Using Principal Component Factor Scores in Multiple Linear Regression Models to Predict Body Weight of Indigenous Chickens from Morphometric Traits in Bench Maji Zone, Southwestern Ethiopia

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Abstract

Background: There is a rich genetic resource base of indigenous chickens in Ethiopia. However, the productivity of indigenous chicken in the country and their generic base has not been explored sufficiently through characterization using multivariate analysis.
Objective: The objectives of this study were to understand complex interrelations among morphometric traits of indigenous chickens and predict body weight using principal component (PC) factor analysis.
Materials and Methods: A total of 660 (180 males and 480 females) randomly selected chickens of age six months and above were used for the study. Data were collected on body weight and morphometric traits.
Results: In factor solution of the PCA with varimax rotation of the transformation matrix, two principal components (PCs) were extracted (PC1 and PC2) explaining 75.76% of the total variation in the original variables. PC1 had the largest share (62.43%) of the total variance and had its loadings on comb length, wattle length, wingspan, comb height, shank length, and keel length while the PC2 shared only 13.33% of the total variance with positive loadings on body length, back length, and neck length. Prediction model based on PC factor scores accounted for 48% of the variation in the body weight and was more valid than the inter-dependent based models (which accounted for 49% of the variation in the body weight) as it removed multi-collinearity which was present as inter-dependent traits were used in the model.
Conclusion: According to the findings of this study, body weight can be estimated more accurately from PC factor scores than inter-dependent original morphometric traits (i.e. comb height, comb length, wattle length, neck length, back length, body length, wingspan, shank length, and keel length) and the results obtained could be used by chicken producers and researchers for selection, management purposes and estimating market values of the chickens, since weight is the pivotal point on which animal production thrives.

Keywords: Body weight; Correlation; Morphometric traits; Multivariate analysis; Principal component factor analysis

1. Introduction

Ethiopia is endowed with many livestock species with an estimated population of 62.6 million cattle, 31.7 million sheep, 33.0 million goats, and 61.5 million poultry (FAOSTAT, 2018). The country has poultry species that have lived, adapted and produced for many years in the country (Tadelle *et al*., 2003; Halima, *et al*., 2007; Aberra and Tegene, 2011). These poultry species contain a highly conserved genetic reservoir, with a high level of heterozygosity, which may provide the biological material for the development of genetic stocks with improved productivity and adaptability. The commonest is the indigenous chicken genetic resources in the hands of resource-poor farmers who rear these birds under the traditional husbandry system of extensive management. Rural backyard poultry production plays a vital role in the rapidly growing economy of the country. It contributes in multiple ways to the livelihood and food security of the rural family (Solomon *et al*., 2008).

In any livestock enterprise, body weight is a crucial piece of information that a producer needs to know to make proper management decisions (feeding and breeding management, marketing, health care, choosing replacement males and females etc.). Without an accurate measurement of body weight, making sound management decisions is daunting, if not impossible (Seifemichael *et al.,* 2013; Newton *et al.,* 2019). The increasing need to estimate the body weight of animals to study their growth pattern has led to the development of multiple linear regression (MLR) equations which were designed to predict the body weight of animals from morphometric traits (Peters *et al*., 2007; Ajayi *et al*., 2008; Mendes, 2011; Khan *et al*., 2014). However, the biological

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interpretation of results obtained from MLR analysis may be misleading because of the existence of a high correlation (multi-collinearity problem) between the predictors that yields a deficiency in the regression model formed (Camdeviren *et al.*, 2005; Mendes, 2009; Eyduran *et al.*, 2010). In the presence of multi-collinearity problem, the standard errors of the parameter estimates could be quite high, resulting in unstable estimates of the regression model. In extreme cases, this problem can cause the least-squares parameter estimates to be far from the true values, resulting in incorrect conclusions about relationships between the response and predictor traits. One of the approaches used to avoid this problem is the application of principal component (PC) factor analysis (Ogah *et al.*, 2009; Yakubu *et al.*, 2009). PC factor scores derived from PC factor analysis offers the opportunity to estimate body weight with a high degree of accuracy and solving the problem of multi-collinearity.

Despite the rich genetic resource base of indigenous chickens in Ethiopia, there is dearth of information on multivariate analysis on body weight and morphometric measurements of the animals. Specifically, the estimation of body weight from morphometric traits of chickens using PC factor analysis has not been exploited. The main purpose of this study was to understand complex inter-relationships among the morphometric traits, investigate relationships between morphometric traits and body weights of indigenous chickens by using orthogonal conformation traits derived from the PC factor scores. The information obtained will aid the management, conservation and selection of indigenous chickens towards improved productivity.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in Bench Maji Zone (BMZ) which is located in the southwestern part of Ethiopia. BMZ is found at a distance of about 561 km from Addis Ababa. It is bordered by Kaffa Zone in the North, Debub Omo Zone in the North East, Sheka Zone in the South West, and Gambela and the South Sudan Republic in the Southern direction. Agro-ecologically, BMZ, consists of 52% lowland (500–1500 m.a.s.l.), 43% intermediate highland (1500–2300) meters above sea level and 5% highland (≥2300 m.a.s.l.). It has an altitude ranging from 500–2500 meters above sea level. The mean annual temperature varies from 15.1 ^{0}C–27.5 ^{0}C. The mean annual rainfall ranges from 400 mm–2000 mm (Figure 1).

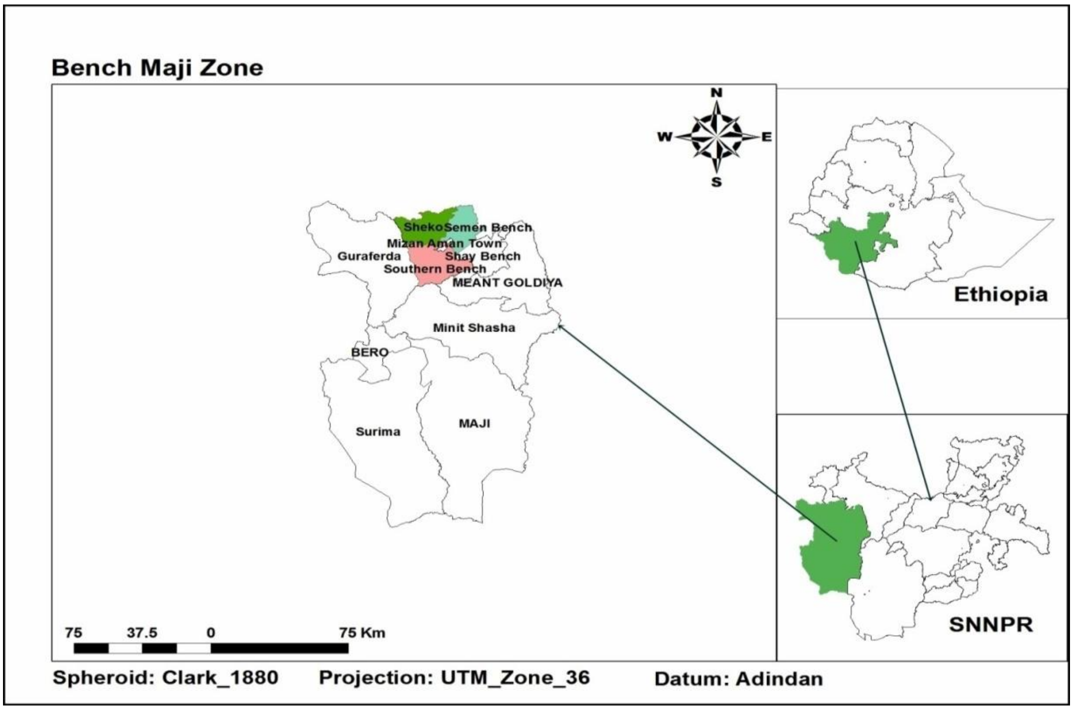

Figure 1. Map of the study area.

2.2. Methods of Sampling and Data Collection

A rapid field survey was made before the actual survey was conducted to explore the available knowledge about the type, distribution, and utility of chicken types. Bench Maji Zone has 10 districts, from which data on distribution and numbers of indigenous chickens were taken. A multi-stage sampling procedure (purposive and random) was applied and hence three districts, namely, North Bench, Sheko, and South Bench were purposively selected based on the information gathered on indigenous chicken population size through a rapid field survey and consultations with Woreda (district) Agricultural experts and extension agents.

2.3. Study Chickens and Traits Measured

A total of 660 indigenous chickens aged six months and above [220 chickens (60 males and 160 females] from North Bench, 220 chickens (60 males and 160 females) from Sheko and 220 chickens (60 males and 160 females from South Bench) were sampled randomly. Body weight and morphometric traits (comb height, comb length, wattle length, neck length, back length, body length, wingspan, shank length, and keel length) were recorded following the recommended FAO descriptors for chicken genetic resources (FAO, 2012). Measuring tapes and a digital balance of 1g precision were used to measure the respective morphometric traits and bodyweights of the sampled chickens.

2.4. Data Management and Statistical Analysis

All statistical analyses were performed using the SAS 9.4 software (version 9.4; SAS Institute Inc., NC, 2014). The analyses were carried out on the females in order to avoid potential sampling bias due to the low number of males (Bene *et al.*, 2007; Ndumu *et al.*, 2008; and Traore' *et al.*, 2008).

2.4.1. Exploratory data analysis

The body weight and morphometric traits were subjected to exploratory data analysis to get results of descriptive statistics and correlation coefficients using the PROC UNIVARIATE and PROC CORR procedures of SAS (version 9.4; SAS Institute Inc., NC, 2014).

2.4.2. Principal component (PC) factor analysis

Estimating the number of PCs

In this study, the criteria Kaiser–Guttman rule, the scree test, and parallel analysis plot were used for determining the number of PCS to be extracted.

Kaiser–Guttman rule: This rule states that the number of PCs to be extracted should be equal to the number of PCs having an eigenvalue greater than one. Eigenvalues measure the amount of variation explained by each PC and will be largest for the first PC and smaller for the subsequent PCs.

Scree test: Plotting the eigenvalues against the corresponding PC produces a screen plot that illustrates the rate of change in the magnitude of the eigenvalues for an increasing number of PCs. The rate of decline tends to be fast first and then levels off. The "elbow," at which the curve bends, is considered to indicate the maximum number of PCs to extract.

Parallel analysis: To support the decision making in the selection of the number of PCs extracted, a graphical method known as *parallel analysis* is used to enhance the interpretation. The correct number of PCs is selected at the cut-off point, where the scree plot and the parallel analysis curve intersect.

PC loading: These are correlation coefficients between the original traits and the PC scores. A high positive correlation between PC1 and a trait indicates that the trait is associated with the direction of the maximum amount of variation in the dataset. A strong correlation between a trait and PC2 indicates that the trait is responsible for the next largest variation in the data perpendicular to PC1, and so on.

2.4.3. Multiple linear regression (MLR) models

Multiple linear regression procedure was used to obtain models for predicting body weight from morphometric traits (i), and PC factor scores (ii)

$$BW = b_0 + b1X1 + \ldots + b_kX_k \quad \text{(i)}$$

$$BW = b_0 + b_1PC_1 + \ldots + b_kPC_k \quad \text{(ii)}$$

Where, BW is the body weight, „b_o" is the intercept, b_1 is the i^{th} partial regression coefficient of the i^{th} morphometric trait, X_i or the i^{th} PC.

3. Results and Discussion

3.1. Exploratory Data Analysis

The means and coefficients of variation calculated for the evaluated traits (Table 1) were consistent with those reported in the literature for chicken by by Eskindir (2012) and Hailemichael (2014). However, the values for chest shank length, body length, wing span, comb length and body weight were higher than the findings of Melaku (2016). These differences found in the different region might be connected with the high influence of the environment on these traits such as temperature, feed supply and health challenges. As observed in Table 1, according to the coefficient of variation (CV), there were two groups of traits. The first group consisted of traits with CVs < 10%, and the second group consisted of traits with CVs > 10%. Wattle length was observed to be the variable of greatest instability.

The correlation coefficients varied from 0.17 (between body weight and back length) to 0.89 (between wattle length and comb length). Among the 45 possible pairs of correlations, all pairs of correlations were found to be significant at $P<0.001$ (Table 2), indicating that the data is suitable for performing PCA. Such positive and very highly significant correlation coefficient values have also been reported in chickens by the studies of Eskindir (2012) and Hailemichael (2014). High positive correlations suggest that selection for a trait may lead to a correlated response in the other trait, thus providing a basis for the genetic manipulation and improvement of the native stock.

Table 1. Descriptive statistic results of body weight and morphometric traits.

S/N	Trait	Label	Mean ± SE	STD	CV	Min.	Max.
1	Comb height (cm)	CH	1.29±0.03	0.66	51.21	0.10	4.50
2	Comb length (cm)	CL	3.19±0.05	1.34	41.89	1.00	7.00
3	Wattle length (cm)	WL	1.65±0.04	1.14	69.05	0.10	6.00
4	Neck length (cm)	NL	16.79±0.06	1.49	8.86	13.00	21.00
5	Back length (cm)	BaL	20.32±0.05	1.33	6.54	17.00	23.00
6	Body length (cm)	BL	37.11±0.09	2.19	5.90	32.00	44.00
7	Wingspan (cm)	WS	58.78±0.19	4.86	8.27	50.00	69.00
8	Shank length (cm)	SL	8.82±0.04	1.10	12.47	6.00	12.00
9	Keel length (cm)	KL	10.69±0.04	1.02	9.54	8.00	13.00
10	Body weight (kg)	BW	1.30±0.01	0.24	18.44	0.70	2.00

Note: *SE = Standard error of mean; STD = Standard deviation; CV = Coefficient of variation; Min.= Minimum; and Max. = Maximum.*

Table 2. Phenotypic correlations and their statistical significance levels among body weight and morphometric traits of chickens in Bench Maji Zone, Southwestern Ethiopia.

Trait	CH	CL	WL	NL	BaL	BL	WS	SL	KL	BW
CH	1.00									
CL	0.79	1.00								
WL	0.79	0.89	1.00							
NL	0.44	0.47	0.45	1.00						
BaL	0.31	0.30	0.35	0.21	1.00					
BL	0.49	0.51	0.53	0.79	0.73	1.00				
WS	0.69	0.79	0.81	0.52	0.36	0.58	1.00			
SL	0.66	0.75	0.76	0.49	0.41	0.58	0.79	1.00		
KL	0.49	0.61	0.60	0.32	0.31	0.42	0.60	0.68	1.00	
BW	0.61	0.66	0.66	0.39	0.17	0.38	0.61	0.54	0.47	1.00

Note: *CH = Comb height; CL = Comb length; WL = Wattle length; NL = Neck length; BaL = Back length; BL = Body length; WS = Wingspan; SL = Shank length; KL = Keel length; and BW = Body weight.*

3.2. PC Factor Analysis

Anti-image correlations computed (not given here) showed that partial correlations were low, indicating that true factors existed in the data. This result is consistent with that of Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy studied from the diagonal of partial correlation, revealing the proportion of the variance in the body measurements caused by the underlying factor (Khan *et al.*, 2010). The KMO measure of sampling adequecy was found to be sufficiently high with a value of 0.782. Eyduran *et al.* (2010) reported that a KMO measure of 0.60 and above is considered adequate. Bartlett's sphericity test for testing the null hypothesis that the correlation matrix is an identity matrix was used to verifying the applicability of PCA. The value of Bartlett's sphericity test was significant (p-value = 0.001), implying that the PCA is applicable to the data set.

3.2.1. Eigenvalues, percentage of total variance with rotated component matrix and communalities

The eigenvalue of the total variance, the rotated component matrix and communalities of the traits investigated are presented in Table 3. Table 3 shows how much of the total variance of the observed traits was explained by each of the PCs after varimax rotation of the component matrix. Two PCs were identified with eigenvalues of 5.62 (PC1) and 1.20 (PC2). PC1 explained 62.43% of the total variance while PC2 explained only 13.33%. Accordingly, the first two PC factors combined accounted for 75.76% of the total variability present in the parameters measured. The communalities are the proportion of variance that each variable has in common with other variables. Thus if communality of a trait is high, it means that the extracted factors explained a big proportion of the variance of the trait. The communality values ranged from 0.568 (NL) to 0.977 (BL) indicating that the data are conformable to PC factor analysis.

PC loadings presented in Table 3 are the correlation coefficient between the first two PC scores and the original traits. They measure the importance of each morphometric trait in accounting for the variability in the PC. That is, the larger the loadings in absolute terms, the more influential the variables are in forming the new PC and vice versa. The first factor (PC1) loaded heavily on comb length (0.909), wattle length (0.901), wingspan (0.831), comb height (0.820), shank length (0.807), and keel length (0.713) while the second factor (PC2) loaded heavily on body length (0.930), back length (0.810), and neck length (0.662). The loading classification found in this study is somewhat similar to those reported by Uda (Yakubu *et al.*, 2009), and immature Uda (Salako, 2006).

Table 3. Eigenvalues and shares of the total variance of indigenous chickens along with factor loadings after varimax rotation and communalities in Bench Maji Zone, Southwestern Ethiopia.

Trait	PC1	PC2	communalities
Comb Height	**0.8197**	0.2269	0.7234
Comb Length	**0.9090**	0.2134	0.8719
Wattle Length	**0.9010**	0.2445	0.8716
Neck Length	0.3599	**0.6620**	0.5678
Back Length	0.1225	**0.8098**	0.6708
Body Length	0.3347	**0.9301**	0.9770
Wing Span	**0.8311**	0.3370	0.8043
Shank Length	**0.8067**	0.3620	0.7819
Keel Length	**0.7127**	0.2044	0.7819
Eigenvalue	5.6188	1.1996	
% of total variance	62.43	13.33	75.76

A scree-parallel analysis plot of eigenvalues against their PCs is shown in figure 2 below. The plot demonstrates the distribution of variance among the components graphically. For each PC, the corresponding eigenvalue is plotted on the *y*-axis. By definition, the variance of each component is less than the preceding one. Here there appears to be a marked decrease in downward slope after the second PC implying that we can summarize the nine morphometric traits by the first two PCs.

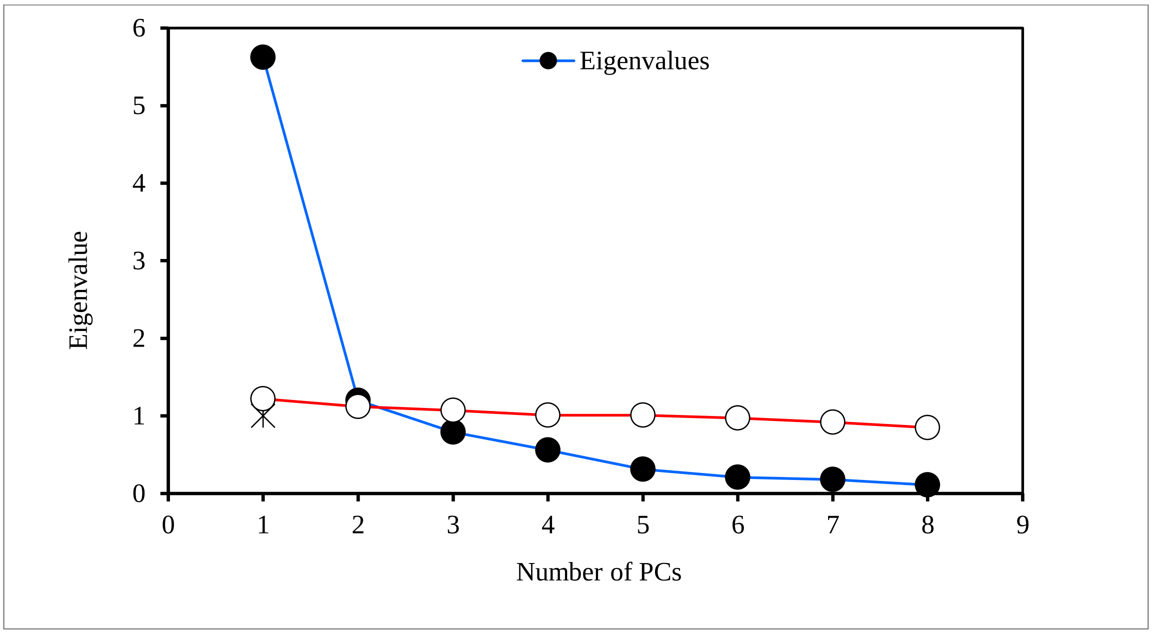

Figure 2. Scree and parallel analysis plots.

3.2.2. MLR models used for body weight prediction of chickens

The interdependent original morphometric traits and their independent PC factor scores were used to the predict body weight of chickens. Table 4 presents the regression coefficient, their standard errors, t-value, p-values, variance inflation factor (VIF) values, and R^2 obtained from MLR analysis. The regression of body weight on CH, CL, WL, WS, and KL was significant, while it was not significant for NL, BaL, BL, and SL. The present findings are consistent with the submissions of Peters *et al.* (2007) in chickens and Teguia *et al.* (2008) in ducks.

Table 4. MLR of body weight on original morphometric traits of indigenous chickens and their PC factor scores in Bench Maji Zone, Southwestern Ethiopia.

Model	Coefficient	SE	t-value	p-value	VIF
Original morphometric traits as predictors					
Intercept	0.6972	0.17	4.14	<0.0001	–
Comb height	0.0592	0.02	3.38	0.0008	3.03
Comb length	0.0370	0.01	3.03	0.0025	6.00
Wattle length	0.0510	0.01	3.48	0.0005	6.31
Neck length	0.0185	0.02	1.15	0.2520	13.05
Back length	–0.0082	0.02	–0.50	0.6143	10.64
Body length	–0.0078	0.01	–0.49	0.6269	27.64
Wingspan	0.0060	0.00	2.21	0.0277	3.93
Shank length	–0.0127	0.01	–1.10	0.2738	3.68
Keel length	0.0209	0.01	2.29	0.0221	1.96
	R^2 = 0.49; R^2 adjusted = 0.49				
Orthogonal morphometric traits as predictors					
Intercept	1.296	0.01	192.70	<0.000	–
PC1	0.185	0.01	24.33	<0.000	1.0
R^2 = 0.36; R^2 adjusted = 0.36					
Intercept	1.296	0.01	192.70	<0.000	–
PC1	0.185	0.01	24.33	<0.000	1.0
PC2	0.278	0.02	12.44	<0.000	1.0
	R^2 = 0.48; R^2 adjusted = 0.48				

To increase meat and egg yields from chicken production, the genetic improvement of body weight is necessary and this requires adequate knowledge of correlated traits that can be considered when selection is to be applied. However, the use of inter-dependent predictors should be treated with caution, since multi-collinearity is associated with unstable estimates of regression coefficients (Ibe, 1989; Malau-Aduli *et al.*, 2004; Yakubu, 2009) rendering the estimation of unique effects of these predictors impossible. This is evident in the present study, where beak length, neck length, and back length had VIF values greater than 10. Rook *et al.* (1990) stated that VIF values above 10 indicate severe collinearity which leads to unstable estimation of the associated least square regression coefficient. To overcome this limitation, the PC factor scores are used as predictors for the prediction of body weights (Keskin, 2007; Ogah *et al.*, 2009; Yakubu *et al.*, 2009). These PCs are orthogonal to each other and are more reliable in weight estimation. In the present study, the use of PC1 as a single predictor explained 38% of the total variability in body weight. However, PC1 and PC2 together accounted for 48% of the variation in body weight of the chickens. The two factors selected were found to have a significant ($p < 0.0001$) positive linear relationship with body weight (Table 4). In other words, body weight is expected to increase as the values of factor 1 and 2 scores increase.

Similarly, Shahin and Hassan (2000) derived regression equations for estimating the body weight of rabbits using independent factor scores. In another related study, McCracken *et al.* (2000) obtained a regression model for body weight prediction using principal component scores of musk ducks; while Keskin *et al.* (2007) used factor scores derived from ten body measurements to predict the carcass weight of sheep.

4. Conclusions

In this study, PC factor analyses were explored in identifying patterns and determine the inter-dependence in nine morphometric traits of indigenous chickens to eliminate redundancy and predict body weight. According to the results of this study, it could be concluded that using inter-dependent morphometric traits as predictors in MLR analysis resulted in a multi-collinearity problem. On the other hand, when independent orthogonal indices (PC factor scores) were used as predictors, problem of multi-collinearity was removed. The results of this study imply that body weight can be estimated more accurately from principal component (PC) factor scores and the results obtained could be used by poultry producers and researchers for selecting, managings, and estimating market values of chickens. This is because body weight is the pivotal determinant for thriving animal production. However, further research is needed to investigate the relationship between body weight with morphometric traits in the same and other ecotypes of chickens in the different region of the country with a larger number of observations.

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