condition, those found fit for slaughter were transported using animal truck to reach the lairage of Abergelle Slaughter house, at Mekelle which generally takes less than 4 hours derive. At the lairage, during the first 24 hours, salt, hay and water were the major feed resources made available to the goats. Then, the goats were fasted overnight with free access to water.

Slaughtering procedure

After overnight fasting, measurement of BW was taken immediately prior to slaughter. Slaughtering was done by cutting the major blood vessels around the throat (Halal method) so that optimal bleeding occurs. Following that, the carcass was suspended by the hind legs (hauled) to take advantage of the rail system and for optimal bleeding, followed by start of flaying. Then, removal of the head, the fore and hind feet was done at the atlanto-occipital, carpal and tarsal joints, respectively. Then the skin (together with the testis) was removed completely using automated technique. After flaying, the carcass was washed followed by evisceration (removal of the stomach, intestines, visceral organs (heart, liver, spleen, lungs and kidneys) urinary bladder as well as internal fats from the stomach, kidney, heart and intestines). The carcass was washed again and the water allowed to drip followed by recording of the HCW using the automatic weight measuring scale. Then the carcass was chilled (at $+4^{o}C$), until packaging and dispatching.

Study design and data collection

Data collection was performed during the dry season, from January to May 2015. The three goat breeds (Abergelle, Afar and CH) were selected purposively. Apparently healthy bucks were selected following stratified random sampling technique considering proportion of breed and age. Bucks which were representative of the goat breeds under study were selected based on their physical (phenotypic) characteristics using the guide developed by FARM-Africa (1996). Age categorization was performed based on the number of erupted pairs of permanent incisors (PPI). The study bucks were comprised of three major age categories; the first group consisted of bucks <1 year old referring to bucks with full milk teeth (0 PPI); the second group consisted of bucks which were 1 to 2 years old, consisting of bucks with one pair of permanent incisors (1 PPI) and the last age category consisted of bucks which were 2-3 years old, referring to bucks with two pairs of permanent incisors (2 PPI) as described in Solomon Abegaz and Kasahun Awgichew (2009).The selected bucks were identified using plastic ear tag, for use throughout ante- and post-mortem data collection.

Data on live animal attributes (breed, age, LBMs and BW) were registered at the lairage. Body weight at slaughter and linear body measurements (LBMs) were taken after an overnight fasting (Solomon Melaku and Simret Betsha, 2008). Body weight (kg) was determined using a hanging scale (capacity 50 kg). Measurements of morphometric traits (cm) was taken using measuring scale with the bucks hold comfortably in upright and standing position on a flat surface.

The morphometric traits considered include heart girth (HG) measured as the distance around the animal taken directly behind the front legs; height at withers (HAW) measured as the height of a standing buck perpendicular to the ground on a flat surface; body length (BL) measured as the distance between the base of neck (first thoracic vertebrae) to the base of the tail; rump height (RH) measured as a perpendicular distance from *Spinailliaca* to the ground; pelvic width (PW) measured as distance between the two pelvic bones across the dorsum and neck circumference (NC) measured as circumference around the neck.

Hot carcass weight (HCW) (kg) was determined after evisceration within 45 minutes after slaughtering with the help of built-in automatic electronic weighing scale available within the rail system of the abattoir. Dressing percentage (DP) was computed as HCW expressed as percentage of BW at slaughter using the formula: $DP = \frac{\text{HCW taken after evisceration}}{\text{BW at slaughter}} * 100$

Data analysis

The collected data on LBMs, BW, HCW and DP were stratified into breed and age classes. Kolmogorov–Smirnov statistics was used to test the normality of the residuals of the quantitative variables. The homogeneity of the variance of the categorical variables was checked using Levene's test using SAS (2002). General Linear Model (GLM) procedure of SAS (SAS, 2002) was employed to assess differences in LBMs, BW, HCW and DP, taking breed and age as class variables (SAS, 2002). The effect of class variables and their interaction were expressed as Least Square Means (LSM) ± SE (standard error) and means were separated using Tukey adjustment.

For developing models for predicting HCW, LBMs and BW were used as predictor variables. Univariate analysis (which is equivalent to correlation analysis) was performed to check independent association between a predictor and the dependent variable (HCW). Collinearity diagnostics was performed by checking Variance Inflation Factor (VIF) where VIF > 10 was taken as a cutoff point (Kaps and Lamberson, 2004). Multivariate analysis of variance (MANOVA) was performed using only those predictor variables which had significant ($P < 0.05$) independent association with HCW in the univariate analysis. Predictor variables which remained to have significant ($P < 0.05$) association with HCW in the multivariate analysis were used to set the final models. The best fit models were chosen using adjusted coefficient of determination (Adj R^2), root mean square error (RMSE), conceptual predictive criterion [C (p)] and Akaike information criterion (AIC). The following statistical model was used to develop the HCW prediction equations: $Y = ß_0 + ß_1X_1 + ß_2X_2 + ß_3X_3 + ß_4X_4 + ß_5X_5 + ß_6X_6 + ß_7X_7$

Where: Y represents the dependent variable (HCW after evisceration), ß0 denotes the intercept; $ß_1$-$ß_7$represent the regression coefficients of the independent variables X_1 to X_7, respectively, X1

- X_7 denote the independent variables (X_1 = HAW, X_2 = HG, X_3 = BL, X_4 = RH, X_5 = PW, X_6 = NC, and X_7 = BW at slaughter).

RESULTS

Linear body measurements, body weight, hot carcass weight and dressing percentage

Summary statistics (Mean ± SD) of the LBMs, BW, HCW and DP of bucks of the study goat breeds by age categories is shown in Table 1 whereas Table 2 displays the effects (LSM $\pm$ SE) of breed, age and their interaction on LBMs, BW, HCW and DP of the three studied goat breeds.

The result in Table 2 demonstrates that there were differences ($P < 0.05$) across the three goat breeds with regards to the morphometric traits, which is basically attributed to breed related differences. Breed and age had influenced ($P < 0.05$) HG, HAW, BL and RH whereas PW and NC were influenced ($P < 0.001$) by age. Overall, bucks of CH had the highest ($P < 0.001$) HG, HAW, BL and RH. Bucks of Abergelle and CH breed had similar ($P > 0.05$) PW and NC and it was the highest ($P < 0.001$) compared to that recorded for Afar goat bucks. Morphometric measurements of bucks of the study goat breeds increased with age. Bucks of Abergelle and CH breed at similar age had comparable ($P > 0.05$) values for most of the LBMs. Across all the 3 age categories, bucks of Abergelle and CH breed had comparable ($P > 0.05$) HG. At youngest (0 PPI) age, RH, PW and NC of bucks of Abergelle and CH were comparable ($P > 0.05$); at age of 1 PPI, bucks of Abergelle and CH had comparable ($P > 0.05$) HAW, BL and PW whereas at age of 2 PPI, Abergelle and CH bucks had comparable ($P > 0.05$) BL. In general, except for similar ($P > 0.05$) measurements of NC in bucks of the three goat breeds at age of 1PPI and that of PW and NC in bucks at age of 2 PPI, bucks of Afar breed had the lowest ($P < 0.05$) value of LBMs (Table 2).

Breed and age were mainly responsible for the difference ($P < 0.001$) in BW of bucks of the study goat breeds. The interaction between breed and age had also contributed to the difference ($P = 0.03$) in BW. Overall, bucks of CH breed were the heaviest ($P < 0.0001$) followed by bucks of Abergelle breed (Table 2). The BW of bucks increased with age and differences in BW were more remarkable at later age (1 PPI and 2 PPI) compared to those at youngest (0 PPI) age. In the youngest (0 PPI) age category, bucks of Abergelle and CH breed had comparable ($P > 0.05$) BW which was higher ($P < 0.001$) than that recorded in Afar breed. Among bucks at age of 1 PPI, bucks of CH breed were heavier ($P < 0.05$) than the other breeds whereas with comparable ($P > 0.05$) BW bucks of Abergelle and Afar breed were lighter ($P < 0.05$) than CH bucks. At age category of 2 PPI, bucks of CH breed were the heaviest ($P < 0.001$) followed by Abergelle breed (Table 2).

Breed and age had affected ($P < 0.001$) the HCW of bucks of the study goat breeds and the influence of the interaction between breed and age on HCW was also important ($P < 0.05$). Overall, the HCW recorded in bucks of Abergelle and CH breeds was comparable ($P > 0.05$) and higher ($P < 0.001$) than that recorded in Afar breed (Table 2). The HCW recorded in bucks of the

three goat breeds increased with age. At age category of 0 PPI and 2 PPI, bucks of Abergelle and CH breed had comparable ($P > 0.05$) HCW which was higher ($P < 0.05$) than that recorded in Afar breed. At age of 1 PPI, bucks of the three goat breeds had comparable ($P > 0.05$) HCW (Table 2).

Breed and age had influenced ($P < 0.05$) DP of bucks of the study goat breeds. Overall, the highest ($P < 0.05$) DP (calculated on slaughter BW basis) was recorded in Abergelle breed whereas bucks of Afar and CH breed had similar ($P > 0.05$) DP which was lower than the DP recorded in Abergelle bucks (Table 2). Dressing percentage increased with age of bucks. In the youngest (0 PPI) age category, bucks of Abergelle breed had the highest ($P < 0.05$) DP whereas the DP recorded in bucks of Afar and CH breed was comparable ($P > 0.05$) and it was lower ($P <0.05$) than that recorded in Abergelle bucks. At age of 1 PPI, with similar ($P > 0.05$) value, the DP recorded in bucks of Abergelle and Afar breed was higher ($P < 0.05$) than that recorded for CH whereas in age group of 2 PPI, the DP recorded in bucks of the three goat breeds was comparable ($P > 0.05$) (Table 2).

Prediction of hot carcass weight from linear body measurements and body weight

Univariate analysis of variance by age categories for each breed showed that in bucks of CH across all (0 PPI, 1 PPI and 2 PPI) age categories; bucks of Abergelle at youngest (0 PPI) age and Afar at age of 0 PPI and 1 PPI, HCW had significant ($P < 0.05$) independent association with all the predictor variables (LBMs and BW). In bucks of Abergelle breed at age of 1 PPI, except BL all the predictor variables had significant ($P < 0.05$) independent association with HCW. In bucks of Abergelle and Afar breed at age of 2 PPI, except PW all the predictor variables had significant ($P < 0.05$) independent association with HCW.

Multivariate analysis of variance by age categories for each breed showed that in bucks of Abergelle breed at youngest (0 PPI) age; BW was the only predictor which had significant ($P < 0.05$) association with HCW. In bucks of CH at youngest (0 PPI) age; HCW had significant ($P < 0.05$) association with HG, BL, NC and BW. In bucks of Afar at age of 0 PPI and 1 PPI, HCW had significant ($P < 0.05$) association with RH, PW, NC and BW. In bucks of CH at age of 1 PPI, Abergelle and Afar breed at age of 2 PPI; HCW had significant ($P< 0.05$) association with NC and BW. In bucks of Abergelle breed at age of 1 PPI, HCW had significant ($P < 0.05$) association with HAW and BW whereas in bucks of CH at age of 2 PPI, HCW had significant ($P < 0.05$) association with HAW, PW, NC and BW. The best fit models for predicting HCW (Table 3) for all age categories of the goat breeds were set using only those predictor variables, which had significant ($P < 0.05$) association with HCW in the multivariate analysis of variance.

Table 2. Effect (LSM ± SE) of breed, age and their interaction on LBMs (cm), BW (kg), HCW (kg) and DP of bucks of study goat breeds.

Age categories	HG [cm]	HAW [cm]	BL [cm]	RH [cm]	PW [cm]	NC [cm]	BW [kg]	HCW [kg]	DP [%]
0 PPI (N = 354)									
Ab	62.8±0.3^{a}	62.9±0.4^{a}	58.9±0.4^{a}	66.7±0.3^{a}	10.0±0.1^{a}	26.8±0.3^{a}	19.2±0.2^{a}	8.6±0.1^{a}	45.1±0.4^{a}
AF	59.7±0.3^{b}	60.9±0.3^{b}	58.0±0.4^{a}	63.0±0.3^{b}	9.4±0.1^{b}	25.2±0.2^{b}	17.6±0.1^{b}	7.5±0.1^{b}	42.8±0.4^{b}
CH	63.6±0.3^{a}	64.9±0.4^{c}	60.4±0.4^{b}	67.9±0.4^{a}	9.8±0.1^{a}	26.2±0.2^{a}	19.9±0.2^{a}	8.6±0.1^{a}	43.5±0.4^{b}
1 PPI (N = 354)									
Ab	63.8±0.3^{a}	63.9±0.3^{a}	59.9±0.4^{ab}	66.7±0.4^{a}	10.1±0.1^{a}	26.9±0.2	19.5±0.3^{a}	8.6±0.1	44.2±0.5^{a}
AF	61.4±0.3^{b}	61.9±0.3^{b}	59.4±0.4^{b}	64.8±0.4^{b}	9.7±0.1^{b}	26.5±0.3	19.5±0.3^{b}	8.6±0.2	43.9±0.4^{ab}
CH	64.8±0.3^{a}	64.9±0.4^{a}	60.9±0.4^{a}	69.5±0.4^{c}	10.2±0.1^{a}	27.1±0.2	20.4±0.3^{b}	8.8±0.1	42.9±0.4^{b}
2 PPI (N = 354)									
Ab	65.5±0.3^{a}	65.2±0.3^{a}	61.6±0.4^{ab}	67.9±0.3^{a}	10.6±0.1	28.6±0.2	20.9±0.3^{a}	9.4±0.2^{ab}	45.1±0.5
AF	63.5±0.4^{b}	62.4±0.3^{b}	61.3±0.4^{b}	65.8±0.4^{b}	10.7±0.1	28.0±0.3	20.0±0.3^{b}	8.9±0.2^{b}	44.7±0.7
CH	66.2±0.5^{a}	67.0±0.5^{c}	62.7±0.4^{a}	70.4±0.6^{c}	10.7±0.1	29.2±0.3	21.9±0.4^{c}	9.8±0.2^{a}	44.7±0.5

$^{a-c}$means within column and section with one letter in common are not significantly separated (P > 0.05)

Ab: Abergelle goat; AF: Afar goat; BL: body length, BW: body weight; CH: Central-Highlands goat; DP: dressing percentage; HAW: height at withers; HCW: hot carcass weight; HG: heart girth; LBMs: linear body measurements; LSM: least square mean; N = sample size; NC: neck circumference; PPI: pair of permanent incisors; PW: pelvic width; RH: rump height; SE: standard error.

Table 3. Best fit models for predicting HCW (kg) of bucks of Abergelle, Afar and Central-Highland goat breeds.

Age categories	Regression models	Adj R^2	RMSE	AIC	C (p)
0 PPI (N = 354)					
Ab	HCW = 0.75 + 0.4 BW	0.55	0.8	-39.5	2
AF	HCW = - 9.4 + 0.1 RH + 0.2 PW + 0.1 NC + 0.4 BW	0.74	0.6	-123	5
CH	HCW = - 0.5 - 0.1 HG + 0.04 BL + 0.1 NC + 0.5 BW	0.73	0.8	-52.3	5
1 PPI (N = 354)					
Ab	HCW = - 1.5 + 0.1 HAW + 0.3 BW	0.49	1.0	14.6	3
AF	HCW = - 3.6 + 0.1 RH – 0.2 PW + 0.2 NC + 0.4 BW	0.76	0.8	-45.9	5
CH	HCW = - 1.32 + 0.1 NC + 0.4 BW	0.61	1.0	-4.30	3
2 PPI (N = 354)					
Ab	HCW = - 3.9 + 0.2 NC +0.4 BW	0.69	1.1	16.9	3
AF	HCW = - 5.3 + 0.2 NC + 0.5 BW	0.51	1.5	104	3
CH	HCW = - 6.4 + 0.1 HAW - 0.3 PW + 0.2 NC + 0.3 BW	0.84	0.9	-20.5	5

Ab: Abergelle goat, Adj R^2: adjusted coefficient of determination; AF: Afar goat, CH: Central-Highlands goat; AIC: Akaike information criterion; BL: body length; BW: body weight; C (p): conceptual predictive criterion;HAW: height at withers; HCW: hot carcass weight; HG: heart girth; N = sample size; NC: neck circumference; PPI: pair of permanent incisors; PW: pelvic width; RH: rump height; RMSE: root mean square error.

DISCUSSION

In this study attempt has been made to assess the meat production potential of the three goat breeds under farmers' management condition. The study goats were kept under similar traditional (extensive) livestock management systems which are generally characterized as low input systems. During the dry season, the feeding management of the goats is constrained by feed shortage and this is common to all production systems. In addition, this study was undertaken during the dry season when the slaughterhouse's throughput is at its maximum.

Linear body measurements, body weight, hot carcass weight and dressing percentage

Our study demonstrated that differences in LBMs of study bucks were due to effects of breed and age. The highest HG, HAW, BL and RH were recorded in CH followed by Abergelle whereas the lowest values of these LBMs were recorded in Afar. On the other hand, comparable PW and NC were recorded in Abergelle and CH (Table 2). Similar report was made by Yoseph Mekasha *et al*. (2008) that breed had noticeable effects on physical linear traits in indigenous bucks of Ethiopia. According to Nsoso *et al*. (2004), the physical linear traits of a specific animal breed are important phenotypic descriptors which can assist in the identification of animal populations with special adaptation traits that have acceptable production performance.

Breed, age and their interaction were responsible for differences in BW of study goat breeds noted in this study. Overall and at age categories of 1 PPI and 2 PPI, CH were the heaviest, Abergelle had intermediate BW whereas Afar breed was the lightest (Table 2). Our result on BW of Afar and CH breed which were noted as lighter and heavier, respectively, is in agreement with the finding of Yoseph Mekasha *et al*. (2008) who categorized Afar breed as small sized and light breed whereas CH breed as a medium and heavy breed in a study involving 5 goat breeds (Afar, Arsi-Bale, Boran, CH and Woito-Guji) indigenous to Ethiopia. Comparison of the BW Afar and CH breed recorded in this study with the BW of bucks of their respective breed at similar age recorded in earlier studies (Mekasha *et al*., 2008; Agga *et al*., 2011) showed differences. For instance, at age of 2 PPI, the BW of Afar breed recorded (20.0 $\pm$ 0.3) kg in this study was higher than that reported (17.6 ± 1.0) kg by Mekasha *et al*. (2008) but it was lower than the BW (21.1 kg) recorded by Agga *et al*. (2011). The BW of Abergelle breed recorded (19.9 ± 0.2) kg in this study was lower than the matured BW (33.6 ± 5.9) kg reported by Berhane and Eik (2006). In the literature, it is well documented that differences in BW are due to many factors which include breed, age (Bielli *et al*., 2000; Yoseph Mekasha *et al*., 2008; Getahun Ejeta *et al*., 2011), season of slaughter, nutrition (Bielli *et al*., 2000; Yoseph Mekasha *et al*., 2007; Rahman *et al*., 2008) and supplementation (Solomon Melaku and Simret Betsha, 2008). Physical condition, agro-climate, housing, disease control and other management practices are the other factors which have potential influence on BW (Rahman *et al*., 2008).

Even though the highest BW was recorded in CH, overall and at age categories of 0 PPI and 2 PPI, the HCW recorded in Abergelle and CH breed was comparable and it was higher than the value of HCW recorded in Afar. Whereas at age of 1 PPI, the three goat breeds under study had comparable HCW (Table 2). In a study conducted by Belay Deribe and Mengistie Taye (2013), HCW (mean $\pm$ SE) of 11.2 $\pm$ 0.5 kg was recorded in CH breed kept on grazing (without any supplementation) which is higher than the HCW (9.1 $\pm$ 0.1)kg of bucks of the same breed recorded in this study. Addisu Abera *et al*. (2002) reported HCW of 8.5 kg for Afar goat which is in very close similarity to the value of HCW (8.4 kg) recorded in bucks of Afar breed in this study.

Our finding on the effect of breed on DP is in line with Ameha Sebsibe *et al*. (2007) who reported breed to have significant effect on DP. Overall, the highest DP (44.8 %) was recorded in Abergelle breed whereas the DP recorded in CH (43.7 %) and Afar (43.8 %) breeds was comparable and it was lower than the DP recorded in Abergelle. A similar pattern was noted in bucks at youngest (0 PPI) age whereas in bucks at age of 1 PPI, bucks of Abergelle and Afar breed had comparable DP and it was higher than that recorded in CH. However, at later age (2 PPI), the three goat breeds had similar DP (Table 2). Ameha Sebsibe *et al*. (2007) in a study involving three goat breeds (Afar, CH and Long-eared Somali) fed on three grainless diets varying in concentrate to roughage ratio found that on slaughter weight basis, Long eared Somali and Afar had higher and similar ($P > 0.05$) DP whereas CH had the lowest ($P < 0.01$) DP whereas the DP was found to be within the range of 42.5 to 44.6 % (on slaughter weight basis) whereas in bucks of CH breed kept on grazing (without any supplementation) Belay Deribe and

Mengistie Taye (2013) recorded DP (mean ± SEM) of 38.9 ± 1.0 % (calculated on BW at slaughter basis) which is found to be lower than the DP (43.7 ± 0.3) % recorded in this study in bucks of CH. In bucks of Afar breed, Addisu Abera *et al*. (2002) recorded DP of 45.5 % which is higher than the DP recorded in bucks of Afar breed (43.8 %) in the current study. Our result on the DP (43.7 % in CH, 43.8 % in Afar and 44.8 % in Abergelle) of bucks of the 3 goat breeds is generally within the range of the DP (calculated on slaughter BW basis) of 42 to 45% recorded for most indigenous goat breeds of Ethiopia reported by Dereje Tadesse *et al*. (2015). On the other hand, Kefyalew Berihun *et al*. (2013) reported a higher mean DP of 47.9-51% for Arsi-Bale goats reared under farmers' management compared to our result and the summary made by Dereje Tadesse *et al*. (2015). Generally, differences in carcass parameters (HCW and DP) are ascribed to breed (Attah *et al*., 2004; Dzakuma *et al*., 2004; Ameha Sebsibe *et al*., 2007), age (Devendra and Burns, 1983; Dzakuma *et al*., 2004; Sebolai *et al*., 2012), nutritional status (Devendra and Burns, 1983;Yoseph Mekasha *et al*., 2008) and BW (Attah *et al*., 2004).

The bucks of the goat breeds under study were kept under traditional (extensive) livestock management systems which are characterized as low input systems (Belay Deribe and Mengistie Taye, 2013). In the mixed crop-livestock farming systems, in which Abergelle and CH goat breeds are reared there is encroachment of arable land for crop production with resultant lack of grazing land forcing livestock to be maintained on unproductive hillsides, crop stubble or over-grazed communal grazing land with resultant inadequate nutrition which affects livestock productivity (Yoseph Mekasha *et al*., 2008). Similarly, the pastoral and agro-pastoral systems from where Afar and Abergelle breeds are originating are also constrained by different factors such as feed shortage, drought and livestock diseases which affect the productivity of livestock including goats. In relation to this, in a study conducted by Assen Ebrahim and Aklilu Hailemichael (2012) involving the highland, mid land and lowland agro ecologies of Tigray region, shortage of feed and health problem were identified as the first and second constraints to small ruminant production both in the highland and midland agro ecologies whereas in the lowland agro ecology, animal health problem was rated as the first most important constraint to small ruminant production followed by shortage of feed, scarcity of water and drought (Assen Ebrahim and Aklilu Hailemichael, 2012). In another study conducted by Anwar Seid and Yayneshet Tesfaye (2014) involving pastoral and agro-pastoral production system of Afar region, it was found that small ruminant production in the pastoral production system is constrained by feed shortage, drought, health problems and water shortage whereas in the agro-pastoral system, feed shortage, drought and unavailability of supplementary feed were reported as major constraints to small ruminant production with conclusion that feed shortage and drought are equally important in both production systems.. In general, the availability of feed resources is seasonal, being governed by seasonal rainfall pattern. Animal productivity is thus determined by the fluctuation in the availability of feed resources (Yoseph Mekasha *et al*., 2008). In addition, poor nutrition and parasitic load may mask the true genetic potential of the animals (Kefyalew Berihun *et al*., 2013).

Prediction of hot carcass weight from linear body measurements and body weight

In this study, an attempt has also been made to set models for estimating HCW (which is determined after slaughter) using live animal body attributes. Age specific models for predicting HCW of the three goat breeds were set (Table 3). In Table 3 it was shown that models developed for predicting HCW of Abergelle and CH bucks at later age (2 PPI) had a higher Adj R^2 (0.69 in Abergelle and 0.84 in CH) showing that such models would explain the variation in HCW better than those models developed for predicting HCW of bucks at age category of 0 PPI and 1 PPI which had low Adj R^2 value. In bucks of Afar breed, the model developed for predicting HCW of bucks at age category of 1 PPI had a higher Adj R^2 (0.76) as compared to the models developed for bucks at age category of 0 PPI and 2 PPI.

The predictor BW was common to all the models developed for predicting HCW in all age categories of the three goat breeds and BW stands as the only predictor variable in the model developed for predicting HCW of bucks of Abergelle breed at youngest age (0 PPI) (Table 3).

With the exception of models set for predicting HCW in age group 0 PPI and 1 PPI of Abergelle breed, in the models set for predicting HCW of bucks of Abergelle breed at age of 2 PPI and bucks of all age categories of Afar and CH goat breed, NC appeared as important predictor. It was also noted that NC and BW were the two important and common predictor variables in the models set for predicting HCW of bucks of Afar and Abergelle breed at age of 2 PPI and CH breed at age category of 1 PPI. In bucks of Afar breed at age category of 0 PPI and 1 PPI, the models set for predicting HCW were based on similar predictor variables (RH, PW, NC and BW)(Table 3).

In this study selection of the best fit models was conducted using multiple criterions, which is in agreement with Sebolai *et al*. (2012) who recommend the use of multiple criteria for determining the best fit prediction models. Mallow's C (p) statistic is important as a measure of the goodness of fit of a prediction model and regression equations with small MSE should be selected in order to improve the precision of the predicted values (Sebolai *et al*., 2012). Since the value of $R^2$is affected by the incorporation of additional predictor variables into the model, the use of R^2 as the only criterion for identifying best fit models is less suitable (Sebolai *et al*., 2012). From Table 3 it can be noted that HCW could be estimated more accurately by a combination of live body measurements than a single predictor which had also increased the value of Adj R^2.However, taking measurement of too many predictor variables may not be so easy under field condition as in the harsh and remote areas of Afar region. In addition, taking measurement of too many different predictor variables will have time and cost implications. Therefore, models which are based on few but important predictor variables would be convenient and applicable.

CONCLUSION

Our study revealed that LBMs, BW, HCW and DP of bucks of the three goat breeds under study were influenced by breed, age and their interaction. The highest BW and LBMs were recorded in CH whereas bucks of Abergelle and CH had comparable HCW. The highest DP recorded in

Abergelle breed may suggest the breed's better meat production potential. The models set for predicting HCW of the study bucks would be an aid for selection of bucks for meat production.

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