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Mammalian Biology
Zeitschrift für Säugetierkunde

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ORIGINAL INVESTIGATION

Effects of environmental factors on organ mass of midday gerbil (*Meriones meridianus* Pallas, 1773)

Jicheng Liao, Ying Wang, Liming Zhao, Naifa Liu*

School of Life Sciences, Lanzhou University, Lanzhou 730000, China

Received 15 March 2009; accepted 16 November 2009

Abstract

We measured and analyzed the organ masses of midday gerbils (*Meriones meridianus* Pallas, 1773) to test whether organ masses would respond to the variation in environmental factors. The results showed that organ masses (as expressed in log of organ dry mass) of midday gerbils changed significantly in different environmental gradients. Altitude was the best predictor of variation for heart dry mass, while it was frost-free period for the dry masses of kidneys, liver, and lung. The integrative effect of frost-free period and precipitation explained the 54.9% of the variables for kidney dry mass and 47.7% of the variables for liver dry mass. Precipitation and latitude explained 8.9% of the variables for spleen dry mass. We concluded that environmental factors had an integrative influence on organ masses. Midday gerbils' heart mass became larger at higher altitude to respond to hypoxia and higher level of energy demand. Primary productivity (surrogated by frost-free period, precipitation, and their interaction) played the most significant role in determining the organ masses of midday gerbils. When encountering unfavorable conditions, midday gerbils had the tendency to grow larger organ masses to promote organ function.

Keywords: Midday gerbil; *Meriones meridianus*; Environmental factors; Phenotypic variation; Organ mass

Introduction

The functional size of organs and aspects of the metabolic physiology of an individual may show great flexibility over timescales of weeks and even days depending on the physiological status, environmental conditions, and behavioral goals (Piersma and Lindström 1997). This flexibility is a way for animals to cope successfully with a much wider range of conditions occurring during various life-cycle events than fixed metabolic machinery would allow. Many organisms display phenotypic plasticity in response to the environment. Some experiments on rodents or mice obtained a series of results on phenotypic variation in designed environments (Timiras et al. 1957; Hock 1961, 1964; Hammond et al. 1999, 2001; Bacigalupe et al. 2004).

Although such experiments were carefully designed, it might result to a potential departure from the original condition. Abiotic and biotic factors, such as seasonal fluctuation, fasting endurance, competition, and predation, may be distinct between natural conditions and the laboratory. The sensitivity of the phenotype to a particular environmental stimulus changes during development (Spicer and Burggren 2003). During adulthood, a short to medium-duration exposure to a different environment may also promote phenotypic changes. These events of phenotypic plasticity are usually referred to as acclimatization when they occur in response to environmental changes in nature and as acclimation when

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*Corresponding author.
E-mail address: naifaliu@sohu.com (N. Liu)

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doi:10.1016/j.mambio.2009.11.003

they are experimentally induced by environmental manipulation in the laboratory (Rezende et al. 2005). If specific challenges are presented during "sensitive periods" of the ontogeny, often called critical windows, the responses may be particularly influential on the adult phenotype. If stress periods are short compared with the lifetime of an organism, then irreversible phenotypic plasticity is unlikely to be a favorable response (Gabriel 2005).

Moreover, the development of an animal's phenotype undergoes a long period. It is not believable for a result to be obtained from a short period or even a few generations. Imagine a species that has inhabited low-elevation environments for millions of years, adapting evolutionally to function well in "normal" levels of atmospheric oxygen (~21%). If one were to expose individuals of this species to high altitude, then they might be expected to exhibit inappropriate physiological responses to reduced atmospheric oxygen (Garland and Kelly 2006).

Thus, such phenotypic variation should be called "physiological adaptation" (environmentally induced changes that occur within individual organisms during their lifetimes, including acclimation and acclimatization) (Garland and Kelly 2006) instead of "evolutionary adaptation" (cross-generational changes in the genetic composition of a population in response to natural selection). Physiological adaptation is one type of phenotypic plasticity, but the ability to be plastic for any particular trait may also be an evolutionary adaptation whose details vary among organisms.

Midday gerbils (*Meriones meridianus* Pallas, 1773) are common in sandy areas in Mongolia and northern China, right across as far west as the Caspian Sea (Luo et al. 2000). Living in colonies in a burrow system and remaining active all year round, they can expand their colonies as long as the environment is suitable for their way of living (Wang and Xu 1992). This shows that they are a highly adaptable species. Their adaptability is expected to be accompanied by certain phenotypic variations. This provides an opportunity for us to test the relationship between variable environments and rodent adaptation. We hypothesize that the organ mass can demonstrate phenotypic plasticity in different environments to match physiological needs. Here, we study organ masses (heart, lung, liver, kidneys, and spleen) of midday gerbils. Our aim is to determine whether the organ masses of midday gerbils respond to environmental factors.

Material and methods

Meriones meridianus samples were trapped by rattrap at 11 sites from March to October of 2004 and 2008 in Gansu, Qinghai and Ningxiahui Autonomous Region, northwest China. Only adult individuals, whose body masses were over 40 g in female and 41 g in male (Zhou et al. 1997), were considered (Table 1).

We weighted and measured the midday gerbils and dissected them to remove the heart, lung, liver, kidneys, and spleen. After cleaning the fat and connective tissue, the organs were dried for at least 48 h at 60 °C and weighed to obtain dry mass (Hammond et al. 2001). We took the dry mass instead of the wet mass because the measurements would be confounded by the differences in water content between factors (i.e., locality, sex, and acclimation temperature) (Bacigalupe et al. 2004).

It has been hypothesized that the general factors influencing the geographic variation in body size include seasonality, temperature, moisture (or humidity), a combination of moisture and temperature, and productivity of the environment (Bergmann 1847; Rosenzweig 1968; James 1970; Boyce 1978; Ochocińska and Taylor 2003;). The body mass of individuals of an animal species can vary largely in different temperatures or altitude environments (Konarzewski and Diamond 1994). In addition, other reports have indicated that the altitude causes a converse variation in animals' body mass (Searcy 1980; Dunbrack and Ramsay 1993; Steudel et al. 1994; Ashton et al. 2000; Freckleton et al. 2003; Ashton 2004; Blackburn and Hawkins 2004; Liao et al. 2006).

First, we $\log_{10}$-transformed body mass and organ dry masses to meet the normality requirements. Body mass and organ dry masses may be influenced by sexual effect. We used independent-sample t-test (confidence interval was 95%) to test the significance of the difference between sample means of the male and female.

Body mass may have an effect on organ dry mass (Hammond et al. 2001); thus, we removed this effect on the dependent variables by using analysis of covariance (ACNOVA). When using the general linear model (GLM) to perform the ACNOVA, we selected organ dry mass as the dependent variable, environmental factor as the fixed factor, and body mass as the covariate.

As grazers, midday gerbils are directly dependent on primary plant productivity. Temperature, frost-free period, and precipitation largely influence plant growth. Their phenotypic characteristics can be influenced by other environmental factors as well. We collected meteorological data (varying from 10 to 30 years) from the National Climatic Data Center, and the data included eight items of environmental factors (altitude, latitude, longitude, mean annual temperature, frost-free period, precipitation, relative humidity, and annual sunshine hours).

Factor Analysis was used to remove redundant (highly correlated) variables from the environmental data. The first two principal components formed the extracted solution. They explained 90.09% of the variability in the original eight variables, and thus we considerably reduced the complexity of the data set using these components. The rotated component matrix indicated that the first component was most highly correlated with altitude, annual mean temperature, and frost-free period, while the second was most highly correlated with latitude and precipitation. We focused on altitude, annual mean temperature, frost-free period, latitude, and precipitation in the further analyses.

We applied multiple linear regression analyses with environmental parameters as independent variables and the organ masses as dependent variables to determine which of the