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Variability of the stable carbon isotope ratio in modern and archaeological millets: evidence from northern China

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ABSTRACT

Stable carbon isotopic analyses of human skeletal remains may provide fundamental evidence for human dietary reconstruction and subsistence strategies. Millet is closely associated with the emergence and development of agriculture-based societies in northern China. Although often overlooked, baseline values of millet seeds are essential for using stable isotope analysis to understand past human and animal diets. Here, we report spatial and temporal variations in the $\delta^{13}C$ values of millets by analyzing modern samples, including seeds and leaves, as well as archaeological samples. The $\delta^{13}C$ values of modern foxtail millet seeds range from −13.9 to −11.3‰, with a mean value of -12.3 ± 0.5‰ (1σ, $n = 66$), while $\delta^{13}C$ values for modern common millet seeds vary between −14.3 and −12.0‰, with a mean value of -12.8 ± 0.6‰ (1σ, $n = 19$). There is an approximately 1‰ temporal change in $\delta^{13}C$ for millet grains. Leaves have lower $\delta^{13}C$ values than grains, implying that eaters living on different tissues of the same plant could show different isotopic values. These background $\delta^{13}C$ values must be considered when reconstructing the dietary history of a millet-based society.

1. Introduction

Palaeodietary reconstructions based on stable carbon isotope analyses of human skeletal remains have greatly improved our understanding of how agriculture developed and expanded. For example, previous studies have revealed that Neolithic populations in northern China relied heavily on millet agriculture (Atahan et al., 2011; Barton et al., 2009; Guan et al., 2008; Hu et al., 2006, 2008; Ling et al., 2010; Pechenkina et al., 2005). Millets are cereal grasses that can produce small grains for human food. In northern China, millets include two cereals with the same geographical distribution: *Panicum miliaceum* (broomcorn or common millet) and *Setaria italica* (foxtail millet). Archaeologists have found that they were cultivated as early as ca. 10,000 years BP in China (Lu et al., 2009; Yang et al., 2012). Millet has long been recognized as an important food source for prehistoric people, and its evolution is closely associated with the emergence and development of agriculture-based societies in northern China (An, 1988; An et al., 2010; Barton et al., 2009; Lee et al., 2007) even during the formation of early state societies in China (Liu and Chen, 2003). The stable carbon isotope signal of food grasses has long been used to trace the diet of ancient peoples in northern China. However, little is known about the reliability of this isotope as a proxy of diet consumption or assimilation.

The conclusions drawn in previous studies often involve interpretations of differences in $\delta^{13}C$ values based on data from a limited number of modern samples (Hu et al., 2006, 2008; Pechenkina et al., 2005). Additionally, interpretations must take into account the spatial and temporal variability in the $\delta^{13}C$ value of millets.

There are essentially three types of plants in the natural world according to different photosynthetic pathways: (1) C_3 plants that use C_3 photosynthesis; (2) C_4 plants that use C_4 photosynthesis; and (3) CAM plants that use CAM photosynthesis. $\delta^{13}C$ values vary significantly among these three types of plants, with C_3 plants having the lowest $\delta^{13}C$ (~−26.5‰), C_4 plants having the highest $\delta^{13}C$ (~−12.5‰), and CAM plants having a mixed isotopic composition (Marino and McElroy, 1991; van der Merwe, 1982). Both common millet and foxtail millet use the C_4 photosynthetic pathway.

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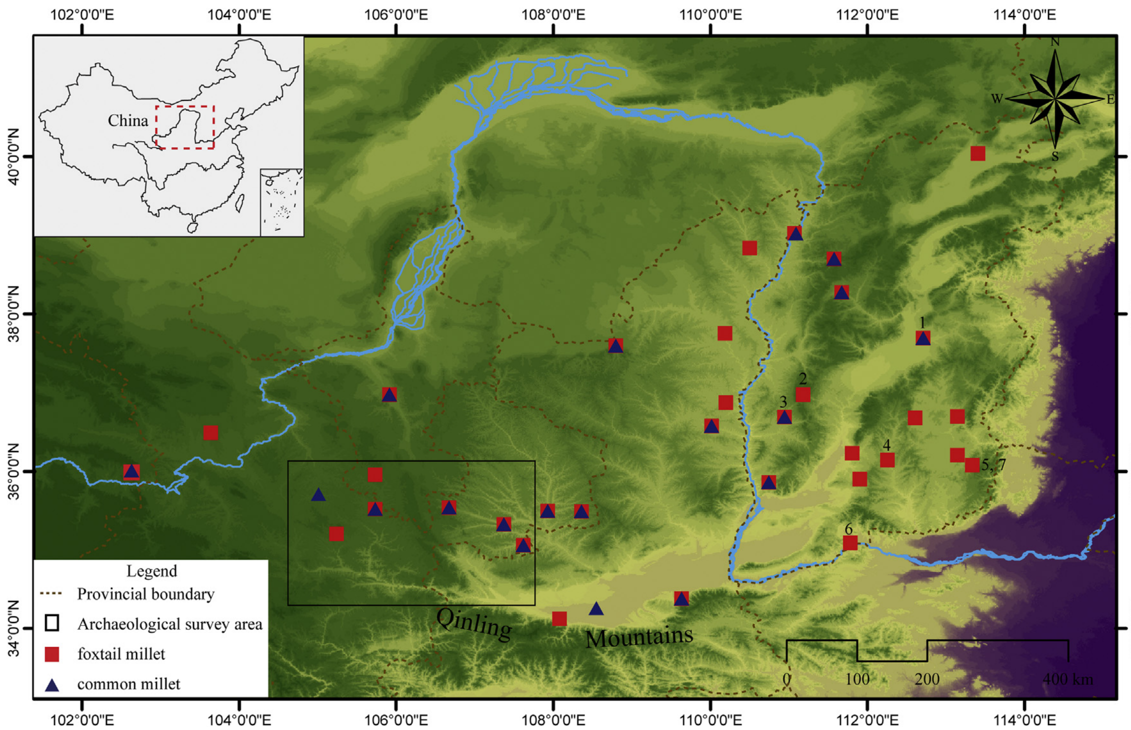

Fig. 1. Map showing the study area and sampling locations of modern millets. Nos. 1–7 represent sites mentioned in the text. The archaeological survey area shows where charred archaeological millet samples were collected. More detailed information is shown in Fig. 2.

Environmental conditions, such as humidity, temperature, light, and CO_2 concentration, can influence the carbon isotopic value of plants (Farquhar et al., 1982, 1989; Korner et al., 1991; O'Leary, 1981, 1988; Smith et al., 1976). The relationship between $\delta^{13}C$ for modern C_3 plants and environmental factors has been widely studied. The $\delta^{13}C$ values of modern C_3 plants are very sensitive to precipitation (Liu et al., 2005; Wang et al., 2003; Zheng and Shangguan, 2007) and are much less sensitive to temperature, altitude, and latitude (Diefendorf et al., 2010; Kohn, 2010).

It has been suggested that environmental factors may have negligible influence on the ^{13}C fractionation of C_4 plants (Wang et al., 2006). Some studies have argued that the $\delta^{13}C$ values of C_4 plants decline slightly when precipitation decreases (Schulze et al., 1996), while another study demonstrated that the abundance of C_4 plants that have higher $\delta^{13}C$ values is closely related to aridity (Feng et al., 2008). Isotopic composition can vary among plant compounds and tissues (Hobbie and Werner, 2004). Many studies show that amount of variation in stable isotope within a single plant is much lower than interspecific variation (Campbell and Fourqurean, 2009; Szpak et al., 2013). The carbon isotopic signal of many crops, such as wheat and maize, has been intensively studied (Lynott et al., 1986; Araus et al., 2007), but few works have done about millet.

The present study (1) documents the temporal and spatial variability of stable carbon isotopes in modern millets across northern China and (2) reveals the extent to which stable carbon isotopic variability is related to climate factors. The implications for archaeological studies are also discussed. To our knowledge, this is the first attempt to investigate this issue systematically. These data

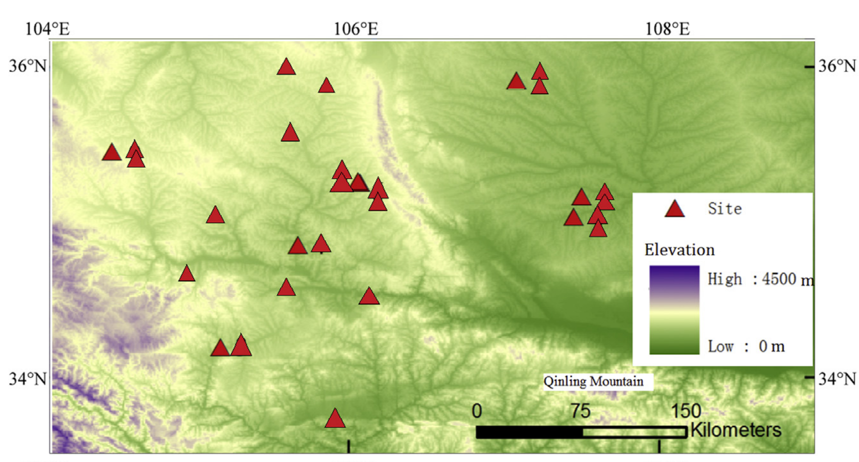

Fig. 2. Map showing the archaeological sites yielding charred millet samples.