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Growth patterns in Barbary partridges *Alectoris barbara* originated from low- and high elevations in West central Morocco

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Abstract – The Barbary partridge, the family Phasianidae, is the main game bird in Morocco and which was reported to be heavier and larger in mountains than in lowlands. In this regard, the purpose of the present study was to investigate posthatching growth of body weight and seven morphometric parameters in Barbary partridges *Alectoris barbara* originated from low- and high elevations, and raised in common captive environment. Gompertz model presents the best fit to the growth curves for body weight, wing, leg and sternum. Mean body weight at hatching was similar between elevations and was relatively higher, compared to that in other studied perdicine species. Adult Barbary partridges from high and low elevations maintained the difference in body weight when raised in common captive environment. This suggests a role of genetic selection and / or maternal effects between the two studied populations. However, all the other growth parameters of morphological traits were similar between captive birds originated from the two elevations. This lack of difference could be related to a potential phenotypic plasticity with a convergence in common captive environment.

Key-words: Barbary partridge; body weight; growth rate; morphometry; mountains; plain.

INTRODUCTION

Barbary partridge *Alectoris barbara* is wildly distributed predominantly in North Africa from Morocco to Egypt, but also occurs in the Canary Islands, Gibraltar and Sardinia (Cramp & Simmons 1980, Madge & Gowan 2002). Over much of its range, it has declined due to hunting pressure and habitat degradation (Madge & Gowan 2002, BirdLife International 2004). It is locally numerous in Morocco, Algeria and Tunisia, and its current status in Libya is unknown and it is perhaps extinct in Egypt (Madge & Gowan 2002). Although the Barbary partridge is the main game bird species in North Africa, little research have been conducted on its biology and ecology. Previous investigations were carried out on some aspects of osmoregulation (Hollander 1971), reproductive ecology (Alaoui 1992, 2001, Akil & Boudedja 2001) and more recently on parasitology (Foronda *et al*. 2005).

Emphasis on Barbary partridge breeding in captivity is growing due its economic value for commercial production (game bird, game bird, meat production), its ecological importance with protection of wild. However, no growth patterns investigation have so far been performed in North African populations.

The morphological growth is one of the fundamental aspects in the study of biology and life history of birds. The growth fact is under control of genetic and environmental conditions in living organisms (Barbato 1991). Research in this area (see Ricklefs 1973, O'Connor 1984, Stark & Ricklefs 1998 for review), have characterized quantitatively the patterns of development and thus facilitated analysis and comparisons. Sufficient information on growth parameters could be used easily at breeding and genetic selection studies, determining fattening period and feeding strategy economically. Based on mean adult body weight, hunted Moroccan Barbary partridges of both sexes in high altitude (High Atlas mountains, 1900 m a.s.l.) revealed to be larger and heavier than those from lowlands (Northwest Morocco, 50 m a.s.l.), and have been suggested as a distinct "race" (Alaoui 2001). Assuming that constraints in growth are facilitated when birds are raised in the same captive conditions, morphological traits of birds originated from different elevations, may change in a number of ways when reared in common aviary environment (see Bears *et al*. 2008). So, in the present work, we tested whether the difference in growth parameters between low- and high elevation populations of Barbary partridge, is maintained in aviary and if so, to see if the corresponding growth patterns are also distinct. For this purpose, we analyzed and modeled postnatal growth patterns of body weight and length of the wing, sternum and leg in Barbary partridge originated from lowlands and mountains of west central Morocco, hatched and raised under identical environmental captive conditions.

MATERIALS AND METHODS

Egg origin and incubation

Birds used in the present work originated from eggs collected (under licence) in the wild during the breeding season (April 2006), in two different sites in the region of Marrakech (Morocco). 12 eggs taken from two nests at 2400 m of altitude in Ouirgane Reserve (High Atlas Mountain) and 11 eggs harvested from two nests in the Haouz plain at Tamazouzt area (540 m of altitude). Eggs were individually marked and artificially incubated in an air-forced incubator (T° = 38.3°C). When eggs started piping, they were transferred into a hatcher set at 70% humidity within the incubator where chicks are left to dry for 5-6 hr.

Maintenance conditions and measurements

After hatching, chicks were individually marked with colored plastic rings and housed together in brooders (50 x 50 x 30 cm), equipped with an infra- red lamp (60 watts). This provides a thermal gradient from 38 ± 2°C under the heater to 25 ± 2°C at the periphery of the brooder allowing the chicks to select the suitable air temperature (Ogilvie 1970). After 7 days, chicks were moved into similar larger brooders (120x80x60 cm) with sand and very small gravels as substrate to stimulate locomotion. From a minimum age of three weeks, the birds have been ringed (numbered aluminum rings) and then transferred to spacious in-room cages (150 x 120 x 70cm). The photoperiod was automatically set to 14L : 10D. Poultry pellets (~18% of protein and 1.5% calcium, 1% phosphorus and vitamins A, D, E) offered in trays from 1 to 15d and a grower diet (25% of protein) with a mixture of seeds (wheat, millet, groats, wild mustard seeds, and lentils) from 16 d. Food and water were provided *ad libitum*. During the whole study, growing partridges were maintained in a ventilated air-conditioned room (T = 25 ± 1°C and RH = 40 ± 10%). Sub-adults were housed in an outdoor aviary set (10 x 5 x 2.5 m) from an age of 10-12 weeks.

The body weight (g) was determined to the nearest 0.01 g using an electronic balance (AND HL-400). The morphometric measurements were made using a caliper (Camlab) to 0.01 mm, during the juvenile period from hatching until the age of an adult size 21 individuals. Seven morphometric parameters, were measured: length of the wing (upper wing, lower wing and hand), the sternum, and length of the leg (upper leg, lower leg and tarsus). All measurements were carried out between 7-9 p. m., daily until the age of 30 days and then every 2-5 days until the age of 60 days and then every 5 to 10 days until the age of 120 days. Sexing of the studied birds was made *a posteriori*, using the only visible sexual dimorphic character, namely spurs present in adult males from an age of 12-13 weeks, and confirmed by observing the socio-sexual behavior during the breeding season.

Data treatment and statistics

The Growth parameters were determined by fitting growth curve data to the two common applied growth equations for birds (Ricklefs 1973): (1) Gompertz: $W_t = A.\exp(-\exp(-K(t-t_i))$; (2) logistic: $W_t = A/(1+\exp(-K(t-t_i))$.

Where W_t represents size at time t (days), A is asymptote value, t_i (d) is the age at the inflection point, and K is growth constant rate (d^{-1}). Growth curve fits were performed using Curve Expert 1.3 (2005). In order to choose the mathematical model, which gives the best fit between the equation and all measurements, we compared reduced *Chi* square for the tested growth models; reduced *Chi* square of approximately 1 is indicative of a good adjustment. Numerous comparisons were done using the general models procedure to test for effect of sex on each variable. Means were compared using Fisher test (F-test) or *t*-Student test with significance thresholds $\alpha = 0.05$.

RESULTS

Body weight and measurements data were obtained on 21 chicks including 10 males and 11 females originated from the plain or mountains. The Gompertz growth model provided the best fit for all measurements (with highest determination coefficient and the lowest residual variance) as compared to logistic model. Also, we considered the Gompertz equation for describing the growth of all the variables studied.

Body weight growth parameters

The general pattern of daily growth in Barbara partridge was sigmoid for body weight (Fig. 1). Estimates of the parameters A, K_G and t_i predicted by the Gompertz equation, are given in Table 1. Body weight at hatching was

Table 1. Mean values of growth parameters for body weight in Barbary partridge originated from the plain and mountains.

Sexe	N	W_h	A	K_G	t_i	r^2
Males	10	15.25 ± 0.97	*491.21 ± 39.25	0.0357 ± 0.0030	36.37 ± 2.9	0.9873 ± 0.0046
Females	11	15.01 ± 0.95	*435.22 ± 51.17	0.0344 ± 0.0025	37.16 ± 4.37	0.9902 ± 0.0013

N: number of individuals; W_h: Body weight at hatching (g); A: Asymptotic body weight (g); K_G: Growth rate (d^{-1}); t_i: Inflection point (d); *: $P < 0.05$.

not significantly different between males and females ($P > 0.05$) and was average respectively of 15.25 ± 0.97 g, (N = 10) and 15.01 ± 0.95 g, (N = 11) and similar between elevations in both sexes. This represents about 3.2% of the breeding female mean asymptotic body weight (435.22 ± 51.17 g, N = 11). Sexual dimorphism in body size was observed at the end of the growing period, with males being significantly heavier than females (491.21 ± 39.25 *vs*. 435.22 ± 51.17 g) ($P < 0.05$) (Table 1). The growth rate constant (K_G), age at maximum growth (t_i), predicted by the Gompertz equation were respectively 0.0357 ± 0.0030 d^{-1} and 36.37 ± 2.9 d for males and 0.0344 ± 0.0025 d^{-1} and 37.16 ± 4.37 d for females. Except for the asymptotic body weight, the other growth parameters in both sexes of the Barbary partridge does not account for a significant effect ($P > 0.05$) (Table 1). The growth rate constant (K_G) and the inflection point (t_i) averaged of 0.035 ± 0.002 d^{-1} and of 37 ± 1.9 d^{-1} respectively.

Morphometric growth parameters

As for body weight, the general pattern of daily growth in Barbary partridge was sigmoid for all the seven-morphometric parameters studied (Fig. 2). No significant differences were detected between sexes for all morphometric parameters of the wing, the leg and the sternum ($P > 0.05$ in all cases). The respective absolute total lengths of wing (arm + forearm + hand), sternum and leg (femur + tibia + tarsus), at hatching averaged 38.2 ± 2.10 mm, 10.60 ± 1.13 mm and 59.26 ± 1.08 mm respectively. The mean growth rates (K_G) of the wing and sternum are relatively higher (0.046 ± 0.004 d^{-1} and 0.044 ± 0.003 d^{-1} respectively), than that of the leg (0.033 ± 0.009 d^{-1}) (Table 3). In both sexes, the mean of the age at maximum growth (t_i) of the lower wing, upper wing and upper leg are reach faster (9.23 ± 1.09 d) than for the hand, lower leg (36.53 ± 1.47 and 24.99 ± 1.98 d respectively) (Table 2).

Intra-specific growth comparison: Plain *vs*. Mountain

Partridges from the mountain have an asymptotic body weight higher than those from the plain, and this difference is much more significant in the case of males (510.965 ± 15.411 g *vs*. 445.131 ± 40.854 g) ($P < 0.001$) than in females (403.197 ± 23.120 g *vs*. 473.652 ± 49.923 g) ($P < 0.05$) (Table 3). Males from mountain and plain have a body weight growth rate higher than that of females (0.037 ± 0.003 g and 0.036 ± 0,003 g *vs*. 0.033 ± 0.001 g and 0,033 ± 0,001 g respectively) ($P < 0.01$) (Table 3).

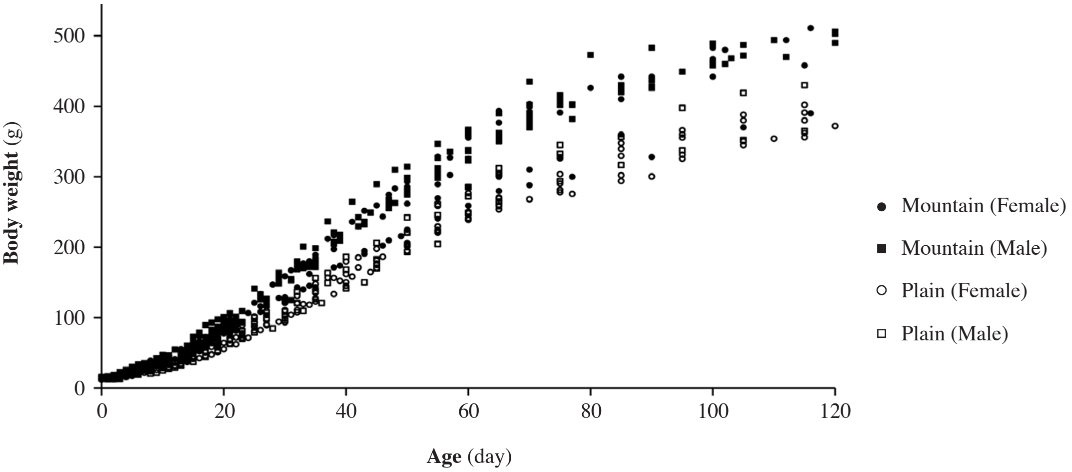

Figure 1. Growth curves of body weight as a function of age in Barbary partridge fitted to the Gompertz equation.

Table 2. Mean values of morphometric growth parameters estimated for Gompertz model in Barbary partridge originated from the plain and mountains. Data are means of 10 males and 11 females.

	Sexe	*A*	K_G	t_i	r^2
Hand	f	55.83 ± 3.91	0.0469 ± 0.007	37.21 ± 1.65	0.813 ± 0.011
	m	57.75 ± 2.59	0.0466 ± 0.005	36.35 ± 0.90	0.851 ± 0.008
Lower wing	f	57.46 ± 3.00	0.0467 ± 0.0033	11.12 ± 1.04	0.8647 ± 0.0230
	m	59.68 ± 2.73	0.0461 ± 0.0032	10.48 ± 0.77	0.8352 ± 0.0146
Upper wing	f	63.94 ± 3.85	0.0454 ± 0.0067	9.36 ± 1.07	0.7893 ± 0.0302
	m	67.25 ± 1.24	0.0458 ± 0.0023	9.31 ± 0.641	0.8029 ± 0.0041
Sternum	f	88.85 ± 7.21	0.0444 ± 0.0037	16.43 ± 1.47	0.9042 ± 0.0159
	m	94.81 ± 6.41	0.0451 ± 0.0028	15.72 ± 0.56	0.8861 ± 0.0113
Upper leg	f	72.39 ± 4.37	0.0316 ± 0.0022	9.33 ± 1.31	0.9063 ± 0.0030
	m	75.39 ± 2.78	0.0330 ± 0.0029	8.95 ± 1.50	0.8945 ± 0.0152
Lower leg	f	94.88 ± 5.52	0.0338 ± 0.0005	24.82 ± 2.89	0.9912 ± 0.0006
	m	99.02 ± 2.25	0.0350 ± 0.0013	22.84 ± 1.77	0.996 ± 0.0004
Tarsus	f	56.79 ± 3.18	0.0378 ± 0.0009	25.99 ± 2.14	0.991 ± 0.0004
	m	56.41 ± 0.06	0.0435 ± 0.0011	23.88 ± 2.20	0.991 ± 0.001

L_h: Length at hatching (g); ***A***: Asymptotic length (g); K_G: Growth rate in (d^{-1}); t_i: Inflection point (d); r^2: coefficient of determination; **m**: males and **f**: females.

DISCUSSION

Except for the asymptotic body weight, there were no significant differences in all the other growth parameters (including all morphological parameters) between the two studied populations from low- and high elevations in West-central Morocco. So, the asymptotic body weight and the other growth parameters are here discussed respectively at intra- and inter-specific levels.

Inter-specific comparison

Although postnatal growth has been investigated in several gallinaceous species (see Starck & Sutter 2000 and references therein), there are relatively few data on wild perdicine phasianids. In a compilation by Starck & Sutter (2000), data were provided only for rock partridges A*lectoris graeca*, grey partridges *Perdix perdix* and the Japanese quail *Coturnix cortunix*. More recently, Pis (2012) reported data on growth parameters of the body weight, tarsus, wing and bill lengths in chukar *Alectoris chukar* and grey partridges.

As a typical precocial land species, Barbary partridge chicks hatched with relatively well developed body weight (15.1 ± 0.9 g: 3.2% asymptotic body weight), comparatively with chukar and grey partridge chicks 12.5 g and 9.6 g (2.3-2.4% asymptotic body weight), respectively (Pis 2012). The Barbary partridge adult body weight (~ 460 g) was intermediate between grey partridges (382 g) and chukars (523 g) (Pis 2012). Based on data for 14 perdicine species (Starck & Sutter 2000, Pis 2012), the Gompertz growth rate (K_G, d^{-1}) for the body weight is found to be allometrically and significantly related to the asymptotic body weight (*A*, g) according to the following equation: $K_G = 0.526*A^{-0,416}$, $r^2 = 0.758$. The Gompertz growth rate corrected for asymptotic body weight ($K_G' = K_G/A^{-0,416}$) in the Barbary partridge revealed to be relatively lower than those calculated for the grey partridge and chukar (0.0447 *vs*. 0.0458 and 0.0516). The slower growth rate observed in Barbary partridge chicks could be attributed to their wild origin compared to the two other species which were probably acclimated to captive conditions and bred for several generations in Western Poland (Pis 2012). In this regard, the investigations of the relation between growth rate and maturation of skeletal muscles over a size range of galliform birds by Dietz & Ricklefs (1997), showed that the slower growth may reduce daily energy and nutrient requirements, allowing chicks to subsist on lower quality diets and providing greater safety margins in case of decrease in food supply.

Adult males of Barbary partridge are significantly heavier than adult females; this male-biased sexual dimorphism in asymptotic body size, often plays a role in intrasexual competition with larger males probably being favoured in territorial contexts.

The locomotory systems of Barbary partridge are sufficiently developed to enable chicks to move in their envi-

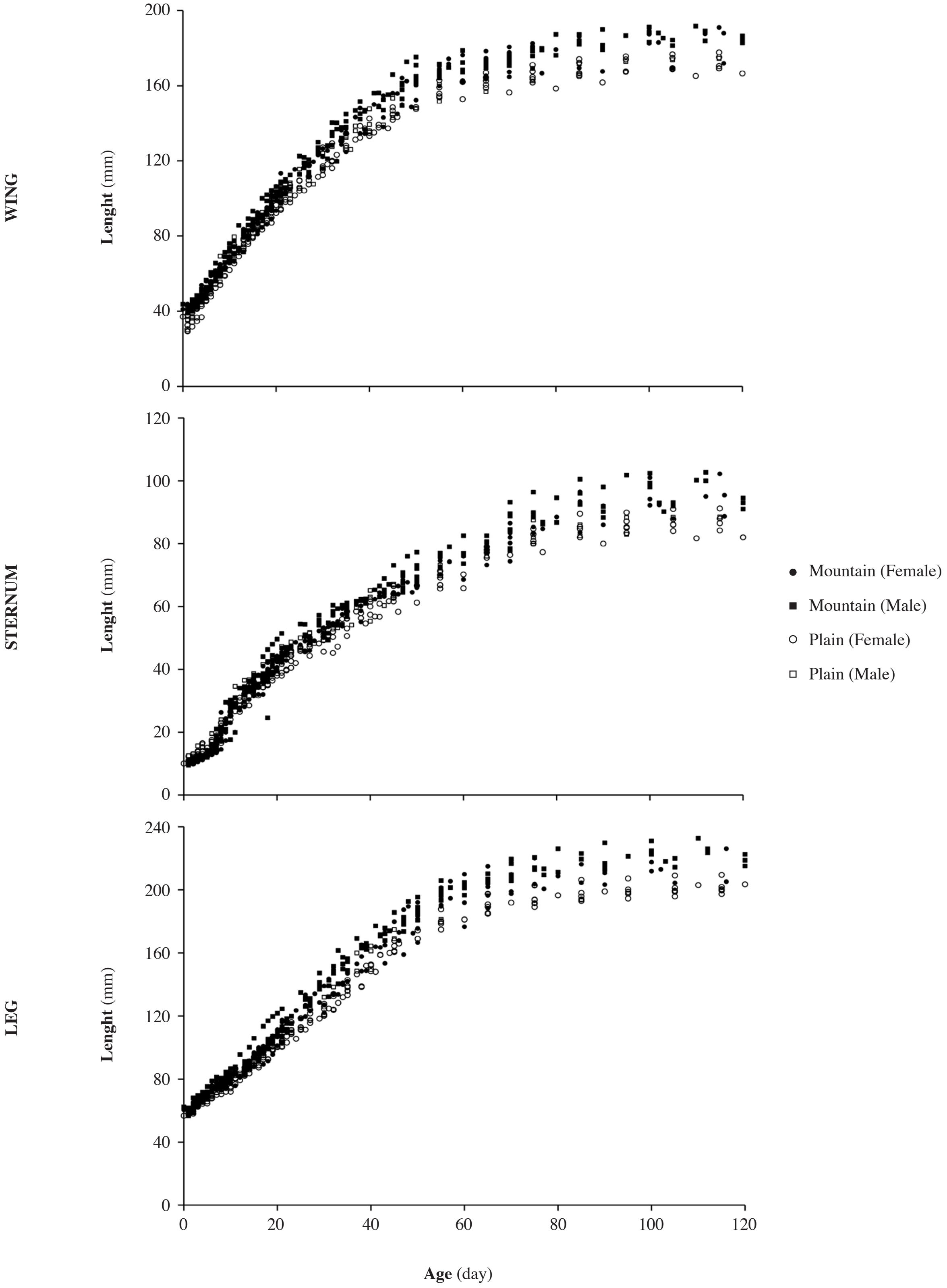

Figure 2. Growth curves of wing, sternum and leg lengths as a function of age in Barbary partridge fitted to the Gompertz equation.

Table 3. Effect of the egg origin and sexes on the growth parameters for body weight in the Barbary partridge.

	Males		**Females**	
	Plain	**Mountain**	**Plain**	**Mountain**
N	5	5	6	5
W_h	15.53 ± 0.05	15.05 ± 0.54	14.86 ± 1.54	15.72 ± 0.76
A	445.13 ± 40.85	***510.96 ± 15.41	403.197 ± 23.120	*473.65 ± 49.92
K_G	0.033 ± 0.001	*0.037 ± 0.003	0.033 ± 0.001	*0.036 ± 0.003
t_i	39.646	35.007	38.655	35.604

N: number of individuals; W_h: Body weight at hatching (g); A: Asymptotic weight (g); K_G: Growth rate (d^{-1}); t_i: Inflection point (d); *: $P < 0.05$; ***: $P < 0.005$.

ronment. After hatching, the upper and lower wing and the upper leg grow faster than the tarsus and low leg (t_i = 10 *vs*. 25 d). The general pattern and mode of development of the locomotory systems in this species are closely adapted to their ecological circumstances during the pre-fledging period. The fast growth of the upper legs and the wings ten days after hatching increases the mobility of chicks and thus improve their chance of escaping potential predators whilst unable to fly and allow the chick to pass more quickly through the vulnerable development period. Captive Barbary partridge chicks can fledge at about three to four weeks after hatching, when attaining only 33% of adult body weight. On the other hand, Barbary partridge chicks hatch with well-developed legs to enable chicks to move in the exposed open environments and to feed themselves from their first day on insects and then seeds and other plant materials. In growing birds, resources are allocated preferentially to growth of the component with the highest current functional priority, with due regard for future needs (O'Connor 1984). Ricklefs (1979) has discussed the significance of highly developed legs at hatching, which he attributed to the need for homoeothermic capacity because leg muscles are the most important source of heat production early in a chick's life. Meanwhile, the growth of sternum becomes faster three weeks after hatching in relation with an important development of breast muscles necessary for fledgling.

Adult Barbary partridges which were reported as heavier in high elevation than in low elevation, maintained this difference in body weight when raised in common captive environment. This suggests a role of genetic selection and/or maternal effects between the two studied populations. On the other hand, all the other morphological traits and related growth parameters were similar between captive birds originated from the two elevations. This lack of difference could be related to a genetic similarity between populations or a phenotypic plasticity with a convergence in common captive environment. Comparatively to other studied perdicine species, Barbary partridge, regardless to its environmental origin, hatch at a higher body weight, but with a lower growth rate for a similar asymptotic body weight. The locomotory system develops faster than the terrestrial one probably as a survival adaptive strategy.

Intra-specific comparison

The comparison of growth parameters in the Barbary partridge originated from low- and high elevations, revealed significant differences in the values of the asymptotic body weight with birds from mountains being larger and heavier. These results are in concordance with data on mean adult body weights reported for Barbary partridges from two other Moroccan localities, one located in the High Atlas mountains and the other one in the plain (North Morocco) (604 g *vs*. 506 g in adult cocks and 497 g *vs*. 455 g in adult hens) (Alaoui 2001). So, this difference in adult body size observed in Barbary partridges between elevations in the field are subsequently maintained in the aviary. This would imply that there were persistent genetic differences between the two studied populations or that the maternal effects (i.e., internal egg quality) influence the final body size according to elevation. Moreover, and according to Bergman's rule, larger body size in cooler mountainous areas would be an advantage for thermoregulation as heat loss is more rapid for small than for large endotherms because of the high surface area to volume ratios in the former (Liknes & Swanson 1996). Nevertheless, birds show no relationship between the strength of Bergmann's rule and body size (Ashton 2002). This author suggests that the fasting endurance is probably a more important factor than the traditional hypothesis of heat conservation. Fasting endurance hypothesis proposes that larger size is favoured in more seasonal environments because larger animals can store more fat and can use those fat stores for greater survival during seasonal stress (Boyce 1979, Lindstet & Boyce 1985). The scaling of fat stores and metabolism with body size confers an absolutely (but not relatively) longer survival time, e.g. greater fasting endurance during seasonal resources shortages for larger animals. As growth, data are difficult to obtain on free-living growing Barbary partridges, the lack of differences in all other morphological traits and growth parameters (including size at hatching) between low- and high elevations in the common captive environment could be explained according two possible scenari. The first one supposes that this lack of differences between growth parametrs exist in the wild and is maintained when populations are raised in common environment. This would imply that the populations are genetically the same, and that their morphological traits are not affected by phenotypic plasticity in response to conditions that differ between elevations in the field. The second scenario assumes that differences exist between elevations in the field, but traits values converge in the common environment. This would imply that differences in the field are due to phenotypic flexibility in response to differences in environmental conditions between low- and high elevation habitats.

According to the first scenario, similar growth parameters in the field maintained in captivity would mean that growth rates are physiologically maximized as suggested in some passerine birds (Ricklefs 1973, King & Hubbard 1981). In the second scenario, potential differences in growth parameters between elevations in the wild, would assume that growth rates are rather submaximal and optimized in relation to the local environment.

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