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The relationship between live weight and body measurements of Chios lambs at different periods

F. E. Atac[1#] & S. O. Altincekic[2]

[1]Department of Animal Science, Faculty of Agriculture, Ege University, 35100, Izmir, Turkey
[2]Department of Animal Science, Faculty of Agriculture, Bursa Uludağ University, 16059, Bursa, Turkey

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Abstract

The data of 60 male Chios lambs raised in western Turkey on a farm registered with the Sheep and Goat Breeders' Association were used. Two datasets were generated to determine the correlations between weaning (90 d) and six-month traits in lambs. A canonical analysis was performed to determine the correlation between body weight measured at the weaning period and six morphological traits — dataset X-weaning weight (WW), body length (BL), wither height (WH), heart girth (HG), chest width (CW), rump width (RW), and rump length (RL)— and body weight measured at six months and six morphological traits —dataset Y-body weight (LW_6), body length (BL_6), wither height (WH_6), heart girth (HG_6), chest width (CW_6), rump width (RW_6), and rump length (RL_6). Only the first (U1V1) of the seven pairs of canonical dimensions was statistically significant. The contribution of body weight, WH, and RW to the explanatory effect of canonical variables estimated from morphological traits of Chios lambs was greater at weaning age than other body measurements. Canonical correlation analysis and variables (U1 and V1) can be used as a generic measure of variables, X and Y, respectively. The cross-loadings indicated that body weight, RW, and WH in the weaning period were more effective in V1 determination than other traits; WH, RL, and LW_6 were more influential in U1 determination. This study is the first to use canonical correlation analysis to determine the correlation between live weight and body measurements in Chios lambs, presenting early selection criteria for Chios lamb breeding studies.

Keywords: Chios lambs, weaning weight, body measurements, canonical correlation coefficient
[#]Corresponding author: funda.erdogan.atac@ege.edu.tr

Introduction

Chios sheep are one of the rare breed specimens in the world, especially with their high milk and fertility. The Chios species is also used to generate new sheep breeds to improve lamb meat production and, in this context, they are used as rootstock material in cross-breeding programmes due to their high fertility and milk yield (Esen *et al.,* 2000; Ceyhan *et al.,* 2007). Chios meat palatability, 250–300 g of daily live weight gain, and satisfactory fattening performance make it highly desirable (Boztepe *et al.,* 2022). Non-breeding male Chios lambs extensively bred in the Aegean region attain slaughter weight at a young age under intensive feeding conditions (Altinel *et al.,* 1998; Zervas *et al.,* 1999; Onenç *et al.,* 2012). Although the Chios breed is suitable for the characteristics of the milk type, it has a large and delicate body type with high withers. Body size-related data are critical in determining morphological structure and developmental potential in animals (Mathapo *et al.,* 2022). Live weight, which affects meat yield, is considered a significant criterion in the animal selection process (Yaprak *et al.,* 2008; Iqbal *et al.,* 2013; Shehata, 2013; Ambarcioglu *et al.,* 2017; Varkoohi *et al.,* 2018; Mokoena *et al.,* 2022). Thus, numerous morphological traits in sheep breeding are frequently measured and recorded to track live

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weights while animals grow. However, weighing of sheep takes a long time and much labour (Gurcan & Akcapinar, 2006; Yakubu & Mohammed, 2012).

It is critical to determine the relationship between a trait measured in the early period and two or more traits measured in the late period. For instance, Tahtali *et al.* (2012) reportedly indicated that wither height, birth weight, and chest width measured at birth could be utilized as early selection criteria in lamb breeding. Alade *et al.* (2010) noted that the traits such as litter size, birth weight, and weaning weight could be used to achieve substantial genetic improvement in growth rate through direct selection to attain high heritability and repeatability estimates. Younas *et al.* (2013) reported that animal body measurements are a positive indicator and are highly correlated with body weight; as a result, it is conceivable to apply these criteria safely to estimate body weight. Khan *et al.* (2014) identified strong genetic relationships between simply-measurable weight and morphological traits in sheep, suggesting that these traits can be considered differentiation criteria during indirect selection to achieve genetic improvement. Lakew *et al.* (2017) also identified strong, positive correlations between body weight and the majority of body measurement data in lambs of both sexes across all age groups, indicating that body measurements are the most practical criteria to make accurate estimations for live weight under farm conditions.

Yet, it might be challenging, in practice, to comprehensively elucidate the relationship between body weight and morphological measures (Fourie *et al.,* 2002; Tahtali *et al.,* 2012; Adhianto *et al.,* 2020; Karna *et al.,* 2020; Faraz *et al.,* 2021). The canonical correlation analysis, applied in this context, refers to measuring the interactions between multiple dependent and independent variables to identify the relationship between different sets of variables. In other words, the multivariate statistical technique designed to support the researcher aims to analyse the complex interactions of the data obtained from two sets of variables. It is also a statistical model involving two correlated, variable datasets that shows how much variance one set shares with other sets or how predictable it is. The most critical aspect of the technique is its ability to focus on the significant relationship between the two variable sets in several canonical variable sets (Ventura *et al.,* 2011; Jacob & Ganesan, 2013; Mokoena & Tyasi, 2021; Akour *et al.,* 2023). Canonical correlation analysis has been used successfully as a comprehensive statistical tool to analyse the relationships between significant traits that provide information that may serve as the basis of indirect selection and management practices in animal husbandry and to effectively estimate multiple trait clusters (Bilgin *et al.,* 2003; Akbas & Takma, 2005; Cankaya & Kayaalp, 2007; Yaprak *et al.,* 2008; Cankaya *et al.,* 2009; Sahin *et al.,* 2011; Tahtali *et al.,* 2012; Atac & Takma, 2018; Kim *et al.,* 2018; Altay *et al.,* 2020; Karadavut, 2020; Kaya *et al.,* 2021; Mokoena & Tyasi, 2021;Ozen *et al.,* 2021).

This study aimed to identify the relationship between live weight of Chios lambs at weaning and six months of age, with six different morphological traits within the same period. It also aimed to determine which traits could be utilized as selection criteria during the weaning period to improve live weight. In this context, the current study is the first and a unique attempt to identify the relationships assessed in Chios lambs by applying canonical correlation analysis appropriate to the data set and with high accuracy.

Materials and Methods

The study was carried out between February (WW; 3-months of age) and May, 2022 (6-months of age) on a farm registered with the Sheep and Goat Breeders' Association in Izmir, western Turkey. All lambs were kept in the maternity chambers (delivery stalls) with their mothers for three days after delivery. The lambs were fed *ad libitum* concentrate and premium alfalfa hay for three months, starting 15 days after birth. Male and female lambs were raised separately after being weaned, which took 90 ± 8 days on average. The lambs had free access to fresh water for drinking, lick blocks for minerals, and roughage. Approximately 200 g of concentrate feed per lamb/day was fed from weaning to six months of age (180 d).

The experimental design included 60 male Chios lambs. Weaning weight (WW) at 3 m and live weight at 6 m (LW_6), as well as morphological measurements for body length (BL), wither height (WH), heart girth (HG), chest width (CW), rump width (RW), and rump length (RL) were taken (Table 1). The body measurements of lambs at weaning and six months of age were measured on a flat surface using a measuring stick, measuring callipers, and tape, and accordingly, researchers measured each lamb on their left side and recorded their live weights using a digital scale with 5 g precision. Live weight measurements of the lambs took place before morning feeding. Only one person collected all of the data to ensure standardization.

The studied morphological measurements were:
Body length (BL): The diagonal distance measured from the sternum tip to the tail base
Heart girth (HG): The circumference of the animal behind the foreleg
Wither height (WH): The distance measured from the ground to the highest point of the wither
Rump width (RW): The distance measured between the left and right tuber coxae
Rump length (RL): The distance measured from the anterior point to the posterior extremity of the pin bone
Chest width (CW): The measurement of the intercostal diameter at the level of the sixth rib

Table 1 Measured variables and variable coding used in the study

Variable name	For Weaning Period (X-Variable Set)	For Six month age (Y-Variable Set)
live weight (kg)	LW_W	LW_6
body length (cm)	BL_W	BL_6
heart girth (cm)	HG_W	HG_6
wither height (cm)	WH_W	WH_6
rump width (cm)	RW_W	RW_6
rump length (cm)	RL_W	RL_6
chest width (cm)	CW_W	CW_6

Canonical correlation signifies the relationship between a linear combination of variables in one group and a linear combination of variables in another group, and the primary objective here is to identify a pair. Canonical variables are the linear combination pairings with the highest correlation among all pairs (Akour *et al.,* 2023). The canonical correlation analysis in this study included seven characters (X: body weight and morphological traits at weaning) in the weaning variable set, and these same seven characters (Y: 6-m body weight and morphological traits) in the six-month age variable set. The U and V letters referred to the canonical variables for X and Y, respectively.

This study used canonical correlation analysis to evaluate the correlation between the weaning period (variable set X) and six month traits (variable set Y). It also utilized Pearson's correlation analysis to identify the linear correlation between traits. All computations were performed using the SPSS 26.0 statistical package program (SPSS, 2019). The following table includes the formula and equations used for the hypothesis and canonical correlation calculations made in the study.

The hypothesis for the statistical significance of canonical coefficients was:

$$H_0 = r_{c1} = r_{c1} = \ldots = r_{cr} = 0 \qquad (1)$$
$$H_1 \neq r_{ci} = 0 \text{ at least one } i = 1,2,\ldots k$$

The most typical method used to test the null and alternative hypotheses is Wilk's Lambda (Λ) test statistic (Equation 2).

$$\Lambda_m = \prod_{i=1}^{m}.(1-\lambda_i) \qquad (2)$$

where Λ_m = Canonical correlation coefficient
$\lambda_i =$ squared canonical correlation
m = number of canonical correlations.

The significance of canonical correlations was measured using the Chi-square variable:

$$X^2 = -\left(N - 1 - \left(\frac{K_x+K_y+1}{2}\right)\right) \ln \Lambda_m \qquad (3)$$

where N = number of cases,
K_x = the number of variables in the X variable set,
K_y = the number of variables in the Y variable set.

Scores (U and V) on canonical variables were estimated.

$$U = Z_x B_x \quad (4)$$
$$V = Z_y B_y \quad (5)$$

Z_x and Z_y = standardized scores, and B_x and B_y = canonical coefficients.
The correlation matrices among variables were calculated using matrix loadings and canonical coefficients:

$$A_x = R_{xx}B_x,\ A_y = R_{yy}B_y \quad (6)$$

$$pv_{xc} = \sum_{i=1}^{k_x} \frac{a^2{}_{ixc}}{k_x} \quad (7)$$

$$pv_{yc} = \sum_{i=1}^{k_y} \frac{a^2{}_{iyc}}{k_y} \quad (8)$$

where Pv = the variance ratio calculated from a set of variables through a canonical variable of the cluster, a^2 = squared correlation and the number of variables in the cluster, rd = redundancy, and rd = (pv) (r^2_c).

Results and Discussion

Table 2 provides descriptive data for each trait analysed in male Chios lambs. Accordingly, analyses revealed that the mean LW_W and LW_6 values were 24.83 ± 3.47 kg and 38.98 ± 5.19 kg, respectively. The average values for BL, HG, WH, RW, RL, and CW measured in the weaning period and at 6 m ranged from 53.31–66.25, 39.15–48.32, 57.83–66.74, 11.18–15.08, 16.85–22.00, and 14.08–17.58 cm, respectively. This study identified the highest correlations between LW and RW (0.746) during the weaning period, whereas the highest correlations were found between LW_6 and RL (0.691) at 6 m (P <0.01). Younas *et al.* (2013) reportedly found a strong and positive correlation (P <0.001) between body length and heart girth in Hissardale sheep. In the current study, the correlations between body length and heart girth in Chios lambs in both age periods (P <0.05) were consistent with this literature. Topal & Macit (2004) also reported a strong correlation (0.867) between body weight and heart girth in Morkaraman sheep. Similarly, Lakew *et al.* (2017) identified a consistent (P <0.001), strong correlation between body weight and heart girth in lambs of both sexes in all age groups. Atta & El Khider (2004) reported that heart girth measurement estimated the potential body weight of male and female Nilotic sheep. In Chios sheep, however, the correlation between heart girth at both weaning and 6 m and body weight was significant (P <0.01), but the correlation between heart girth at weaning and live weight at 6 m was not statistically significant.

Table 2 Descriptive values for measured characteristics (cm) in male Chios lambs (n = 60)

Variables	Mean	Std Error	Std Deviation	Minimum	Maximum
LW_W	24.83	0.45	3.47	18.00	31.00
BL_W	53.31	0.58	4.53	42.00	63.00
HG_W	39.15	0.40	3.11	32.00	46.00
WH_W	57.83	0.37	2.88	51.00	66.00
RW_W	11.38	0.14	1.11	9.00	14.00
RL_W	16.85	0.20	1.54	13.00	20.00
CW_W	14.08	0.17	1.28	11.00	17.00
LW_6	38.98	0.67	5.19	26.00	48.00
BL_6	66.25	0.41	3.19	59.00	74.00
HG_6	48.32	0.38	2.91	42.00	53.00
WH_6	66.74	0.41	3.14	59.00	73.00
RW_6	15.08	0.14	1.06	13.00	18.00
RL_6	22.00	0.20	1.54	18.00	25.00
CW_6	17.58	0.18	1.42	14.00	21.00

BL: body length; HG: heart girth; WH: wither height; RW: rump width; RL: rump length; CW: chest width; W: weaning period; 6: six months of age

Table 3 displays the correlation between the live weights and the morphological traits analysed in the two periods in male Chios lambs. According to the bivariate correlation matrix, the strongest correlations identified between the live weight and other respective traits at the weaning period were: LW_6 (r = 0.817), RL_6 (r = 0.769), RW_W (r = 0.746), and WH_6 (r = 0.706).

The 6-m measurements, however, identified a substantial correlation between live weight and RL_6 (r = 0.691), BL_6 (r = 0.671), RW_W (r = 0.665), and CW_6 (r = 0.064). The correlation between the two-body weights measured in two periods and HG_W was relatively weak compared to other traits.

The weakest correlations estimated were for HG_W and RL_W (r = 0.18) at weaning time, and CW_6 and RW_6 (r = 0.24) at 6 m, and for BL_W and BL_6 (r = 0.12) at weaning and 6 m (*P* <0.01, *P* <0.05, respectively.

In this study, for the first time, a correlation between body weight and morphological traits measured at weaning and six months of age was determined using canonical correlation analysis in Chios lambs. The results revealed a strong (*P* <0.01) correlation between the body measurements assessed in male Chios lambs at both weaning and 6 m. The canonical correlation analysis also revealed that the traits that best represent the weaning period were live weight, wither height, and rump width, whereas the traits that best represented 6 m lambs were wither height, rump length, and live weight. In both age periods, live weight and height at wither were important measurements.

Although the measurements taken during weaning were strong indicators for the 6-m period, it is necessary to use the canonical correlation coefficient to estimate and explain the relationships between the analysed variable set while interpreting the correlations (Table 4), since it is difficult to explain the relationships among the traits simultaneously. Statistically, the correlation between U1V1 (r = 0.963) was the highest (*P* <0.001), and this article interpreted the correlation between the initial canonical variable. Younas *et al.* (2013) reported a strong and positive correlation between live weight and wither height in various age groups of Hissardale sheep. Atta & El Khider (2004) also documented that the live weight of Nilotic sheep for both sexes could be estimated using wither height. Topal & Macit (2004) indicated that two traits in combination—wither height and heart girth (R^2 = 75.2%)— were successful indicators for estimating live weight in Morkaraman sheep. Sahin *et al.* (2011) estimated body measurements before weaning and body weight at 6 m in Merino lambs using canonical correlation, and accordingly, found that if the wither height and live weight increased at weaning, the withers height_6 and body weight_6 would also increase at 6 m. Iqbal *et al.* (2014) reported that body length and wither height were optimal combinations for estimating body weight in Kajli lambs between the ages of four and six months. Correspondingly, Ozen *et al.* (2021) reported that canonical coefficients led to increases in linear measurement combinations of 0.118 and 0.127 units for every unit increase in body weight and wither height, respectively, at the weaning period for Bafra lambs. They further noted that wither height, chest circumference, and chest girth were the most effective traits correlating weaning and variates measured at 6 m, and could serve as a basis for early selection criteria in Bafra lambs.

Table 4 Results of the canonical correlation analysis

Pair of canonical variables	Canonical correlation	Squared canonical correlation	F-Value	Df1	Df2	Probability Pr>F	Wilks' Lambda
U1 V1	0.963	0.927	5.983	49	237.957	<0.001	0.017
U2 V2	0.682	0.465	2.257	36	209.152	<0.001	0.237
U3 V3	0.610	0.372	1.764	25	179.814	0.018	0.443
U4 V4	0.452	0.204	1.136	16	150.335	0.327	0.706
U5 V5	0.261	0.068	0.687	9	121.837	0.720	0.887
U6 V6	0.221	0.048	0.646	4	102.000	0.631	0.951
U7 V7	0.010	0.000	0.005	1	52.000	0.943	1.000

Table 3 The correlations between morphologic traits measured in male Chios lambs

	LW_W	LW_6	BL_W	BL_6	HG_W	HG_6	WH_W	WH_6	RW_W	RW_6	RL_W	RL_6	CW_W	CW_6
LW_W	1													
LW_6	0.817**	1												
BL_W	0.586**	0.314*	1											
BL_6	0.618**	0.671**	0.123	1										
HG_W	0.438**	0.249	0.309*	0.267*	1									
HG_6	0.576**	0.555**	0.102	0.618**	0.235	1								
WH_W	0.595**	0.489**	0.268*	0.502**	0.225	0.414**	1							
WH_6	0.706**	0.628**	0.133	0.655**	0.311*	0.539**	0.734**	1						
RW_W	0.746**	0.665**	0.322*	0.674**	0.304*	0.645**	0.626**	0.706**	1					
RW_6	0.478**	0.529**	0.255*	0.352**	0.149	0.369**	0.160	0.291*	0.333**	1				
RL_W	0.604**	0.554**	0.183	0.593	0.181	0.336**	0.625**	0.475**	0.562**	0.153	1			
RL_6	0.769**	0.691**	0.403**	0.653**	0.364**	0.492**	0.734**	0.622**	0.718**	0.270*	0.688**	1		
CW_W	0.528**	0.587**	0.203	0.528**	0.308*	0.353**	0.363**	0.431**	0.475**	0.345**	0.520**	0.618**	1	
CW_6	0.678**	0.664**	0.140	0.556**	0.265*	0.447**	0.525**	0.719**	0.591**	0.243	0.432**	0.691**	0.553**	1

* P <0.05; ** P <0.01
BL: body length; HG: heart girth; WH: wither height; RW: rump width; RL: rump length; CW: chest width; W: weaning period; 6: six months of age

Table 5 provides comparisons of model variables interpreted using standardized canonical coefficients. Considering the comparisons between the variables, body weight and WH affected the U1 and V1 determinations more, respectively. However, the variables that contributed most to the U1 canonical variable were WH and BL, while these traits were RL and LW_6 for V1. Considering the most substantial contribution to canonical coefficients estimated from body measurements in this study, wither height and body length contributed the most during weaning, but rump length and LW_6 contributed the most at 6 m.

Accordingly, Sahin *et al.* (2011) reported that chest girth and live weight were the most substantial contributors to the canonical coefficients estimated from pre-weaning body measurements of Merino lambs; however, it was wither height and live weight at 6 m. Tahtali *et al.* (2012) documented that the wither height and chest circumference were the best contributors to the canonical coefficients of morphological traits in the weaning period of Karayaka lambs. Mokoena & Tyasi (2021) also revealed that wither height and live weight measurements at birth and weaning constituted the best contribution to canonical variables to increase body weight in goats, specifying that these measurements are potential genetic improvement criteria.

Table 5 Standardized canonical coefficients for canonical variables

			X-Variable Set				
U1	LW_W	BL_W	HG_W	WH_W	RW_W	RL_W	CW_W
	0.7402	-0.2666	-0.0224	0.3597	0.1677	-0.1639	0.1677
			Y-Variable Set				
V1	LW_6	BL_6	HG_6	WH_6	RW_6	RL_6	CW_6
	0.2206	-0.0921	0.1460	0.4584	0.0646	0.3677	0.0373

BL: body length; HG: heart girth; WH: wither height; RW: rump width; RL: rump length; CW: chest width; W: weaning period; 6: six months of age

Table 6 lists the loadings of each set's variables on the canonical dimensions generated by cross-loadings that represent the correlations between the opposite canonical variables and the variables in V1 and U1. According to the cross-loading, body weight, RW, and WH in the weaning period were more effective in V1 determination, whereas WH, RL, and LW_6 were more effective in U1 determination.

Table 6 Cross loadings of the original variables with opposite canonical variables

			X-Variable Set				
V1	LW_W	BL_W	HG_W	WH_W	RW_W	RL_W	CW_W
	-0.870	-0.304	-0.360	-0.758	-0.810	-0.613	-0.600
			Y-Variable Set				
U1	LW_6	BL_6	HG_6	WH_6	RW_6	RL_6	CW_6
	-0.810	-0.703	-0.655	-0.857	-0.429	-0.829	-0.768

BL: body length; HG: heart girth; WH: wither height; RW: rump width; RL: rump length; CW: chest width; W: weaning period; 6: six months of age

The current study found that the canonical variables, U1 and V1, explained 58% and 45%, respectively, of the total variation of the morphological traits measured during the weaning period. In contrast, U1 and V1 variables explained 42% and 54%, respectively, of the total variation in morphological traits measured at 6 m (Table 7).

Table 7 Total variation for variables explained by canonical variables

X – Variable Set				Y – Variable Set			
Variance extracted		Redundancy		Variance extracted		Redundancy	
U1	0.58	V1	0.45	V1	0.54	U1	0.42

Conclusion

The most significant and critical aspect of animal breeding studies is the regular record keeping. Body measurements are significant performance criteria used in herd tracking to identify phylogenetic traits, as they provide crucial information about animals, developmentally and morphologically. However, it is essential to shorten the breeding time between generations in lambs and evaluate any traits that may be advantageous for potential early selection. By performing canonical correlation analysis, it is possible to reveal and interpret the correlational structure between two sets consisting of at least two variables without compromising their integrity. The most significant factors in the relationship between the traits measured in Chios lambs were live weight and wither height. Therefore, taking the live weights of the lambs during the weaning period will substantially help breeders select the best animal. Furthermore, the findings of this study may expectedly add to the literature and advance breeding practices.

Author's Contributions

FEA designed the study and acquisition of data; FEA and SOA conducted the statistical analyses and wrote the manuscript.

Conflict of interest declaration

The authors declare no conflict of interest.

Institutional Review Board Statement

In the study there is no need for ethical approval due to the lack of blood sampling from the animals and the absence of any surgical procedures.

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References

Adhianto, K., Harris, I., Nugroho, P. & Putra, W.P.B., 2020. Prediction of body weight through body measurements in Boerawa (Boer × Etawah crossbred) bucks at Tanggamus regency of Indonesia. Bulg. J. Agric. Sci. 26(6), 1273–1279.

Akbas, Y. & Takma, C., 2005. Canonical correlation analysis for studying the relationship between egg production traits and body weight, egg weight, and age at sexual maturity in layers. Czech. J. Anim. Sci. 50, 163–168.

Akour, I.A., Rahamneh, A.L., Al Kurdi, B., Alhamad, A., Al–Makhariz, I., Alshurideh, M., Al–Hawary, S., 2023. Using the canonical correlation analysis method to study students' levels in face-to-face and online education in Jordan. Inf. Sci. Lett. 12(2), 901–910. http://dx.doi.org/10.18576/isl/120229.

Alade, N.K., Dilala, M.A., Abdulyekeen, A.O., 2010. Phenotypic and genetic parameter estimates of litter size and body weights in goats. IJSN 1(2), 262–266.

Altay, Y., Karabacak, A., Aytekin, I., 2020. Determination of the relationship between ultrasonic measurements at different fattening times and carcass properties. Turk. J. Agric. Res. 7(2), 183–191. https://doi.org/10.19159/tutad.722236.

Altınel, A., Evrim, M., Özcan, M., Başpınar, H., Deligözlü, F., 1998. Studies on possibility of producing high quality lambs by crossbreeding among Sakız, Kıvırcık, and German Black Headed mutton sheep. Turk. J. Vet. Anim. 22, 257–265.

Ambarcıoğlu, P., Kaya, U., Özen, D., Gürcan, İ.S., 2017. An examination of the relationships between live weight and body measurements in Karacabey Merino sheep through the path analysis approach. Kafkas Univ. Vet. Fak. Derg. 23(6), 857–863.

Ataç, F.E. Takma, Ç., 2018. The factors effect on weaning weight of Hair goats in West Anatolia. J. Anim. Prod. 59(2), 11–16. https://doi.org/10.29185/hayuretim.446178.

Atta, M., El khidir, O.A., 2004. Use of heart girth, wither height, and scapuloischial length for prediction of liveweight of Nilotic sheep. Small Rumin. Res. 55, 233–237. https://doi.org/10.1016/j.smallrumres.2004.01.005.

Bilgin, O.C., Emsen, E., Davis, M.E., 2003. An application of canonical correlation analysis to relationships between the head and scrotum measurements in Awassi fat tailed lambs. J. Anim. Vet. Adv. 2, 343–349.

Boztepe, S., Aytekin İ., Şahin Ö. & Coşkun G. 2022. Yerli kuzu fabrikası: sakız koyunu kitap, canlı ağırlık, büyüme ve karkas özellikleri. Vadi Matbacılık, 44–57, ISBN: 978–625–8299–35–9.
Ceyhan, A., Erdogan, I., Sezenler, T., 2007. Some production characteristics of Kıvırcık, Gokceada, and Sakız breeds of sheep conserved as gene resources. JOTAF 4(2), 211–218.
Çankaya, S., Kayaalp, GT., 2007. Estimation of relationship between live weights and some body measurements in German farm × Hair crossbred by canonical correlation analysis. J. Anim. Prod. 48(2), 27–32.
Çankaya, S., Altop, A., Olfaz, M., Erener, G., 2009. Canonical correlation analysis for estimation of relationships between some traits measured at pre- and post-slaughtering periods in Karayaka hoggets. Anadolu. J. Agric. Sci. 24(1), 61–66.
Esen, F., Yıldız, N., 2000. Akkaraman, Chios × Akkaraman hybrid (F1) lambs yield characteristics: I. growth. vitality, body size. Turk. J. Vet. Anim. 24(3), 223–231.
Faraz, A., Tirink, C., Eyduran, E., Waheed, A., Tauqir, N.A., Nabeel, M.S., Tariq, M.M., 2021. Prediction of live body weight based on body measurements in Thalli sheep under tropical conditions of Pakistan using CART and MARS. Trop. Anim. Health Prod. 53, 301. https://doi.org/10.1007/s11250–021–02748–6.
Fourie, P., Neser F., Olivier J., Van Der Westhuizen, C., 2022. Relationship between production performance, visual appraisal, and body measurements of young Dorper rams. S. Afr. J. Anim. Sci. 32(4), 256–262.
Gürcan, İ.S., Akçapınar, H., 2006. Estimation of live weight by statistical methods using body measurements in Merino Sheep. Lalahan Livest. Res. Inst. J. 46, 7–17.
Iqbal, M., Javed, K., Ahmad, N., 2013. Prediction of body weight through body measurements in Beetal goats. Pak. J. Sci. 65(4), 458–461.
Iqbal, Z.M., Javed, K., Abdullah, M., Ahmad, N., Ali, A., Khalique, A., Aslam, N., Younas, U., 2014. Estimation of body weight from different morphometric measurements in Kajli lambs. J. Anim. Plant Sci. 24(3), 700–703.
Jacob, N., Ganesan, R., 2013. Canonical correlation analysis between physiological and physical parameters in small ruminant. Current Biotica 6(4), 445–451.
Karadavut, U., 2020. Estimation of canonical correlation method of relations between milk and wool yield traits in Akkaraman sheep. JGIAS 8(1), 43–47. https://doi.org/10.22194/JGIASS/8.889.
Karna, D.K., Acharya, A.P., Das, B.C., Nayak, G.D., Dibyadarshini, M.R., 2020. Morphometry of Ganjam goats of Odisha and age specific body weight prediction from linear body measurements. Pharma. Innov. J. 9(4),171–175.
Kaya, U., Özkan, H., Çamdeviren, B., Karaaslan, İ., Yakan, A., 2021. A novel approach for evaluating of goat milk quality: Canonical correlation analysis between major milk composition parameters and fatty acid components in Damascus goats. Large Anim. Rev. 27, 351–356.
Khan, M.A., Tariq, M.M., Eyduran, E., Tatliyer, A., Rafeeq, M., Abbas, F., Rashid, N., Awan, M.A., Javed, K., 2014. Estimating body weight from several body measurements in Harnai sheep without multicollinearity problem. J. Anim. Plant Sci. 24(1), 120–126.
Kim, T.W., Kim, C.W., Noh, C.W., Kim, S.W., Kim, Il–S., 2018. Identification of association between supply of pork and produc–tion of meat products in Korea by canonical correlation analysis. Korean J. Food Sci. Anim. Resour. 38(4), 794–805. https://doi.org/10.5851/kosfa.2018.e20.
Lakew, M., Tesema, Z., Zegeye, A., 2017. Body weight prediction from linear body measurements in Awassi crossbred sheep of north-eastern Ethiopia. J. Appl. Agric. Biotechnol. 2(2), 28–36.
Mathapo, M.C., Mugwabana, T.J., Tyasi, T.L., 2022. Prediction of body weight from morphological traits of South African non-descript indigenous goats of Lepelle Nkumbi local municipality using different data mining algorithms. Trop. Anim. Health Prod. 54, 102. https://doi.org/10.1007/s11250–022–03096–9.
Mokoena, K., Tyasi, T.L., 2021. Evaluation of relationships between some growth traits measured at birth and weaning in South African non-descript goat kids using canonical correlation analysis. Am. J. Anim. Vet. 16(3), 139–143. https://doi.org/10.3844/ajavsp.2021.139.143.
Mokoena, K., Molabe, K.M., Sekgota, M.C., Tyasi, T.L., 2022. Predicting body weight of Kalahari Red goats from linear body measurements using data mining algorithms. Vet. World 15(7), 1719–1726. https://doi.org/10.14202/vetworld.2022.1719–1726.
Ozen, D., Kocakaya, A., Ozbeyaz, C., 2021. Estimating relationship between live body weight and type traits at weaning and six months of age in Bafra lambs using canonical correlation analysis. J. Anim. Plant Sci. 31(2), 386–393. https://doi.org/10.36899/japs.2021.2.0226.
Önenç, S.S., Özdoğan, M., Ataç, F.E., Taşkın, T., 2012. Fattening performance and carcass traits of Chios male lambs fed under traditional and intensive feeding conditions. Trop. Anim. Health Prod 44, 1057–1062. https://doi.org/10.1007/s11250–011–0040–x.
Sahin, M., Cankaya S., Ceyhan, A., 2011. Canonical correlation analysis for estimation of relationships between some traits measured at weaning time and six–months in Merino lambs. Bulg. J. Agric. Sci. 17(5), 680–686.
Shehata, M.F., 2013. Prediction of live body weight and carcass traits by some live body measurements in Barkı lambs. Egyptian J. Anim. Prod. 50(2), 69–73.
SPSS, 2019. IBM Corp. Released, IBM SPSS Statistics for Windows, Version 26.0. Armonk NY: IBM Corp.
Tahtali, Y., Cankaya, S., Ulutas, Z., 2012. Canonical correlation analysis for estimation of relationships between some traits measured at birth and weaning time in Karayaka lambs. Kafkas Univ. Vet. Fak. Derg. 18(5), 839–844. https://doi.org/10.9775/kvfd.2012.6578.
Topal, M., Macit, M., 2004. Prediction of body weight from body measurements in Morkaraman sheep. J. Appl. Anim. Res. 25, 97–100. https://doi.org/10.1080/09712119.2004.9706484.
Varkoohi, S., Bani-Saadat, H., Razzagh-Zadeh, S., 2018. Estimation of genetic parameters for growth and body measurement traits in different ages in Iranian Makuei sheep. Iran. J. Appl. Anim. Sci. 8(1), 77–82.

Ventura, H.T., Lopes, P.S., Peloso, J.V., Guimaraes, S.E.F., Carneiro, A.P.S., Carneiro, P.L.S., 2011. A canonical correlation analysis of the association between carcass and ham traits in pigs used to produce dry-cured ham. Genet. Mol. Biol. 34(3), 451–455. https://doi.org/10.1590/S1415–47572011000300014.

Yakubu, A., Mohammed, G., 2012. Application of path analysis methodology in assessing the relationship between body weight and biometric traits of red Sokoto goats in northern Nigeria. Biotechnol. Anim. Husb. 28, 107–117. https://doi.org/10.2298/BAH1201107Y.

Yaprak, M., Koycegiz, F., Kutluca, M., Emsen, E., Ockerman, H.W., 2008. Canonical correlation analysis of body measurements, growth performance, and carcass traits of red Karaman lambs. J. Anim. Vet. Adv. 7(2), 130–136.

Younas, U., Abdullah, M., Bhatti, J.A., Pasha, T.N., Ahmad, N., Nasir, M., Hussain, A., 2013. Inter-relationship of body weight with linear body measurements in Hissardale sheep at different stages of life. J. Anim. Plant Sci. 23(1), 40–44.

Zervas, G., Hadjigeorgiou I., Zabeli G., Koutsotolis K., Tziala C., 1999. Comparison of a grazing with an indoor system of lamb fattening in Greece. Livest. Sci. 61, 245–251. https://doi.org/10.1016/S0301–6226(99)00073–1.