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Phenotypic characterization of the indigenous chickens *(Gallus gallus)* in the northwest of Algeria

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Abstract. This study was conducted to characterize local chickens in the northwest of Algeria based on some phenotypic traits and to look at prediction of body weight from morphometric measurements (linear body). The results indicated that the predominant comb colour was dark red (77.8 %), followed by light red (22.2 %). Tarsus colour was either white (40.9 %), grey (31 %), yellow (15.39 %), dark (8.05 %), or green (4.51 %). Most chickens (81.7 %) had orange eyes, while 10.37 and 7.92 % had yellow and dark-brown eyes, respectively. The dominant earlobe colour was white (73.96 %), followed by red (16.81 %). The remaining proportion included yellow and red-mottled yellow and black earlobes. Proportions of the adaptive genes were low. Incidences of Na, F, Pti, Cr, R, and P genes were 8.82, 0.45, 1.22, 5.54, 3.35, and 4.7 %, respectively. The calculated gene frequencies ranged from 0.002 to 0.045. Variations were also found in quantitative morphological traits. Sex-associated differences ($P < 0.001$) were observed in almost all the parameters evaluated with higher values recorded for males. Phenotypic correlations of body weight and biometric traits ranged from −0.13 to 0.88 and −0.15 to 0.97 for males and females, respectively. From the factor analysis with varimax rotation of the intercorrelated traits, three principal components which accounted for 71.6 and 73.2 % of the total variance were extracted in males and females, respectively. Orthogonal body shape characters derived from the factor analysis accounted for 84.3 and 94.2 % of the variation in body weight of males and females, respectively. Information obtained from this study could be useful in an appropriate management, breeding programmes for selection and utilization of Algerian chicken genetic resources.

1 Introduction

Village chickens make substantial contributions to household food security throughout the developing world, as they represent almost 80 % of poultry production in Africa (Sonaiya, 1997). Indigenous chickens serve as an investment for households in addition to their use as meat and egg sources both for consumption and for selling (Muchadeyi et al., 2007; Moula et al., 2011). These indigenous chickens are generally kept according to an extensive or scavenging system with few or no inputs for housing, feeding, and health care (Mtilleni et al., 2012). These breeds are well adapted to the local climatic conditions, feed, and management stresses, with better resistance to diseases (Iqbal and Pampori, 2008). Some major genes have been found potentially useful to the tropical production environment (Fayeye, 2006). Due to the global climate change, it is expected that the Mediterranean zone will expand northwards to the French Massif Central. In the south, heat waves and droughts are predicted to become more frequent. The ability of livestock to adapt to climatic variations will therefore be a factor of great importance in the Mediterranean region, which reinforces the interest for the conservation of these breeds adapted to these harsh conditions and for their selection for improved performances. This implies that these breeds first have to be characterized (Mbap, 1985). The first phase of characterization involves

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the identification of populations based on morphological descriptors that can also provide useful information on the suitability of breeds for selection (Ajayi et al., 2012). Up to now, the body weight (BW) prediction from some morphological traits has not been reported in Algerian indigenous chickens. In Algeria, few studies have concerned the characterization and identification of local populations of chickens (Moula et al., 2009, 2012; Halbouche et al., 2009; Mahammi et al., 2014, 2016). The present study therefore sought first to characterize the local chickens of the northwest of Algeria based on some qualitative and quantitative traits and second to use these criteria to estimate body weight through multiple linear regression.

2 Materials and methods

2.1 Description of the study area

The survey area includes three provinces: Mostaganem, Relizane, and Mascara. It is located in the northwestern part of Algeria between the Mediterranean Sea and Saharan Atlas chain. Different landscapes can be found in the area, due to influence of several topographic factors (latitude, altitude, distance from sea) on climate and, consequently, on geomorphological and pedological processes. Mostaganem (littoral zone) is located at 35°55′52″ N, 0°05′21″ E, at an altitude of 85 m, has an area of 2269 km^2 large, and is characterized by a Mediterranean climate. Relizane (plains zone) is located at 35°44′00″ N, 0°33′00″ E, at an altitude of 139 m, has an area of 4851 km^2, and is characterized by a semi-arid climate. Finally, Mascara (mountainous zone) is located at 35°23′47″ N, 0°08′24″ E, at an altitude of 600 m, with an area of 5135 km^2, and is characterized by a semi-arid climate. The average yearly temperatures and total precipitation amounts are 17.9 °C and 347 mm for Mostaganem, 16.7 °C and 347 mm for Mascara, and 18.3 °C and 349 mm for Relizane, but maximal temperatures are higher by 3.4 to 4.1 °C. Monthly variations in temperatures and precipitation amounts in these regions can be found in Fig. 1.

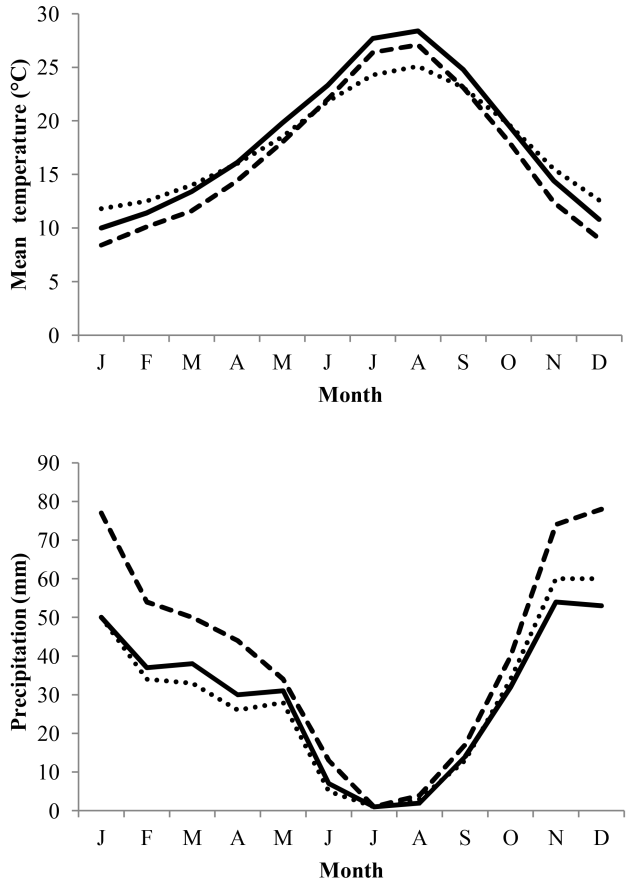

Figure 1. Climatic data on the regions of Mostaganem (dotted line), Relizane (full line), and Mascara (dashed line) obtained from the website www.fr.climate-data.org.

2.2 Experimental animals and their management

The study has been carried out in 18 districts according to the following distribution: (1) Aïn Nouïssy, Bouguirat, Fornaka, Hadjaj, Oued El Kheïr, and Sayada from Mostaganem province; (2) Beniane, Bouhnifia, El-Bordj, Ghomri, Ghriss, and Tighennif from Mascara province; and (3) Ami Moussa, Mazouna, Oued El Djemâa, Oued Rhiou, Yellel, and Zemmoura from Relizane province. Three separate villages were selected from each district. Villages in close proximity to large cities were avoided to keep at minimum the influence of urban-affiliated farming systems on a typical rural village-based chicken management system (Desta et al., 2013). A total of 1552 chickens including 409 males and 1143 females over ∼ 5 months of age were randomly sampled from 180 households. The data were collected between April 2012 and May 2013. The chickens were reared by rural farmers according to the traditional scavenging system. During the daytime birds are often left to search for their own food and roam freely close to the homestead. Almost all the farmers in the study areas provided supplementary feed to their birds throughout the year. The chicken shelters were mostly made of bricks, wood, corrugated sheeting, and plastic. These were in poor hygienic condition and did not offer sufficient protection from cold during the night.

2.3 Data collection

For qualitative traits, all the birds were individually observed for various phenotypic attributes, including feather distribution (naked neck, feather tarsus, and crested head) and feather structure (frizzled feather), comb type (simple, rose, and pea comb), comb colour, tarsus colour, earlobe colour, wattle colour, and eye colour as described by FAO (2012). We recorded the genotype for several major genes known for their implication in resistance to heat, such as the naked neck gene (Na / na), frizzle gene (F / f), feathered shank gene

(Pti / pti), rose comb gene (R / r), and crested-head gene (Cr / cr). Occurrence and distribution of the qualitative traits among the population was expressed as a percentage of the total number of birds. The theoretical frequency p of the dominant alleles (Na, F, Pti, R, Cr) and the theoretical frequency q of the recessive alleles (na, f, pti, r, and cr) were calculated using the Hardy–Weinberg equilibrium as follows:

$$q=\sqrt{\frac{m}{t}} \text{ and } p=1-q, \tag{1}$$

where m is the observed number of birds with recessive phenotypes under consideration and t the total number of birds.

Nine quantitative traits were taken from 778 birds, of which 456 were females and 322 males. Body length (BL, in cm), wing span (WS, in cm), tarsus length (TL, in cm), tarsus circumference (TC, in cm), beak length (BkL, in cm), wattle length (WL, in cm), and comb length (CL, in cm) were measured using a tailor's tape, while breast width (BrW, in cm) was measured using a calliper. Live body weight (LBW, in g) was taken by direct measurement using a digital 5 kg scale. All measurements and weighings were taken by the same person to avoid individual variations.

2.4 Statistical analysis

A chi-square test (χ^2) was used to compare proportions for comb colour, tarsus colour, eye colour, earlobe colour, and those of dominant alleles of major genes between bird populations sampled in the three provinces and between males and females. This analysis followed the procedure of Marascuilo (1966) to determine which pairs of provinces have statistically differing qualitative traits proportions.

Least-squares means and standard errors (SE) were calculated for body weight and body linear measurements. Province and sex effect on each parameter was assessed by the following general linear model (GLM) of SAS (Statistical Analysis System, 2001):

$$yijk=\mu+A_i+B_j+(AB)_{ij}+eijk, \tag{2}$$

with $yijk$ as the studied parameters measured on the hen, μ the mean, A_i the effect of province (i: Mascara, Mostaganem, and Relizane), B_j sex effect (j: male and female), $(AB)_{ij}$ the interaction between province and sex, and $eijk$ the residual. Tukey's test was used to correct for multiple comparisons for the province effect and for the interaction between sex and province. Differences were considered significant at $P<0.05$.

In a second step, the relationship between morphometric traits was assessed through the Pearson coefficients of correlation between quantitative traits.

In a third step, a principal components analysis (PCA) was done to propose linear relationship equations between morphometric traits that explain the largest part of variability between our populations, and which are statistically independent by construction. Bartlett's test of sphericity was used to check whether the correlation matrix between traits was significant or not. Data were also inspected for multiple colinearity and singularity.

In a last step, a multiple regression procedure using a stepwise variable selection was used to obtain models of prediction of body weight from body measurements and from established principal components factors:

$$\mathrm{BW}=a+b_1X_1+\ldots+b_kX_k, \tag{3}$$

$$\mathrm{BW}=c+d_1\mathrm{PC}_1+\ldots+d_k\mathrm{PC}_k, \tag{4}$$

where BW is the body weight, a and c are the regression intercepts, b_i and d_i are the ith partial regression coefficients of the ith linear body measurement or principal component, and X_i and PC_i are the ith morphometric traits or principal component. Cumulative proportion of variance criterion was employed in determining the number of principal components to extract. Statistical analysis was carried out using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA) and R Commander version 3.1.1.

3 Results and discussion

3.1 Frequency of major genes

Qualitative traits recorded on chickens in the study area are presented in Table 1. The predominant comb colour was dark red (77.8 %), which is consistent with results obtained by Moula et al. (2012) on indigenous chickens in Kabylie. Males had significantly darker combs than females. This finding agrees with results of Guni et al. (2013) in Tanzania and Liyanage et al. (2015) in Sri Lanka. As the intensity of the red colouration is an indication of the quality of sperm in the case of male birds (Navara et al., 2012), our results indicate that there is probably good fertility in the birds investigated. Moreover, it is biologically important to study this phenotype because it is an indicator of chickens' health and egg laying status (Hume, 2011).

Various leg colours were observed in the current study. Overall, white and grey tarsi were much more frequent than yellow and black tarsi, with green being the least frequent. A region effect was observed for this trait, due to a higher occurrence of black ($P<0.001$) and green colouring ($P<0.05$) and a lower occurrence ($P<0.001$) of white colouring in Mostaganem province (12.6 %). Our study thus highlighted the large variability in tarsus colour between local populations as previously studies reported more frequent white and yellow tarsi in the humid forest zone of Cameroon (Fosta et al., 2010) and in the districts of Jarso and Horro in Ethiopia (Desta et al., 2013) but more frequent black tarsi in Nigeria (Egahi et al., 2010) and Libya (El-Safty, 2012). The occurrence of various types of tarsus colours in this study might have been due to combinations of pigment-controlling genes responsible for colour determination. We also more frequently observed green tarsus in males than in females

Table 1. Occurrence (%) of comb colour, tarsus colour, eye colour, and earlobe colour of 1552 local chickens from the northwest of Algeria summarized by province and by sex.

Character	Province				Sex			
	Mostaganem	Relizane	Mascara	χ^2	Males	Females	χ^2	Total
Number	$N=570$	$N=587$	$N=395$		$N=409$	$N=1143$		$N=1552$
Comb colour								
Dark red	75.79^a	78.36^a	80.00^a	2.55ns	82.40	76.20	6.70**	77.83
Light red	24.21^a	20.61^a	20.00^a	2.55ns	17.60	23.79	6.70**	22.16
Tarsus colour								
Grey	32.98^a	29.13^a	31.14^a	2.00ns	28.70	31.85	1.48ns	31.05
White	32.98^a	46.51^b	44.30^b	24.30***	38.60	41.80	5.77*	40.90
Yellow	15.09^a	14.14^a	17.72^a	2.40ns	15.90	15.22	0.10ns	15.39
Black	12.63^b	6.13^a	4.30^a	26.50***	9.00	7.70	0.74ns	8.05
Green	6.32^b	4.09^{ab}	2.53^a	8.14*	7.90	3.41	13.43***	4.51
Eye colour								
Orange	78.60^a	85.86^b	80.00^{ab}	11.02***	83.40	81.10	1.04ns	81.70
Brown	8.07^a	7.67^a	8.10^a	0.08ns	7.09	8.22	0.53ns	7.92
Yellow	13.33^b	6.47^a	11.90^b	15.90***	9.50	10.67	0.42ns	10.37
Earlobe colour								
White	73.51^a	73.94^a	74.68^a	0.16ns	71.60	74.80	1.57ns	73.96
Red	15.61^a	17.55^a	17.47^a	0.93ns	21.55	15.14	8.77**	16.81
Other[1]	10.88^a	8.51^a	7.85^a	3.10ns	6.85	10.06	8.76**	9.21

Percentages within a row with different superscripts are significantly different: * $P<0.05$; ** $P<0.01$; *** $P<0.001$; ns: not significant ($P \geq 0.05$); [1] yellow and red-mottled yellow and black earlobes.

($P<0.001$). However, white tarsus was more commonly observed in females than males ($P<0.05$). Frequencies of other colours did not show a sex effect ($P>0.05$). According to Desta et al. (2013), the low incidence of green-shanked chickens observed in this study is not surprising, because it is unfavourably correlated with adult viability. The variability in eye colour is much less than for tarsus as orange represents 81.7 % of the total, with yellow and brown showing much lower frequencies, consistent with data in the literature (Fosta et al., 2010). Variation in eye colour to a large extent depends on the pigmentation (carotenoid pigments) and blood supply to a number of structures within the eye (Crawford, 1990, as cited in Eskindir et al., 2013). Differences between districts for this feature were observed. The proportion of orange-eyed chickens was higher in Relizane ($P<0.001$) than in Mostaganem, while yellow eyes were less frequent ($P<0.001$). Variations were also observed in earlobe colour. White earlobes were the most frequent (73.96 %) in the three regions, followed by red earlobes (16.81 %). This is consistent with the findings of other researchers (Roxas et al., 1996; Egahi et al., 2010; Faruque et al., 2010). White earlobe is a characteristic feature of chickens of the Mediterranean region (Sørensen, 2010). The remaining proportion (9.21 %) is a mix of yellow, red-mottled, yellow, and black earlobes. A higher proportion of red earlobe chickens was observed in males ($P<0.01$).

The frequencies of the dominant alleles of major genes in the population were quite low, ranging between 0.45 and 8.82 % depending on the gene considered (Table 2), consistent with previous findings of Abdelqader et al. (2008) in Jordan, Sola-Ojo et al. (2011) and Fajemilehin (2010) in Nigeria, and Hassaballah et al. (2014) in Chad. The low frequency of these major genes, despite the advantage they give for heat stress adaptation, is probably attributable to social reasons, as naked neck and frizzle-feathered birds are judged ugly and thus sold at lower prices (Yakubu, 2010). Moreover, Fajemilehin (2010) reported that these birds are used in rituals and sacrifices as people consider these birds to be either fetishes or witches. Finally, in the case of the frizzle gene, the low frequency could also be due to the lethality of the gene in its homozygotic state (Haaren-Kiso et al., 1995, as cited in Fayeye et al., 2006).

Frequencies of the dominant alleles varied among regions for all genes except pea comb and crested head. The same pattern was observed for all genes, with a significantly ($P<0.01$) lower frequency of dominant alleles in the region of Mostaganem than in Relizane, with Mascara showing an intermediate value. This might be explained by the ecological characteristics of the areas (plains vs. mountains, urban vs. rural) as indicated by Halbouche et al. (2012) and/or significant variation in farmers' preferences for some particular mutant traits.

Table 2. Occurrence (%) of major genes carriers in 1552 local chickens from the northwest of Algeria summarized by province and by sex.

Phenotype	Province				Sex			
	Mostaganem	Relizane	Mascara	χ^2	Males	Females	χ^2	Total
N	570	587	395		409	1143		1552
[Na]	5.61[a]	11.40[ab]	9.60[b]	12.50**	10.51	8.22	1.96ns	8.82
[F]	0.00[a]	1.02[b]	0.25[ab]	7.90*	0.73	0.35	0.98ns	0.45
[Pti]	0.20[a]	2.00[b]	1.52[ab]	8.70*	1.95	0.96	2.46ns	1.22
[R]	0.70[a]	5.60[b]	3.80[b]	21.90**	6.11	2.36	13.08**	3.35
[P]	5.01[a]	3.20[a]	6.30[a]	5.30ns	0.49	6.21	22.00**	4.70
[Cr]	5.30[a]	4.30[a]	7.90[a]	5.90ns	1.96	6.82	13.64**	5.54
[Other[1]]	83.20[b]	72.50[a]	70.63[a]	26.30**	78.25	75.07	1.65ns	75.90

ns: Not significant ($P \geq 0.05$); * $P < 0.01$; ** $P < 0.001$; [1] Individuals exhibiting none of the characters studied.

Table 3. Percentages (%) and allelic frequencies of visible genes from 1552 local chickens in the northwest of Algeria.

Character	Allele	Expected	Observed	Percentage	Allelic frequency
Naked neck	Na	1164	137	8.82	0.045
Other*	Na^+	388	1415	91.18	0.955
Frizzle	F	1040	7	0.45	0.002
Other	f^+	512	1545	99.55	0.997
Feathered tarsus	Pti	1164	19	1.22	0.006
Other	pti+	388	1533	98.78	0.994
Rose comb	R	1164	52	3.35	0.017
Other	r^+	388	1500	96.65	0.983
Pea comb	P	1164	73	4.70	0.024
Other	p^+	388	1479	95.30	0.976
Crested	Cr	1164	86	5.54	0.030
Other	cr+	388	1466	94.46	0.970

* Individuals exhibiting none of the characters studied.

A higher proportion of crest-headed birds and pea combs were observed in females than in males ($P < 0.001$), while the rose comb chickens were observed more in males than in females ($P < 0.001$). However, the exact number and geographical distribution of these mutant phenotypes are not clearly established in Algeria, and only a very limited number of works have been published (Moula et al., 2009; Mahammi et al., 2014).

Table 3 shows the gene frequencies of naked neck, frizzled, ptilopody, crested, rose comb, and pea comb birds as 0.045, 0.002, 0.006 0.03, 0.017, and 0.024 respectively. The expected phenotypic ratio and gene frequencies for the feather distribution gene (F / f) were calculated with the assumption that the number of homozygous dominant individuals (FF) equals zero. This is because the homozygous dominant FF is mostly lethal (Osewa, 2003, as cited in Sola-Ojo et al., 2011). The low frequencies for these dominant genes suggest that they are at the brink of extinction. The results of this study agree with that of Sola-Ojo et al. (2011) where the calculated gene frequencies of 0.077 was obtained for naked neck, 0.078 for frizzle, 0.076 for ptilopody, and 0.074 for crested in the Nigerian Fulani ecotype chickens. Incidence of pea and rose comb reported in this study is consistent with the results of Ikeobi et al. (2001), which showed gene frequencies of 0.02 and 0.01, respectively, in Nigerian local chickens.

This situation requires scientific concern to ensure that these adaptive genes are preserved and available for utilization in future livestock improvement programmes. Naked neck and frizzle gene frequency should be increased as they have been shown to have a favourable effect on production traits under heat stress (Mathur and Horst, 1988). Wright et al. (2009) noted that the pea comb is an adaptive trait in cold climates as it reduces heat loss and makes the chicken less susceptible to frost lesions. Shoffner et al. (1993) also observed that birds with ptilopody had better body weight

Table 4. Least-squares means (LSM ± SE) of province and sex effect for live body weight (g) and eight linear measurements (cm) of 778 local chickens from the northwest of Algeria (Mostaganem: males = 106, females = 145; Relizane: males = 102, females = 163; Mascara: males = 114, females = 148). Explanations on trait abbreviations can be found in Sect. 2.3.

Trait	Sex	Province[1]				*P* value[2]			
		Mostaganem	Relizane	Mascara	All	Province (P)	Sex (S)	P × S	R^2
LBW	M	1637.57 ± 25.20^{a}	1814.25 ± 25.69^{b}	1702.00 ± 24.30^{a}	1716 ± 17.53	****	****	ns	0.23
	F	1404.24 ± 21.55^{a}	1494.45 ± 20.32^{b}	1450.53 ± 21.33^{ab}	1451 ± 10.41				
	Total	1502.78 ± 18.39^{b}	1617.54 ± 17.90^{c}	1559.95 ± 18.00^{a}					
BL	M	30.07 ± 0.15^{b}	30.93 ± 0.16^{a}	30.75 ± 0.14^{a}	30.6 ± 0.08	***	****	****	0.30
	F	28.86 ± 0.13^{b}	28.88 ± 0.12^{b}	28.24 ± 0.12^{a}	28.7 ± 0.08				
	Total	29.36 ± 0.12^{ab}	29.67 ± 0.11^{b}	29.33 ± 0.11^{a}					
WS	M	46.82 ± 0.37^{b}	47.60 ± 0.38^{b}	46.30 ± 0.35^{a}	46.9 ± 0.11	****	****	*	0.31
	F	40.97 ± 0.31^{a}	43.09 ± 0.30^{b}	41.79 ± 0.31^{a}	42.0 ± 0.22				
	Total	43.44 ± 0.28^{a}	44.83 ± 0.28^{b}	43.76 ± 0.28^{a}					
TL	M	9.49 ± 0.10^{b}	10.15 ± 0.10^{a}	9.90 ± 0.09^{a}	9.85 ± 0.06	*	****	****	0.24
	F	8.94 ± 0.08^{a}	8.61 ± 0.08^{b}	8.93 ± 0.08^{a}	8.81 ± 0.04				
	Total	9.18 ± 0.07	9.20 ± 0.07	9.35 ± 0.07					
TC	M	4.60 ± 0.05^{a}	4.82 ± 0.05^{b}	4.50 ± 0.05^{a}	4.63 ± 0.02	****	****	ns	0.37
	F	3.69 ± 0.05^{a}	4.02 ± 0.04^{b}	3.77 ± 0.04^{a}	3.83 ± 0.03				
	Total	4.07 ± 0.04^{a}	4.33 ± 0.04^{b}	4.09 ± 0.04^{a}					
BrW	M	5.80 ± 0.07^{b}	5.49 ± 0.07^{a}	5.54 ± 0.07^{a}	5.61 ± 0.04	ns	****	****	0.10
	F	5.90 ± 0.06^{a}	6.14 ± 0.05^{b}	5.97 ± 0.06^{a}	6.01 ± 0.03				
	Total	5.86 ± 0.05	5.89 ± 0.05	5.78 ± 0.05					
BkL	M	2.44 ± 0.04	2.43 ± 0.04	2.45 ± 0.03	2.44 ± 0.17	ns	**	ns	0.05
	F	2.39 ± 0.03	2.38 ± 0.03	2.38 ± 0.03	2.38 ± 0.02				
	Total	2.41 ± 0.02	2.40 ± 0.02	2.41 ± 0.02					
CH	M	3.56 ± 0.05^{b}	3.61 ± 0.05^{b}	3.77 ± 0.05^{a}	3.65 ± 0.03	**	****	***	0.74
	F	1.85 ± 0.04^{a}	1.97 ± 0.04^{b}	1.85 ± 0.04^{a}	1.89 ± 0.02				
	Total	2.57 ± 0.06	2.60 ± 0.6	2.69 ± 0.06					
WL	M	2.92 ± 0.05^{a}	3.08 ± 0.05^{b}	3.01 ± 0.05^{ab}	3.00 ± 0.03	ns	****	**	0.50
	F	1.97 ± 0.05	1.87 ± 0.04	1.86 ± 0.05	1.89 ± 0.02				
	Total	2.37 ± 0.05	2.34 ± 0.05	2.36 ± 0.05					

[1] Least-squares means within an effect (province or interaction between province and sex) with different superscripts are significantly different ($P < 0.05$). [2] P, S, P × S: province, sex, and interaction between province and sex fixed effects; ns: $P \geq 0.10$; * $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$; **** $P < 0.001$.

and egg production. However, the rose comb gene should be counter-selected as it is associated with reduced fertility, especially in homozygous roosters (Buckland et al., 1969).

3.2 Province and sex effect on quantitative traits

Descriptive statistics for live weight and body measurement traits of adult chickens in the northwest of Algeria are presented in Table 4. The average live weight of the sampled chickens was 1716 ± 17.53 g for males and 1451 ± 10.41 g for females, which is higher than the findings of Moula et al. (2012) (males = 1427 ± 18 g; females = 1144 ± 18 g) for Kabylie chickens from Algeria and Getu et al. (2014) (males = 1630 ± 0.03 g; females = 1370 ± 0.02 g) for chickens from north Gondar zone in Ethiopia. Higher live weights were reported from Fulani ecotype chickens in Nigeria (males = 2400 ± 0.14 g; females = 1500 ± 0.14 g) (Jesuyon and Salako, 2013) and for Southern Highlands chickens of Tanzania (males = 2095 ± 29.9 g; females = 1525 ± 15.9 g) (Guni et al., 2013). According to Desta et al. (2013), live weight may vary because of inaccuracies of weighing scales, individual differences in measuring accuracy, age of the bird, and season of the year in which the chicken is weighed (during seasons of relatively better feed supply most likely chickens have higher live weight). Moreover, genetic and other environmental (stochastic) factors possibly affect the live weight of village chickens.

Results showed that live weight and all morphometric traits showed a significant sexual dimorphism in favour of males, except for breast width, which was 6.7 % larger in females. Sexual dimorphism was especially pronounced for comb height and wattle length, i.e. two traits that are highly

Table 5. Pearson correlations between traits recorded for males (below diagonal divide, $n = 322$) and females (above diagonal divide, $n = 456$). Correlations that are significantly different from zero are written in italics.

Traits	LBW	BL	WS	TL	TC	BrW	BkL	CH	WL
LBW	–	*0.29*	*0.97*	*0.66*	*0.89*	*0.72*	*−0.15*	*0.6*	*−0.15*
BL	*0.73*	–	*0.31*	*0.36*	*0.40*	−0.03	−0.07	*−0.14*	−0.02
WS	*0.80*	*0.55*	–	*0.63*	*0.90*	*0.68*	*−0.17*	*0.58*	*−0.14*
TL	*0.88*	*0.76*	*0.75*	–	*0.54*	*0.36*	−0.04	*0.30*	*−0.17*
TC	*0.65*	*0.45*	*0.68*	*0.56*	–	*0.51*	*−0.13*	*0.37*	*−0.13*
BrW	−0.05	0.08	0.22	0.25	−0.11	–	*−0.18*	*0.64*	*−0.14*
BkL	*−0.13*	*−0.14*	*−0.19*	*−0.13*	*−0.21*	−0.04	–	*−0.11*	−0.04
CH	*0.59*	*0.43*	*0.45*	*0.69*	*0.14*	*0.29*	−0.06	–	*−0.10*
WL	*0.27*	*0.21*	*0.19*	*0.20*	*0.16*	*−0.13*	−0.01	0.10	–

involved in sexual selection (+93.1 and +58.7 % in males compared to females, respectively). The size of the combs and wattles are associated with gonad development and secretion of sex hormones (Nesheim et al., 1979). It was moderate (between 11.8 and 20.9 %) for traits related to general size of the birds and lower for body length and beak length (less than 6.6 %). The effect of province was highly significant ($P < 0.001$) for live body weight, wing span, and tarsus circumference. As for major genes frequencies, there was a gradient between Relizane birds with higher values and Mostaganem birds with lower values, with Mascara birds showing intermediate values. According to Abdelqader et al. (2008), the wide variations in local chicken performance are ascribed in their study to many factors, mainly the variations in management practices between households, the effects of crossbreeding with exotic lines, and the availability of scavenging feed resources and feed supplements. In addition, empirical support relating morphometric variation and regional climates in birds is provided by a number of studies (Rand, 1936; James, 1970; Power, 1970, as cited in Bulgarella et al., 2007).

Finally, the interaction of between region and sex was highly significant ($P < 0.01$) for body length, tarsus length, breast width, and comb height. For body length and tarsus length, birds of the region of Mostaganem had the lowest values among the three regions in males but the highest in females. It was also true for wattle length but with a much lower amplitude. Conversely, for breast width, males from Mostaganem regions showed the highest values and females the lowest values. Otherwise, ecotype × sex interaction effects was highly significant ($P < 0.01$) in BrW : LBW ratio (data not shown). The highest values were recorded in male and female birds of Mostaganem.

3.3 Phenotypic correlations between traits

Pairwise correlations between body weight and linear body measurements for males and females are presented in Table 5. These correlations were generally high in both sexes, except for beak length and wattle length. This has been the trend in most studies (Semakula et al., 2011; Ajayi et al., 2012; Egena et al., 2014). The high and significant correlations between body measurements and body weight suggest that we would have a good predictability of body weight based on other measures. This is because an increase in any of the body measurement will invariably lead to a corresponding increase in the body weight of the chickens (Ajayi et al., 2008). A similar observation was reported by Udeh and Ogbu (2011). Correlations between traits within males and females were generally comparable, but in some cases we observed a large difference of correlations between both sexes. This was the case for correlations between breast width and either body weight, wing span, tarsus circumference, or comb height, which were higher in females than in males. Conversely, the correlations between body length and either body weight, tarsus length, or comb height were larger in males than in females. Studying morphometric traits and correlation between body weight and body size traits in Isa Brown and Ilorin ecotype chickens, Fayeye et al. (2014) observed that linear body measurements measured on male birds were more highly correlated with body weight (0.68–0.95) than in female chickens, except for breast breadth. Semakula et al. (2011), working with indigenous chickens of the Lake Victoria Crescent Agro-ecological Zone in Uganda, reported that all measurements were strongly correlated with body weight in males, while in females all measurements were significant except body length and femur length in 6–8-month-old chickens. These differences between males and females suggest that the traits included to predict body weight from body measurements would differ between males and females.

3.4 Principal components analysis

The principal component matrices for males and females chickens are presented in Table 6. The sampling adequacy was 0.68 for males and 0.67 for females, above the 0.50 limit value recommended by Kaiser (1974) for a reliable interpretation of the analysis. Communalities ranged between 0.57 and 0.91 for males and 0.55 and 0.92 for females, in-

Table 6. Eigenvalues and share of total variance along with factor loading and communalities for eight linear body measurements of male and female chickens. Bold indicates variables with a strong association ($|r| > 0.7$) with the principal component.

	Males				Females			
Traits	PC1	PC2	PC3	Communality	PC1	PC2	PC3	Communality
BL	**0.80**	−0.06	−0.04	0.65	−0.29	**0.85**	−0.08	0.82
WS	**0.84**	0.01	−0.25	0.77	**0.71**	0.65	−0.03	0.92
TL	**0.94**	0.13	−0.03	0.91	0.34	0.70	0.17	0.63
TC	0.64	−0.37	−0.44	0.74	0.51	**0.74**	−0.02	0.81
BrW	0.23	**0.81**	0.06	0.71	**0.86**	0.17	−0.03	0.77
BkL	−0.12	−0.05	**0.83**	0.71	−0.23	−0.09	**0.73**	0.59
CH	0.69	0.40	0.21	0.68	**0.87**	0.00	0.02	0.76
WL	0.36	−0.56	0.35	0.57	−0.20	−0.11	**−0.71**	0.55
Eigenvalue	3.860	1.305	1.034		3.424	1.364	1.066	
Percentage of variance explained by the axis	42.33	16.31	12.93		42.79	17.05	13.33	
Cumulative percentage of variance explained by the axes	42.33	58.64	71.57		42.79	59.84	73.17	

dicating that a good amount of variance has been accounted for by the component solution. Similarly high communalities have been reported by Egena et al. (2014) in Nigerian indigenous chickens raised according to an extensive management system and in different breeds of broiler chickens (Mendes, 2011; Ajayi et al., 2012).

In this study, three principal components with eigenvalues higher than 1 were extracted for each sex and accounted for 71.6 and 73.2 % of the total variance in males and in females, respectively. In males, PC1 is comprised of the general size of the birds, with high importance of tarsus length, wing span, and body length. The second and third axes were almost exclusively explained by breast width for PC2 and beak length for PC3. Consistent with the difference in the matrix of correlations between traits in males and females, the constitution of PCA axes was different in both sexes. In females, PC1 was more correlated with comb height, breast width, and wing span. PC2 was determined by body length, tarsus circumference, and tarsus length (0.70) and was the equivalent of axis 1 in males – i.e. it represented general size. As for males, the third axis had a high contribution of beak length, which also represented an opposite direction between beak and wattle length. The present findings are consistent with the literature, in which general size is generally reported as the main factor of variation and thus constitutive of the first axis of PCA in chickens, rabbits, or turkeys (Shahin and Hassan, 2000; Ajayi et al., 2011; Egena et al., 2014). The principal component analysis allowed for better understanding of the complex correlations among the traits and reduced the number of traits, using only the three first PCs, without loss of information.

3.5 Prediction of body weight

Body weight is an important attribute in poultry production as it forms the basis for not only assessing growth and feed efficiency but also making economic and management decisions. However, under some circumstances, a scale may not be available. Practical difficulties in measuring live weight at field level have led scientists to develop prediction models to estimate live weight using linear body measurements (Assan, 2013). Multiple regression models are useful for predicting body weight of the animals, but their biological interpretation may be misleading because of the number of predicted variables included in the model (Mendes, 2009). At the same time, the co-linearity between predictor variables could lead to incorrect identification of the most important predictors (Sharma, 1996), and this would result in incorrect conclusions about relationships between dependent and predictor variables. This can be avoided by using the principal components analysis (PCA) in place of the original variables since the principal components (PCs) are orthogonal and uncorrelated (Yakubu et al., 2009; Ogah, 2011).

As can be seen from Table 7, TL alone accounted for 78 % of the variation in body weight in males. However, the precision of the regression could be increased up to 91.3 % when including BrW, WS, CH, and BL. The first research that related BW and tarsus length in one breed of chickens had an R^2 of 0.66 (Lerner, 1937, as cited in Latshaw and Bishop, 2001). In females chickens (Table 8), WS alone accounted for 97.2 % of the variation in BW and was nearly not improved by the addition of BrW, TL, TC, CH, and BL in the regression equation. Liyanage et al. (2015), using a regression analysis, showed significant relationships of body weight with every linear trait, while chest circumference and shank length were the best predictors of live weight in vil-

Table 7. Final stepwise equations for prediction of body weight for males.

Step	Predictor	Intercept	*a*	SE	Probability	R^2
	Original body measures					
1	TL	−749.2	250.4	7.41	<0.001	0.781
2	TL	−191.7	271.2	10.06	<0.001	0.860
	BrW		−135.7			
3	TL	−1906.3	202.4	4.12		0.907
	BrW		−141.2		<0.001	
	WS		51.6			
4	TL	−1979.5	185.2	14.45	<0.001	0.910
	BrW		−146.1			
	WS		53.7			
	CH		47.3			
5	TL	−2452.1	160.4	5.73	<0.001	0.913
	BrW		−142.1			
	WS		54.7			
	CH		56.5			
	BL		20.1			
Final predictive equation: LBW = −2452.1 + 160.4 TL − 142 BrW + 54.7 WS + 56.5 CH + 20.1 BL						
	Principal component axes					
1	PC1	1716.35	−152.9	7.62	<0.001	0.812
2	PC1	1716.35	−152.9	7.13	<0.001	0.836
	PC2		47.8			
3	PC1	1716.35	283	6.70	<0.001	0.843
	PC2		−48.8			
	PC3		−31.6			
Final predictive equation: LBW = 1716 + 283 PC1 − 48.8 PC2 − 31.6 PC3						

PC1, PC2, and PC3: first, second, and third principal component, respectively; *a*: regression coefficient; R^2: coefficient of determination; SE: standard error of model.

lage chickens in Sri Lanka. Yakubu et al. (2009) and Ajayi et al. (2012) reported that the highest contributor to the variation in body weight in normal feathered Nigerian indigenous chickens was body length, which again highlights the importance of determining specific equations for local populations, which differ for a lot of characteristics, including genetic background and environmental factors of production.

According to the results of PCA, using PC1 as a single predictor already explained 81.2 and 80 % of the total variability in body weight in males and females, respectively. The accuracy of the models was further improved ($R^2 = 0.843$ for males and $R^2 = 0.942$ for females) when including other PC axes in the regression equation. The lower R^2 values obtained with the regressions on PC axes than on original measures suggest that the co-linearity between traits leads to overestimation of the goodness of fit of the equation based on original measures. Many researchers have used the independent factor scores derived from multivariate technique of principal component factor analysis in chicken data. Egena et al. (2014) reported that the combination of PC1 and PC2 resulted in $R^2 = 0.684$ for estimation of BW in Nigerian chickens raised according to an extensive management system. Likewise, Ayayi et al. (2012) reported that the combination of PC1 and PC2 explained 82, 74, 78.8, and 75.5 % of the total variability in BW in normal-feathered, frizzle-feathered, naked neck, and Anak Titan birds in the order listed. Ibe (1989) analysed the body weight of *Gallus gallus* at different ages, together with four body linear measurements: breast and thigh widths, and shank and keel lengths. In all ages the first two principal components explained at least 85 % of the total variation.

This study, however, did not have the specific objective of obtaining principal components to be used in chicken breeding programmes, because, in genetic terms, every ecological niche (i.e. ecological zone or environment) is governed by its own peculiar variability (Egena et al., 2014). Our objec-

Table 8. Final stepwise equations for prediction of body weight for females.

Step	Predictor	Intercept	a	SE	Probability	R^2
	Original body measures					
1	WS	−493	46.3	0.37	<0.001	0.972
2	WS	−533.6	43.6	3.06	<0.001	0.976
	BrW		25.8			
3	WS	−612.2	40.6	2.04	<0.001	0.980
	BrW		29.2			
	TL		20.4			
4	WS	−579.6	35.8	5.43	<0.001	0.982
	BrW		35.2			
	TL		21.8			
	TC		32.4			
5	WS	−546.9	33.6	3.92	<0.001	0.982
	BrW		31.3			
	TL		22.8			
	TC		42.7			
	CH		18.4			
6	WS	−562.5	33.9	3.45	0.003	0.983
	BrW		31.5			
	TL		22.7			
	TC		42.5			
	CH		17.0			
	BkL		10.3			
Final predictive equation: LBW = −562.5 + 33.9 WS + 31.5 BrW + 22.7 TL + 42.5 TC + 17.0 CH + 10.3 BkL						
	Principal component axes					
1	PC1	1451.5	161.8	7.15	<0.001	0.800
2	PC1	1451.5	161.8	2.52	<0.001	0.942
	PC2		142.7			
Final predictive equation: LBW = 1451.5 + 161.8 PC1 + 142 PC2						

PC1 and PC2: first and second principal component, respectively; a: regression coefficient; R^2: coefficient of determination; SE: standard error of model.

tive was to show that the use of orthogonal variables gave a better and more dependable estimation of body weight since it was able to break multicollinearity, a problem commonly connected with the use of interdependent original body dimensions (Egena et al., 2014).

4 Conclusions

This study has highlighted a great phenotypic and phaneroptic diversity of local poultry genetic resources found in the Algerian rural areas, reared extensively for household consumption and obtaining extra income. Phenotypes observed were unevenly distributed across space, reflecting the adaptive fitness of birds to areas according to specific skills of each phenotype. Other attributes of economic interest in tropical and subtropical conditions were also observed, such as naked neck and frizzled. However, the low frequencies of major genes' dominant alleles under study would suggest that the carrier animals are in serious danger of extinction and are currently endangered. Otherwise, the use of factor and principal component scores in multiple linear regression analysis has been shown to be useful in prediction of body weight of indigenous chickens. This might present valuable knowledge for genetically improving body weight. Therefore, indigenous chickens deserve special attention and conservation. These results may be useful in the context of breeding programmes for the future creation of strains that are resistant to harsh climates and efficient in terms of production.

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