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Prediction of carcass composition of lambs by joint dissection and carcass traits

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Abstract: The aim of the study was to test the possibility of using carcass measurements and joint tissue composition to predict the half-carcass tissue composition of lambs more accurately. With this purpose in mind, 6 different carcass joints (neck, flank, shoulder, ribs, hind limb, and tail) from 42 Kıvırcık male lambs were dissected. In addition, various carcass characteristics were recorded. When carcass characteristics and measurements were used alone in the prediction equations, accuracy (between 37%–68%) was similar to the equations that included only joint dissections (36%–75%). However, when joint dissection and various carcass traits were combined, half-carcass tissue composition was predicted more accurately (65%–90%) than in measures using either joint dissection or various carcass traits alone. Flank was the most successful predictive joint for prediction of muscle weight, when combined with some carcass traits, while the equation built with hind limb and various carcass traits was most successful for predicting total fat weight. Carcass traits yielded accuracy that was similar to joint dissection results, especially for muscle and total fat weights. Therefore, for these parameters, carcass traits are preferred as this measure is cost-effective, noninvasive, and practical. However, for greater accuracy, joint dissection and various carcass characteristics and measurements should be combined.

Key words: Joint dissection, lamb meat, multiple linear regression, prediction equations, tissue composition

1. Introduction

In recent years people have moved towards consuming low-fat and fat-free meat due to nutritional needs and the socio-economic development they have experienced [1,2]. Therefore, carcasses with a high meat ratio coupled with low fat and bone content are preferable to some consumers, and these meats are sold by butchers at a high price [3].

Dressing percentage, carcass conformation and fatness, percentages of high-value joints and muscle, and fat and bone content are the most important characteristics that determine carcass quality [4,5]. Tissue composition of lamb carcasses may vary according to carcass joints, and joints with a high percentage of muscle are considered more valuable and are offered to consumers at high prices [6,7].

In order to predict carcass composition, studies have been conducted using regression equations developed by x-ray, ultrasound, tomography, magnetic resonance (MR), various carcass measurements, and video image analysis (VIA) results [8–10]. These methods predominate for predicting carcass composition and are relatively fast, practical, and highly accurate; some are cheaper than others. However, because of inadequate applicability or repeatability of these prediction methods, the ideal method has not yet been developed. It is not practical to dissect the whole carcass in order to determine the weight/percentage of muscle, bone, and fat in carcasses. Additionally, there are huge costs associated with whole-carcass dissections [11]. In previous studies, a specific joint of the carcass (hind limb, shoulder, flank, or loin) was selected in order to predict carcass composition [12–14]. Yalcintan et al. [15] reported that the tissue components of the hind limb are similar to the whole carcass for goat kids, and therefore, it can be used to predict carcass components. Abouheif et al. [16] found a high level of correlation between the muscle and bone percentages in the hind limb and the half-carcass muscle and bone percentages when they investigated the effect of slaughter weight on tissue components in Merino carcasses. Díaz et al. [17] reported that tissue composition of the hind limb and loin had a significant correlation with the carcass composition of light lambs.

Some breed-specific characteristics, such as growth rate or tail structure, may cause significant interbreed variation in the carcass composition of lambs [18]. For example, great interbreed variation exists in terms of localization of adipose tissue [19].

In previous studies, dissection results (weights or percentages) or various carcass characteristics were investigated separately for carcass composition prediction [20–23]. However, there was limited information regarding

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the use of both parameters in the same prediction equations. Therefore, the aim of this study was to determine the most accurate carcass joint for the estimation of half-carcass composition and to determine whether more accurate and practical estimates can be obtained when various carcass measurements are utilized in addition to carcass joint dissections.

2. Materials and methods

2.1. Slaughter procedures

The study was conducted using 42 male Kıvırcık lambs, which were reared at the experimental sheep farm of İstanbul University Faculty of Veterinary Medicine with the approval of the İstanbul University Ethics Committee (approval number: 2016/01). Lambs were fed their mothers' milk until 75 days of age. Good quality alfalfa hay, ad libitum, and lamb starter feed (50 grams per day) [89% dry matter (DM), 17% crude protein, and 2866 kcal/kg DM, ME 12 MJ/kg KM] were given to the lambs after they were two weeks old. Lamb starter feed was gradually increased according to lamb age, and lambs were fed 200 g/lamb of concentrate feed twice a day after weaning. Lambs were slaughtered when they reached 27.51 ± 1.58 kg of live weight (129.67 ± 25.81 days old) in the experimental slaughterhouse of the Faculty of Veterinary Medicine after a 12 h fasting period. Afterwards, noncarcass components (head, skin, feet, internal organs, and testicles) were removed from the carcasses. Gastrointestinal tracts were emptied after removal for calculation of empty body weight, which is the subtraction of gut content from slaughter weight. Following carcass dressing, hot carcass weight including the kidneys, kidney knob, and channel fat were recorded, as described by Colomer-Rocher et al. [24], and the carcasses were chilled for 24 h at 4 °C before further analyses.

2.2. Carcass characteristics and joint composition

After the carcasses were chilled for 24 h, cold carcass weight was recorded. Dressing percentage was calculated using slaughter weight (DP-1) and empty body weight (DP-2). Then, chest width, carcass length, rump circumference, chest circumference, hind limb length, carcass compactness, and hind limb compactness was measured or calculated according to Yılmaz et al. [25] and Ekiz et al. [26], as described below.

· Chest width (CW): widest carcass measurement at the ribs.

· Carcass length (CL): from the caudal edge of the last sacral vertebra to the dorsocranial edge of the atlas.

· Rump circumference (RC): circumference of buttocks from the greatest width in a horizontal plane on the hanging carcass.

· Chest circumference (CHC): circumference of chest from the greatest width in a horizontal plane on the hanging carcass.

· Hind limb length (HLL): length from perineum to distal edge of the tarsus.

· Carcass compactness (CC): hot carcass weight/internal carcass length.

· Hind limb compactness (HLC): hind limb weight/hind limb length.

At 24 h after slaughter, the carcasses were evaluated for conformation and fatness scores using 1–15 scales, as described by the European Union [27,28]. After the removal of the kidneys, kidney knob, and channel fat (KKCF), the carcasses were split down the dorsal midline into two halves, according to Colomer-Rocher et al. [24]. Back fat thickness and the longissimus dorsi (LD) muscle section area were measured between the 13th thoracic and 1st lumbar vertebrae [29]. Back fat thickness was measured by digital calliper, and the LD muscle section area was drawn on tracing paper and then measured by planimeter. Afterwards, the remaining half-carcasses were separated into neck, shoulder, flank, ribs, hind limb, and tail joints, according to Colomer-Rocher et al. [24], and weights of these joints were recorded. All joints were vacuum packed and placed in cold storage units at –20 °C for preservation.

Each joint was thawed at room temperature one day before the dissection. All joints were dissected into muscle, bone, subcutaneous and intermuscular fat, and other tissues (ligaments, tendons, major blood vessels, and the thick connective tissue associated with some muscle) to determine tissue composition, according to Fisher and de Boer [30].

2.3. Statistical analyses

SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. The descriptive statistics of carcass tissue composition, carcass traits, and carcass measurements are presented in Tables 1 and 2.

A variety of regression analyses were used to predict carcass tissue composition. A simple linear regression analysis was applied for prediction of half-carcass tissue composition by using the dissection results of each joint. In the stepwise regression analysis, carcass traits and joint weights/percentages as independent variables, were tested to predict half-carcass composition (for both weights and percentages). Finally, all investigated variables were combined in the stepwise regression model in order to determine which carcass joints or characteristics could be used to create the most accurate prediction equation for each carcass tissue. In the stepwise analysis, $P \leq 0.05$ for entry and $P \geq 0.10$ for output were used as standards. The criterion used for comparing the equations and determining the best model were; a) significance of the models, b) corrected determination coefficients (R^2), c) root mean square errors (RMSE), and d) mean absolute error (MAE) [31].

Table 1. Descriptive information about half-carcass tissue composition.

Parameters	Abbr.	Mean	SD	Min.	Max.	% CV*
Half-carcass tissue composition,%						
Muscle	MP	49.60	2.73	43.16	54.85	5.50
Bone	BP	21.07	1.56	17.94	24.60	7.40
Subcutaneous fat	SCFP	13.54	3.03	7.68	21.36	22.38
Intermuscular fat	IMFP	8.34	1.26	5.39	11.28	15.11
Total fat	TFP	21.87	3.23	13.42	30.74	14.77
Half-carcass tissue composition, g						
Muscle	MW	2673.97	193.68	2172.80	3091.00	7.24
Bone	BW	1137.32	123.16	874.20	1421.30	10.83
Subcutaneous fat	SCFW	737.96	200.46	369.50	1220.88	27.16
Intermuscular fat	IMFW	450.45	77.51	276.40	615.20	17.21
Total fat	TFW	1188.41	236.43	645.90	1757.38	19.89

Abbr.: Abbreviations, SD: Standard deviation, Min.: Minimum, Max.: Maximum, *%CV: Coefficient of variation.

3. Results and discussion

The mean half-carcass tissue composition of Kıvırcık lambs was 49.60% muscle, 21.07% bone, 13.54% subcutaneous fat, 8.34% intermuscular fat, and 21.87% total fat (Table 1). Demir [32] and Yilmaz et al. [33] reported a higher muscle proportion for Kıvırcık lambs in their studies. However, both of these previous studies had higher slaughter weights than the current study, therefore these results were expected.

When only the results from joint composition weights are used for the prediction of half-carcass tissue composition, the suitable carcass joints are: shoulder for muscle weight; ribs for subcutaneous fat weight; and hind limb for bone, intermuscular fat, and total fat weights (Table 3). When half-carcass tissue composition is predicted using percentages of joint tissue composition, the eligible joints are: neck for muscle percentage, ribs for bone and subcutaneous fat percentages, flank for intermuscular fat percentage, and hind limb for total fat percentage. Among carcass tissue, muscle and subcutaneous and total fat weights were predicted more accurately by both weight and percentage. However, none of the carcass joints alone were adequate for prediction of all tissue composition. At least 3 carcass joints should be dissected for prediction of tissue composition.

Carrasco et al. [22] found that the loin and hind limb could be used for prediction of muscle and total fat percentages in light Churra Tensina lambs slaughtered at 22–24 kg live weight, similar to findings regarding total fat. Both Ruíz De Huidobro and Cañeque [34] and Miguélez et al. [35] reported that the hind limb was the most suitable joint for prediction of carcass muscle percentages, followed by loin and shoulder. In a departure from these results, Carrasco et al. [22] reported that the loin was more successful for the prediction of half-carcass muscle and fat percentages. Miguélez et al. [35] reported that the lowest predictive accuracy for all carcass tissue components was obtained from neck tissues, in contrast to the current study. Furthermore, Kempster et al. [36] stated that the composition of any joint, with the exception of the neck, was suitable for prediction of carcass composition. Argüello et al. [21] reported that the hind limb was preferred for prediction of muscle percentages; shoulder and flank for subcutaneous fat; and hind limb, flank, and ribs for intermuscular fat in goat carcasses. They also stated that shoulder dissection results could be used for muscle and subcutaneous and intermuscular fat; although there may be better predictors for these tissue components, the shoulder was the most cost-effective predictor in their study. However, in our study the shoulder was preferred for the prediction of muscle weight.

While others suggested that the hind limb and/or loin should be selected, the neck was the best carcass joint for prediction of half-carcass muscle percentage in the current study. Similar to some previous studies, the hind limb may be used for prediction of half-carcass total fat percentage. Differences among studies may be due to breed [37], production system [22], and slaughter weight [38] and may account for differences in both muscle and total fat percentages.

The equation including cold carcass weight, tail percentage, and hind limb length provided the greatest accuracy for prediction of muscle weight, while cold carcass weight and carcass length offered similar accuracy for total

Table 2. Descriptive information about various carcass characteristics and measurements.

Parameters	Abbr.	Mean	SD	Min.	Max.	% CV*
Cold carcass weight, kg	CCW	11.28	0.98	9.10	13.15	8.69
Dressing percentage-1, %	DP-1	40.88	2.54	34.50	46.8	6.20
Dressing percentage-2, %	DP-2	49.43	2.02	45.14	53.36	4.08
Shoulder weight, kg	SW	1.09	0.09	0.93	1.30	8.44
Flank weight, kg	FW	0.52	0.08	0.31	0.68	14.71
Neck weight, kg	NW	0.43	0.06	0.33	0.53	12.69
Ribs weight, kg	RW	1.50	0.18	1.22	1.82	12.14
Hind limb weight, kg	HLW	1.87	0.16	1.48	2.23	8.37
Tail weight, kg	TW	0.06	0.03	0.02	0.17	44.99
Kidney knob and channel fat, kg	KKCF	0.04	0.01	0.01	0.07	30.04
Back fat thickness, cm	BFT	1.42	0.95	0.05	4.19	67.17
Longissimus dorsi muscle section area, cm^2	LDMSA	9.52	1.74	3.10	14.40	18.32
Shoulder percentages, %	SP	19.48	1.04	17.48	21.45	5.33
Flank percentages, %	FP	9.25	1.17	4.98	10.93	12.62
Neck percentages, %	NP	7.74	0.73	5.94	8.95	9.41
Ribs percentages, %	RP	26.73	2.02	22.39	30.84	7.55
Hind limb percentages, %	HLP	33.36	1.52	29.83	36.31	4.54
Tail percentages, %	TP	1.13	0.46	0.47	2.87	40.23
Kidney knob and channel fat percentages, %	KKCF	0.78	0.22	0.24	1.26	28.06
Conformation	CS	5.07	0.60	3	6	11.84
Fatness	FS	5.17	1.03	3	7	20.01
Chest width, cm	CW	19.94	1.57	17.00	24.00	7.85
Carcass length, cm	CL	65.46	2.13	61.40	70.60	3.25
Rump circumference, cm	RC	49.16	2.05	46.10	54.30	4.16
Chest circumference, cm	CHC	65.36	1.86	61.10	68.90	2.84
Hind limb length, cm	HLL	29.33	4.28	22.10	36.00	14.59
Carcass compactness, g/cm	CC	205.12	37.02	169.78	424.24	18.05
Hind limb compactness$^{\mu}$, g/cm	HLC	95.02	6.95	78.94	112.42	7.31

Abbr.: Abbreviations, SD: Standard deviation, Min.: Minimum, Max.: Maximum, *%CV: Coefficient of variation.

fat weight. The remaining predictive models had relatively lower accuracy (Table 4). The equation including hind limb compactness and hind limb percentages produced the highest accuracy for prediction of half-carcass muscle percentage, tail weight and chest circumference produced the highest accuracy for prediction of subcutaneous and total fat percentages, while the stepwise analysis offered one variable [hind limb percentage (HLP)] for half-carcass intermuscular fat percentage, and the coefficient of determination for this model was significantly low. An equation could not be built for bone percentage with the variables investigated in this study.

Muscle and total fat weights were predicted more accurately than other tissue compositions, similar to joint dissection results. In addition, almost all coefficients of determination were similar to the joint dissection results for weights of tissue composition. For this reason, various carcass characteristics and measurements with joint weights and percentages might become an alternative for joint dissection, especially for muscle and total fat weights.

The equations built with carcass traits and measurements for prediction of tissue percentages had lower accuracy than joint dissection results. In addition, bone percentage cannot be predicted with the investigated carcass traits and measurements, unlike the joint dissection results. For this reason, when percentages of half-carcass tissue composition are predicted, joint dissection results should be preferred.

Table 3. Equations for prediction of half-carcass tissue composition using different joints' tissue compositions according to simple linear regression analysis.

Parameters	Joints	Equations*	R^2	MAE	RMSE	P values
Half-carcass tissue composition, g						
Muscle	Shoulder	Y= 1095.15 + 2.791 × SMW	0.642	85.548	114.533	< 0.001
Bone	Hind limb	Y= 340.53 + 2.082 × HLBW	0.454	69.938	89.893	< 0.001
Subcutaneous fat	Ribs	Y= 358.53 + 1.561 × RSCFW	0.653	95.833	116.683	< 0.001
Intermuscular fat	Hind limb	Y= 299.58 + 1.361 × HLIMFW	0.360	52.244	61.290	< 0.001
Total fat	Hind limb	Y= 359.29 + 2.882 × HLTFW	0.751	94.787	116.588	< 0.001
Half-carcass tissue composition, %						
Muscle	Neck	Y= 32.016 + 0.403 × NMP	0.483	1.5294	1.940	< 0.001
Bone	Ribs	Y= 15.910 + 0.255 × RBP	0.393	0.9682	1.199	< 0.001
Subcutaneous fat	Ribs	Y= 7.547 + 0.372 × RSFP	0.573	1.6598	1.955	< 0.001
Intermuscular fat	Flank	Y= 5.911 + 0.131 × FIMFP	0.338	0.7683	1.012	< 0.001
Total fat	Hind limb	Y= 8.395 + 0.875 × HLTFP	0.690	1.472	1.778	< 0.001

* SMW: Shoulder muscle weight, HLBW: Hind limb bone weight, RSCFW: Ribs subcutaneous fat weight, HLIMFW: Hind limb intermuscular fat weight, HLTFW: Hind limb total fat weight, NMP: Neck muscle percentage, RBP: Ribs muscle percentage, RSCFP: Ribs subcutaneous fat percentage, FIMFP: Flank intermuscular fat percentage, HLTFP: Hind limb total fat percentage.

Table 4. Equations for prediction of half-carcass tissue composition using various carcass characteristics, measurements and joint weights and percentages according to stepwise regression analysis.

Parameters	Equations*	R^2	MAE	RMSE	P values
Half-carcass tissue composition, g					
Muscle	Y= 321.439 + 189.798 × CCW − 121.304 × TP + 11.857 × HLL	0.684	88.330	107.629	< 0.001
Bone	Y= 926.766 + 662.326 × RW − 29.271 × RP	0.476	69.119	88.075	< 0.001
Subcutaneous fat	Y= 1037.784 + 175.430 × CCW − 29.425 × CL − 38.166 × FP	0.592	104.866	126.561	< 0.001
Intermuscular fat	Y= 474.964 + 39.464 × CCW − 14.081 × HLP	0.365	51.454	61.032	< 0.001
Total fat	Y= 732.400 + 221.254 × CCW − 31.170 × CL	0.650	115.001	138.269	< 0.001
Half-carcass tissue composition, %					
Muscle	Y= 40.112 − 0.130 × HLC + 0.539 × HLP	0.383	1.721	2.119	< 0.001
Bone	Y= -	-	-	-	-
Subcutaneous fat	Y= − 27.255 + 55.497 × TW + 0.569 × CHC	0.424	1.746	2.272	< 0.001
Intermuscular fat	Y= 17.480 − 0.274 × HLP	0.109	0.959	1.173	0.033
Total fat	Y= − 22.098 + 64.499 × TW + 0.612 × CHC	0.448	1.844	2.384	< 0.001

* Detailed information of the abbreviations were given in Table 2.

Miguélez et al. [35] reported that using cold half-carcass weight, KKCF, half-carcass length, and hind limb length was suitable for prediction of half-carcass muscle percentage. Cold half-carcass weight, KKCF, and hind limb length were suitable for predicting half-carcass fat percentage. The coefficient of determination for muscle was similar, and the coefficient of determination for bone and total fat was lower in Miguélez et al. [35]. Díaz et al. [39] than in the current study, indicating that parameters related with carcass fatness (KKCF, fatness score, and fat thickness) were more useful than others for prediction of fat percentage and predicted the fat pro percentage portion with a higher coefficient of determination than found in the current study. Similar to others, Lambe et al. [40] reported that cold carcass weight, fatness score, and back fat thickness can be used for the prediction of both muscle

Table 5. Equations for prediction of muscle weight and percentage with joint dissection and various carcass traits according to stepwise regression analysis.

Parameters	Equations*	R^2	MAE	RMSE	P values
Carcass joints, g					
Neck	Y= – 62.260 + 167.083 × CCW – 87.993 × TP + 14.620 × HLL + 2.835 × NMW	0.754	76.963	94.880	< 0.001
Hind limb	Y= 393.512 + 169.215 × CCW + 0.794 × HLMW – 5.704 × HLC – 1801.268 × TW	0.765	76.502	92.772	< 0.001
Flank	Y= 1548.796 + 186.958 × CCW – 144.986 × TP + 18.207 × HLL + 1.446 × FMW – 44.899 × FP – 47.995 × SP – 24.272 × LDMSA	0.817	68.882	81.916	< 0.001
Ribs	Y= – 795.508 + 122.453 × CCW + 0.941 × RMW + 43.398 × HLP	0.739	79.393	97.824	< 0.001
Shoulder	Y= 566.991 + 2.007 × SMW + 520.087 × HLW	0.767	70.516	92.277	< 0.001
Tail	Y= 321.439 + 189.798 × CCW – 121.304 × TP + 11.857 × HLL	0.684	88.330	107.623	< 0.001
Carcass joints, %					
Neck	Y= 28.769 + 0.345 × NMP + 0.197 × HLL	0.568	1.369	1.772	< 0.001
Hind limb	Y= 6.773 – 0.151 × HLC + 0.447 × HLMP + 0.406 × CL	0.552	1.507	1.806	< 0.001
Flank	Y= 35.974 + 0.179 × FMP – 0.102 × HLC + 0.444 × HLP	0.614	1.393	1.676	< 0.001
Ribs	Y= 47.695 + 0.248 × RMP – 6.350 × RW	0.515	1.456	1.879	< 0.001
Shoulder	Y= 21.673 + 0.310 × SMP – 0.126 × HLC + 0.305 × CL	0.573	1.497	1.763	< 0.001
Tail	Y= 40.112 – 0.130 × HLC + 0.539 × HLP	0.383	1.721	2.119	< 0.001

* NMW: Neck muscle weight, HLMW: Hind limb muscle weight, FMW: Flank muscle weight, RMW: Ribs muscle weight, SMW: Shoulder muscle weight, NMP: Neck muscle percentage, HLMP: Hind limb muscle percentage, FMP: Flank muscle percentage, RMP: Ribs muscle percentage, SMP: Shoulder muscle percentage. Rest of the information about abbreviations were given in Table 2.

and fat percentages. None of the investigated fatness parameters appear in any equations made with various carcass characteristics for prediction of half-carcass tissue composition, unlike Miguélez et al. [35], Díaz et al. [39], and Lambe et al. [40].

When the dissection results of carcass joints and various carcass characteristics were evaluated in the same analysis for prediction of half-carcass muscle weight, the equation including cold carcass weight, tail percentage, hind limb length, flank muscle weight, flank percentage, shoulder percentage, and LD muscle section area was the best equation, among others (R^2: 0.817; $P < 0.001$) (Table 5). The equation built with shoulder, hind limb, neck, ribs, and tail followed. Similar to muscle weight, the equation built with flank muscle percentage was more accurate than others; however, muscle weights were predicted more accurately than muscle percentages. The equations built with tail were least successful, for both half-carcass muscle weight and percentage. The accuracy of our prediction models was lower than Díaz et al. [39] and Carrasco et al. [22] for both muscle weight and percentage, although the equations were built with both joint dissections and the carcass measurements investigated in the current study.

The model that includes shoulder bone weight, rib weight, hind limb compactness, chest circumference, and tail percentage was the most accurate equation for half-carcass bone weight (R^2: 0.718; $P < 0.001$) (Table 6). Rib bone percentage can be used alone for prediction of bone percentage and gave the highest accuracy among joint bone percentages, as none of the investigated carcass characteristics appear in the equations for half-carcass bone percentage. When the accuracy of prediction models for half-carcass bone weight and percentages were evaluated, bone weight was predicted with higher accuracy.

The equation made with cold carcass weight, tail subcutaneous fat weight, carcass length, LD muscle section area, back fat thickness, and shoulder percentage was the best one for prediction of half-carcass subcutaneous fat weight (Table 7). In contrast to using various carcass characteristics alone, when joint dissections are added the fatness related characteristics take a place in the equations, similar to Díaz et al. [39] and Lambe et al. [40]. Similar to subcutaneous fat weight, tail and some carcass characteristics created the best prediction equation for subcutaneous fat percentage (R^2: 0.728; P <

Table 6. Equations for prediction of bone weight and percentage with joint dissection and various carcass traits according to stepwise regression analysis.

Parameters	Equations	R^2	MAE	RMSE	P values
Carcass joints, g					
Neck	Y= 2213.519 + 755.444 × RW – 30.312 × RP + 1.660 × NBW – 21.500 × CHC – 17.654 × LDMSA	0.661	53.602	70.839	< 0.001
Hind limb	Y= 1169.723 + 1.140 × HLBW + 278.396 × RW + 3.989 × HLC – 17.524 × CHC	0.639	56.018	73.076	< 0.001
Flank	Y= 40.999 + 361.333 × RW + 1.615 × FBW + 205.381 × HLW	0.544	60.803	82.218	< 0.001
Ribs	Y= 212.197 + 0.897 × RBW + 37.929 × CCW + 521.949 × NW	0.660	53.815	70.944	< 0.001
Shoulder	Y= 1605.169 + 1.258 × SBW + 304.307 × RW + 5.939 × HLC – 23.412 × CHC – 62.596 × TP	0.718	50.850	64.650	< 0.001
Tail	Y= 407.228 + 391.341 × RW + 6.786 × TBW	0.481	67.830	87.643	< 0.001
Carcass joints, %					
Neck	Y= 17.908 + 0.127 × NBP	0.181	1.010	1.393	0.005
Hind limb	Y= 11.275 + 0.474 × HLBP	0.267	1.079	1.317	< 0.001
Flank	Y= 17.901 + 0.154 × FBP	0.157	1.092	1.417	0.011
Ribs	Y= 15.910 + 0.255 × RBP	0.393	0.968	1.199	< 0.001
Shoulder	Y=13.154 + 0.374 × SBP	0.283	1.059	1.303	< 0.001
Tail	Y= 18.942 + 0.049 × TBP	0.110	1.130	1.452	0.032

* NBW: Neck bone weight, HLBW: Hind limb bone weight, FBW: Flank bone weight, RBW: Ribs bone weight, SBW: Shoulder bone weight, TBW: Tail bone weight, NBP: Neck bone percentage, HLBP: Hind limb bone percentage, FBP: Flank bone percentage, RBP: Ribs bone percentage, SBP: Shoulder bone percentage, TBP: Tail bone percentage. Rest of the information about abbreviations were given in Table 2.

0.001). Additionally, neck was the least successful joint for prediction of both subcutaneous fat weight and percentage.

Equations that combined flank intermuscular fat weight and percentages with carcass characteristics and measurements for prediction of half-carcass intermuscular fat weight (R^2: 0.638; P < 0.001) and percentage (R^2: 0.413; P < 0.001) had the highest accuracy (Table 8). On the other hand, neck and tail were the least successful for prediction of the half-carcass intermuscular fat weight and percentage. However, these results indicate that the equations for prediction of half-carcass intermuscular fat percentage had the lowest accuracy when compared with other half-carcass tissue compositions. When joint composition and various carcass characteristics and measurements were combined, the result was more successful than using them each separately.

The equation made with hind limb total fat weight, hind limb compactness, carcass length, shoulder weight, and dressing percentage-2 had the highest coefficient of determination for prediction of total fat weight (R^2: 0.902; P < 0.001) (Table 9). Flank (R^2: 0.811; P < 0.001), tail (R^2: 0.807; P < 0.001), ribs (R^2: 0.786; P < 0.001), shoulder (R^2: 0.775; P < 0.001), and neck (R^2: 0.650; P < 0.001) followed, respectively. Similar to total fat weight, neck was the least successful joint for prediction of total fat percentage.

When the parameters investigated in the study were combined together (various carcass measurements and characteristics, joint weight, and percentages and joint tissue compositions), half-carcass total fat weight was predicted more successfully than other carcass components (best models: total fat weight, R^2: 0.902; muscle, R^2: 0.817; subcutaneous fat, R^2: 0.803; bone, R^2: 0.718; and intermuscular fat, R^2: 0.638, respectively). Similar results were observed for half-carcass total fat percentage (best models: total fat weight, R^2: 0.823; subcutaneous fat, R^2: 0.728; muscle, R^2: 0.614; intermuscular fat, R^2: 0.413; and bone, R^2: 0.393, respectively).

When all sets of equations in the study were investigated, the half-carcass tissue weight most accurately predicted was total fat, similar to Ruíz De Huidobro and Cañeque [34], Díaz et al. [39], and Miguélez et al. [35]. However, a study that used joint dissection results in addition to various carcass characteristics and measurements, joint weights, and percentages was not found.

In the current study, when only joint tissue percentages were used for prediction of half-carcass muscle weight and

Table 7. Equations for prediction of subcutaneous fat weight and percentage with joint dissection and various carcass traits according to stepwise regression analysis.

Parameters	Equations	R^2	MAE	RMSE	P values
Carcass joints, g					
Neck	Y= 1037.784 + 175.430 × CCW – 29.425 × CL – 38.166 × FP	0.592	104.866	126.561	< 0.001
Hind limb	Y= –142.513 + 2.093 × HLSCFW + 7.371 × HLC + 23.642 × DP-2 – 17.382 × CL	0.781	74.528	92.615	< 0.001
Flank	Y= – 890.492 + 150.184 × CCW + 1.750 × FSCFW – 851.035 × FW + 227.995 × KKCFP	0.725	79.106	103.786	< 0.001
Ribs	Y= – 512.566 + 1.223 × RSCFW + 321.531 × RW + 252.425 × HLW	0.796	74.664	89.523	< 0.001
Shoulder	Y= 831.868 + 107.381 × CCW + 1.564 × SSCFW – 27.737 × CL + 4.199 × HLC	0.738	81.399	101.304	< 0.001
Tail	Y= 2508.845 + 115.269 × CCW + 8.416 × TSCFW – 31.433 × CL – 31.735 × LDMSA + 49.622 × BFT – 43.873 × SP	0.803	70.473	87.871	< 0.001
Carcass joints, %					
Neck	Y= – 27.255 + 55.497 × TW + 0.569 × CHC	0.424	1.746	2.272	< 0.001
Hind limb	Y= 0.537 + 0.674 × HLSCFP + 0.102 × HLC	0.648	1.452	1.775	< 0.001
Flank	Y= – 7.627 + 58.636 × TW + 0.143 × FSCFP + 0.565 × CHC – 0.461 × RC	0.674	1.250	1.709	< 0.001
Ribs	Y= – 0.957 + 0.354 × RSCFP + 5.863 × RW	0.696	1.398	1.650	< 0.001
Shoulder	Y= 18.984 + 0.369 × SSCFP + 1.832 × CCW – 0.477 × CL	0.633	1.515	1.814	< 0.001
Tail	Y= 14.880 + 51.312 × TW + 0.147 × TSCFP + 0.509 × DP-2 – 0.197 × HLL – 0.398 × CL	0.728	1.266	1.559	< 0.001

* HLSCFW: Hind limb subcutaneous fat weight, FSCFW: Flank subcutaneous fat weight, RSCFW: Ribs subcutaneous fat weight, SSCFW: Shoulder subcutaneous fat weight, TSCFW: Tail subcutaneous fat weight. HLSCFP: Hind limb subcutaneous fat percentage, FSCFP: Flank subcutaneous fat percentage, RSCFP: Ribs subcutaneous fat percentage, SSCFP: Shoulder subcutaneous fat percentage, TSCFP: Tail subcutaneous fat percentage. Rest of the information about abbreviations were given in Table 2.

percentage, the prediction accuracy was 64% (shoulder) and 48% (neck); for half-carcass total fat weight and percentage it was 75% (hind limb) and 69% (hind limb), respectively. When carcass measurements were used alone for half-carcass muscle weight and percentage, prediction accuracy was 68% and 38%; for half-carcass total fat weight and percentage it was 65% and 45%, respectively. However, when joint dissection results were combined with various carcass characteristics and measurements and joint weights and percentages, the combination predicted the half-carcass muscle weight with 82% accuracy and percentage with 61% accuracy, and half-carcass total fat weight was predicted with 92% accuracy and percentage with 82% accuracy.

In Miguélez et al. [35], the prediction accuracy for half-carcass muscle percentage was 76% using joint dissection results and 64% for conformation and fatness scores with cold carcass weight, which is higher than our study for both parameters. Díaz et al. [39] reported a prediction accuracy of 63% for half-carcass muscle percentage when they used various carcass characteristics and measurements. Miguélez et al. [35] reported the prediction accuracy for half-carcass fat percentage as 82% for joint tissue percentages and 61% for prediction equations formed with conformation and fatness scores along with cold carcass weight. On the other hand, the prediction equations for half-carcass total fat percentage using various carcass characteristics and measurements produced 84% accuracy in Díaz et al. [39].

The accuracy of equations for prediction of half-carcass muscle percentage in the current study was lower than in Díaz et al. [39] and Miguélez et al. [35]. However, the current equations predicted total fat percentage more accurately than those used in the above studies. On the other hand, the prediction equations built with weights were more successful for both half-carcass muscle and total fat weights.

In addition, the neck was the least successful carcass joint when its dissection results were combined with

Table 8. Equations for prediction of intermuscular fat weight and percentage with joint dissection and various carcass traits according to stepwise regression analysis.

Parameters	Independent variables	R^2	MAE	RMSE	P values
Carcass joints, g					
Neck	Y= 474.964 + 39.464 × CCW – 14.081 × HLP	0.365	51.454	61.032	< 0.001
Hind limb	Y= 453.649 + 0.989 × HLIMFW + 278.780 × SW – 12.492 × HLP	0.514	43.610	53.393	< 0.001
Flank	Y= 449.306 + 1.266 × FIMFW + 418.230 × SW – 11.373 × CL + 384.590 × NW	0.638	35.452	46.091	< 0.001
Ribs	Y= – 119.429 + 25.815 × CCW + 0.935 × RIMFW + 307.965 × FW	0.558	41.661	50.913	< 0.001
Shoulder	Y= – 88.101 + 32.811 × CCW + 1.287 × SIMFW + 98.072 ×K KCFP	0.443	47.706	57.181	< 0.001
Tail	Y= 477.309 + 39.327 × CCW – 14.084 × HLP	0.365	51.448	61.036	< 0.001
Carcass joints, %					
Neck	Y= 17.480 – 0.274 × HLP	0.109	0.956	1.173	0.033
Hind limb	Y= 6.357 + 0.357 × HLIMFP	0.240	0.897	1.094	0.001
Flank	Y= 13.679 + 0.125 × FIMFP – 0.230 × HLP	0.413	0.728	0.952	< 0.001
Ribs	Y= 3.233 + 0.276 × RIMFP + 5.277 × FW	0.397	0.762	0.965	< 0.001
Shoulder	Y= 5.191 + 0.263 × SIMFP + 1.826 × KKCFP	0.213	0.927	1.103	0.009
Tail	Y= 17.480 – 0.274 × HLP	0.109	0.956	1.173	0.033

* HLIMFW: Hind limb intermuscular fat weight, FIMFW: Flank intermuscular fat weight, RIMFW: Ribs intermuscular fat weight, SIMFW: Shoulder intermuscular fat weight, HLIMFP: Hind limb intermuscular fat percentage, FIMFP: Flank intermuscular fat percentage, RIMFP: Ribs intermuscular fat percentage, SIMFP: Shoulder intermuscular fat percentage. Rest of the information about abbreviations were given in Table 2.

Table 9. Equations for prediction of total fat weight and percentage with joint dissection and various carcass traits according to stepwise regression analysis.

Parameters	Independent variables	R^2	MAE	RMSE	P values
Carcass joints, g					
Neck	Y= 732.400 + 221.254 × CCW – 31.170 × CL	0.650	115.001	138.269	< 0.001
Hind limb	Y= 887.173 + 2.184 × HLTFW + 5.690 × HLC – 37.548 × CL + 709.954 × SW + 19.957 × DP-2	0.902	56.861	73.086	< 0.001
Flank	Y= 861.546 + 111.452 × CCW + 2.010 × FTFW – 60.135 × FP + 151.906 × KKCFP – 24.682 × RC + 4.601 × HLC	0.811	76.700	101.441	< 0.001
Ribs	Y= – 509.732 + 1.113 × RTFW + 75.900 × CCW + 286.487 × RW	0.786	88.065	108.086	< 0.001
Shoulder	Y= 1007.289 + 178.081 × CCW + 1.555 × STFW – 33.232 × CL	0.775	85.539	110.710	< 0.001
Tail	Y= 1339.221 + 160.580 × CCW – 34.360 × CL + 5.828 × TTFW + 3502.398 × KKCFW + 46.633 × BFT	0.807	81.361	102.744	< 0.001
Carcass joints, %					
Neck	Y= – 18.629 + 56.894 × TW + 0.515 × CHC + 0.150 × NTFP	0.506	1.776	2.246	< 0.001
Hind limb	Y= 34.031 + 0.798 × HLTFP + 0.075 × HLC – 0.562 × CL 6.857 × SW	0.823	1.073	1.346	< 0.001
Flank	Y= - 6.063 + 58.933 × TW + 0.170 × FTFP + 0.636 × CHC – 0.494 × RC	0.685	1.339	1.793	< 0.001
Ribs	Y= 2.422 + 0.374 × RTFP + 6.814 × RW	0.656	1.437	1.874	< 0.001
Shoulder	Y= 16.675 + 0.393 × STFP + 1.769 × CCW – 0.382 × CL + 2.869 × KKCFP	0.710	1.300	1.721	< 0.001
Tail	Y= 22.023 + 63.866 × TW + 0.148 × TTFP + 0.592 × DP-2 – 0.488 × CL – 0.154 × HLL	0.723	1.332	1.681	< 0.001

* HLTFW: Hind limb total fat weight, FTFW: Flank total fat weight, RTFW: Ribs total fat weight, STFW: Shoulder total fat weight, TTFW: Tail total fat weight, NTFP: Neck total fat percentage, HLTFP: Hind limb total fat percentage, FTFP: Flank total fat percentage, RTFP: Ribs total fat percentage, STFP: Shoulder total fat percentage, TTFP: Tail total fat percentage. Rest of the information about abbreviations were given in Table 2.

various carcass measurements and characteristics, joint weight and percentages, and joint tissue compositions for prediction of half-carcass tissue composition, similar to Kempster et al. [36] and Miguélez et al. [35].

4. Conclusion

According to the joint dissection results, none of the joints can be used alone with adequate accuracy for prediction of half-carcass tissue composition. The prediction equations including numerous carcass traits yielded accuracy similar to joint dissection results, especially for muscle and total fat weights. Therefore, for these parameters, carcass traits, which are cost-effective and practical, may be preferred for carcass evaluation. On the other hand, when the joint dissection and various carcass characteristics and measurements are combined, half-carcass tissue composition is predicted more accurately (65%–90%) than it is with methods using joint dissection or various carcass traits alone.

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Contribution of authors

PDK, AY, and BE designed the experiment. PDK, NO, HY, OK, AY, and BE collected the data. PDK and BE performed the statistical analysis. PDK wrote the paper. All authors reviewed and approved the paper.

Conflict of interest

The authors have no conflict of interest to declare.

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