TECHNICAL RESPONSE

ASIAN ARCHAEOLOGY

Response to Comment on "Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 B.P."

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Guedes *et al*. have drawn attention to a mismatch between the predictions of their "thermal niche model" and the records we have published of early barley finds in the northeastern Tibetan Plateau. Here, we consider how that mismatch usefully draws our attention to the additional variables that may account for it—namely, variations in genetic expression and agricultural practice.

We welcome the interest shown by Guedes *et al*. in our paper on human adaption to "the roof of the world" (*1*) and the introduction of their "thermal niche model" into the debate (*2*). As we write, thousands of Tibetan farmers look forward to this coming year's barley harvest, as they have all their lives, at altitudes at which Guedes's *et al*. model predicts that barley cultivation is not sustainable. Modern barley cultivation covers the whole arable region of the Tibetan Plateau, from 1000 m above sea level (masl) up to 4750 masl, but mainly distributed from 3000 to 4000 masl on the plateau (*3*, *4*) (Fig. 1). The earliest historical records of barley cultivation on the Tibetan Plateau are in the Tang dynasty (618 to 907 C.E.) (*5*); in Qaidam Basin higher than 3000 masl regions, no later than the Qing dynasty (1636 to 1911 C.E.) (*6*); in the Yushu region higher than 4200 masl, in the early 20th century (*7*); in western Sichuan province (Luhuo) higher than 3500 masl and the western plateau (A Li region) higher than 4000 masl, no later than the Qing dynasty (*8*, *9*); and in the southern plateau higher than 4400 masl—Sajia and Yamdrok Lake—in the Yuan (1271 to 1368 C.E.) and Qing dynasties, respectively (*9*) (Fig. 1). Archaeological studies show that barley cultivation widely appeared on the plateau higher than 3000 masl regions or even higher than 4000 masl in the southern plateau as early as 3600 years ago (*1*), and at least 3000 years ago in the Nuomuhong region on the edge of Qaidam Basin (Fig. 1) higher than 3000 masl, evidenced by rich and diverse crop remains [see the supplementary materials in (*1*)].

The mismatch between the predictions of Guedes's *et al*. model and the actual growth of barley today and in the past should not, however, be taken as negating the value of the model; scientific models are often at their most productive

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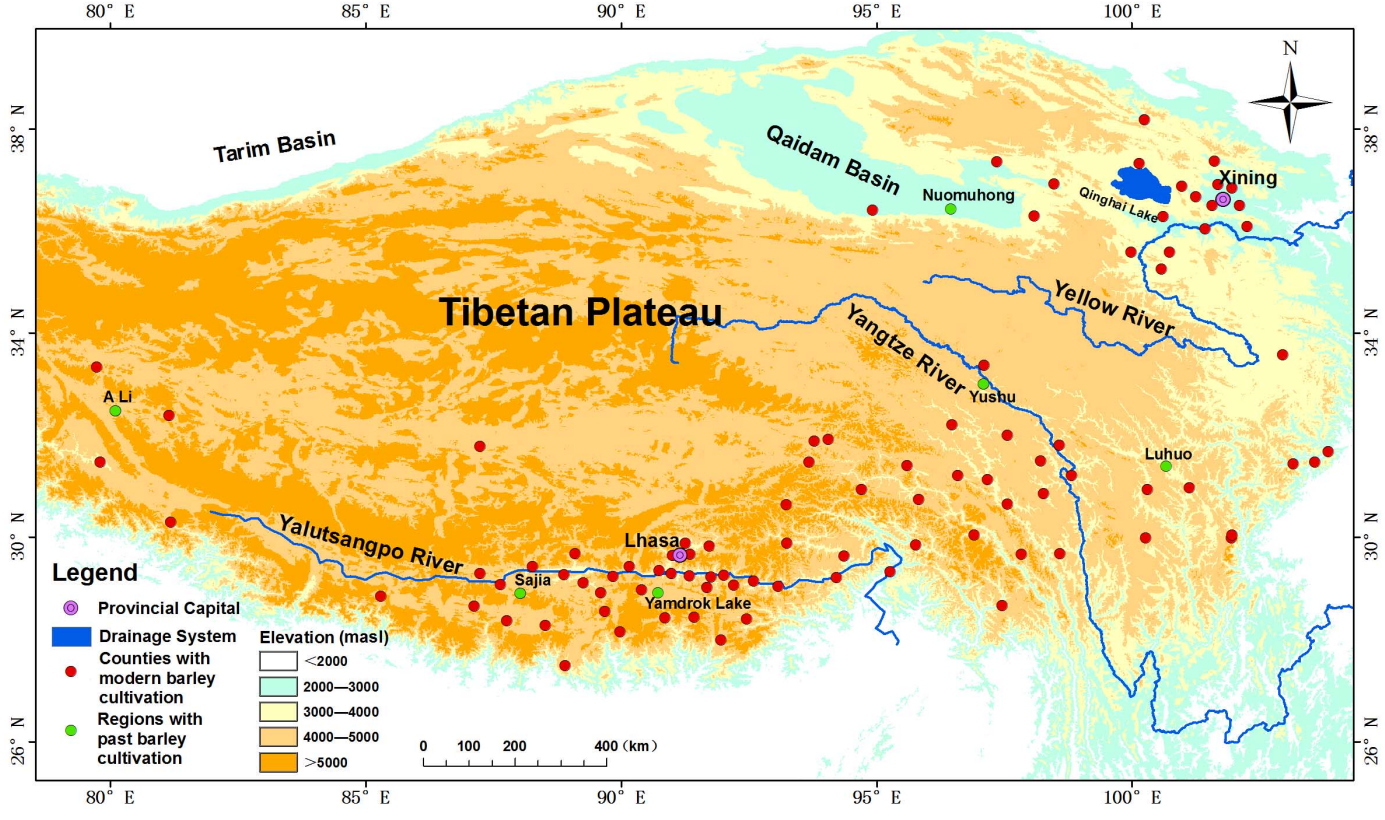

Fig. 1. The modern and past barley cultivation on the Tibetan Plateau. Red circles show locations where barley cultivations are documented since 1949. Green circles show locations of barley cultivation documented in historical records.

when they do not fit the observable data. In these cases, they force us to consider different parameters, not factored into the extant model, that may nonetheless be substantially influencing the data. In this case, we can follow Guedes's *et al*. barley data to its source and reflect on what those further variables and parameters might be.

Alongside a series of equivalent sources for wheat, rice, and millet, the principal data source for barley used in Guedes and Butler 2014 (*10*) is Stewart and Dwyer 1987 (*11*). The latter describes phenotypic observations of 192 *Hordeum vulgare* plants grown in pots in a Canadian greenhouse. Two observations can be made on this study: First, the variety of *H. vulgare* is not specified; second, while preliminary results of a field trial at one location were promising, the authors had not extended their study to field conditions. We can thus reflect on whether within-crop genetic diversity and field conditions (particularly cultivation practice) are the different parameters in question. There is a considerable body of recent research into altitudinal range and Ethiopian barley, examining traits and their expression at a range of altitudes up to 3300 masl. This research provides substantial evidence of diversity in a range of traits in relation to adaption to altitude (*12*–*14*). In terms of cultivation practice, two key well-documented variables can serve to modify and mitigate ambient thermal and seasonal environments—namely, flexibility in sowing times, and cultivation depth and strategy (*3*, *4*, *15*).

Guedes *et al*. also make observations on millet cultivation, to which similar considerations may apply. Although we have here drawn attention to the mismatch between their model output and observable cereal growth today and in the past, we do not discount the potential utility of the model. That utility is in drawing attention to factors that may account for the mismatch. In this instance, the likely factors are diversity in genetic expression and in field cultivation techniques. Both those factors are worthy of further scientific enquiry.

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