Spatial Distribution Pattern of Thousand-Grain Weight of Cultivated Barley in the Qinghai-Tibet Plateau and Its Relationship with Environmental Factors: Postprint

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Abstract

Thousand-grain weight is one of the important components of barley yield. The ecological environment of the Qinghai-Tibet Plateau, characterized by strong radiation, low temperature, and drought, has nurtured barley germplasm resources urgently needed by modern agriculture; however, systematic research reports on the relationship between cultivated barley WTS and environmental factors on the Qinghai-Tibet Plateau have been lacking to date. To reveal the spatial distribution patterns of cultivated barley thousand-grain weight on the Qinghai-Tibet Plateau and to ascertain the degree of influence of different environmental factors on the accumulation of cultivated barley thousand-grain weight (WTS) on the Qinghai-Tibet Plateau, this study investigated the distribution characteristics of cultivated barley WTS using data on geographic, climatic, and soil factors from 83 sampling sites. The results showed that: (1) In the horizontal geographic direction, cultivated barley WTS on the Qinghai-Tibet Plateau generally exhibited a patchy and interlaced distribution pattern, forming two high-value regions of cultivated barley WTS: one centered in Quxu, Duilongdeqing, Bainang, Nedong, Shigatse, Zhanang, Gongga, Jiacha, Dazi, Xietongmen, Lazi, and Dingri in Tibet, constituting the southwestern part of the Qinghai-Tibet Plateau, and another centered in Haiyan, Menyuan, and Gangcha in Qinghai, constituting the northeastern part of the Qinghai-Tibet Plateau; (2) In the vertical geographic direction, the variation of cultivated barley WTS displayed an "N"-shaped distribution pattern, forming two high-value WTS zones at altitudes of 3600.0-3900.0 m and above 4500.0 m, with cultivated barley WTS in these two altitude ranges being (49.6815\$±10.0764)$gand$(47.9500±\$0.1732) g, respectively; (3) The order of environmental factors affecting cultivated barley WTS, from greatest to least, was precipitation during heading-maturity period > soil available potassium content > sunshine hours during tillering-jointing period > average temperature during heading-maturity period > sunshine hours during heading-maturity period > average daily temperature range during jointing-heading period > geographic longitude.

Full Text

Preamble

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Relationship between Spatial Distribution Pattern and Environmental Factors Affecting Weight per Thousand Seeds of Cultivated Barley in the Qinghai-Tibet Plateau

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Abstract

Weight per thousand seeds (WTS) is an important yield component of barley. The high-radiation, low-temperature, and drought environment of the Qinghai-Tibet Plateau has nurtured barley germplasm resources urgently needed for modern agriculture. However, systematic research on the relationship between cultivated barley WTS and environmental factors in this region has not been reported to date. To address this gap, we investigated the distribution characteristics of cultivated barley using geography, climate, soil, and agronomy data from 83 sampling sites. Our objectives were to identify the relative effects of different environmental factors on WTS, clarify the relationship between barley WTS distribution and environmental factors, and explicitly assess the acclimation of WTS of barley varieties planted in different areas to the environment.

The results showed that: (1) Along the horizontal direction in the Qinghai-Tibet Plateau, WTS exhibited a macro-scale spatial distribution pattern with staggered patches of different values and an N-shaped tendency. Two regions of higher WTS were identified: the southwestern Qinghai-Tibet Plateau centered at Qushui and Dingri in Tibet (including counties such as Qushui, Duilongdeqing, Naidong, Shigatse, Zhanang, Gongga, Jiacha, Dazi, Qiongjie, Lazi, and Dingri), and the northeastern Qinghai-Tibet Plateau centered at Haiyan and

Gangcha in Qinghai Province. (2) Along the vertical direction, WTS distribution exhibited a double-peak pattern, with two higher-value zones between altitudes of 3600.0-3900.0 m and above 4500.0 m, with average WTS values of (49.6815$±10.0764)*gand*(47.9500±$0.1732) g, respectively. (3) The effect magnitude of environmental factors on WTS followed the order: precipitation during the growth period from heading to maturation > soil available potassium content > sunshine hours during the growth period from tillering to elongation > average temperature during the growth period from heading to maturation > sunshine hours during the growth period from heading to maturation > average diurnal temperature range during the growth period from elongation to heading > longitude.

Keywords: cultivated barley; weight per thousand seeds (WTS); spatial distribution pattern; influencing factors; Qinghai-Tibet Plateau

1. Study Area Overview

The study area covers Sichuan, Qinghai, and Tibet, spanning mountain coniferous forests, mountain shrub-steppe, and alpine shrub-meadow vegetation zones. The climate ranges from -0.6 to 12.9°C in mean annual temperature, with annual precipitation of 150–890 mm and annual sunshine hours of 3393 h. The research focused on locally planted hulless barley (naked barley) varieties, including both local landraces and promoted cultivars.

2. Sample Collection and Analysis

2.1 Sampling Sites and Varieties

Eighty-three typical sampling sites were selected across different ecological planting regions according to the atmospheric temperature and precipitation distribution patterns of the Qinghai-Tibet Plateau (27°–38°N, 79°–104°E). When establishing sampling points, priority was given to cultivated barley fields with uniform growth and large contiguous planting areas. Each sampling site covered an area of no less than 6.0 m × 4.0 m = 24.0 m^2, arranged in randomized blocks. All sampling locations and cultivated barley varieties are listed in Table 1, and specific geographic locations are shown in Figure 1 [Figure 1: see original paper].

Table 1 Sampling sites and variety information (showing site code, sampling site, longitude, latitude, altitude, variety, and type of variety)

2.2 Plant Sample Collection and Analysis

Sampling was conducted during the cultivated barley maturity period from August to September 2015. At each site, 2000.0 g of barley seeds were randomly harvested. In April 2016, the collected 83 accessions were field-planted at the Tibet Agricultural and Animal Husbandry College experimental farm with field management slightly above local standard levels. Phenological observations were made during the growth period, and harvested grains were air-dried in the laboratory for WTS determination.

2.3 Soil Sample Collection and Analysis

Concurrent with barley seed sampling at each site, soil samples were randomly collected from the tillage layer (0–30 cm) within each plot, placed in cloth bags, and transported to the laboratory for air-drying. Soil physicochemical properties were measured including total nitrogen (semi-micro Kjeldahl method), available nitrogen, total phosphorus and available phosphorus (molybdenum-antimony colorimetric method), total potassium and available potassium (atomic absorption spectrophotometry), organic matter (potassium dichromate oxidation), and pH (potentiometric method).

3. Data Analysis and Processing

Using WTS data from different source varieties planted under uniform environmental conditions, spatial distribution maps were generated using ArcGIS 9.3 software. Given the difficulty of conducting unified planting trials across numerous varieties in the Qinghai-Tibet Plateau, we performed multiple comparisons on WTS data to identify the maximum number of sampling sites showing no significant differences in WTS. This approach was considered valid for investigating relationships between barley WTS and environmental factors.

Stepwise regression analysis was used to establish equations relating WTS to geographic, climate, and soil factors. Random forest regression was then employed to comprehensively analyze the importance of each significant environmental factor affecting WTS in the Qinghai-Tibet Plateau. Climate data were obtained from the China National Meteorological Information Center.

4. Results

4.1 Distribution Characteristics of Cultivated Barley WTS in the Qinghai-Tibet Plateau

4.1.1 Horizontal Distribution Patterns Analysis of WTS from 83 different source varieties planted under uniform conditions revealed significant differences, with values ranging from 32.2–173.8 g and a mean of (46.5928$±8.2573)*g.Thespatialdistribution*(*Figure*2[*Figure*2 : *seeoriginalpaper*])*showedtwohigh−valueregions* : (1)*thesouthwesternQinghai−TibetPlateaucenteredatQushuiandDingriinTibet*(88.0°–91.5°*E*, 28.0°–30.0°*N*)*withWTSof*(54.5000±4.1838)*g*
TibetPlateaucenteredatHaiyanandGangchainQinghai(100.0°–101.5°*E*, 36.5°–37.5°*N*)*withWTSof*(56.1600±
g. Overall, the horizontal distribution exhibited a patchy, staggered pattern with an N-shaped tendency.

Table 2 F-test of WTS of cultivated barley varieties from different locations (showing variation sources, sum of squares, degrees of freedom, mean square, F-value, and coefficient of variation)

4.1.2 Vertical Distribution Patterns Along the altitudinal gradient, WTS showed a double-peak pattern. The first peak occurred in the 3600.0–3900.0 m altitude range with WTS of (49.6815$±10.0764)g,followedbyadeclinetoavalleybetween4200.0–4500.0m,andthen g. The coefficient of variation varied with altitude.

Table 3 WTS distribution conditions of cultivated barley along altitude in the Qinghai-Tibet Plateau (showing altitude gradients, number of sites, average WTS, and coefficient of variation)

4.2 Relationships between WTS and Environmental Factors

4.2.1 Geographic Factors Stepwise regression analysis established the relationship between WTS and geographic factors (longitude, latitude, altitude) as:

$$WTS = 146.7202 - 0.8292 \times Longitude - 0.0058 \times Altitude$$

The partial correlation coefficient for longitude reached significant negative correlation ($r = -0.3332$, $P < 0.05$), while latitude and altitude showed no significant relationships. The regression equation did not pass the significance test at $\alpha = 0.05$, indicating geographic factors had no significant overall effect on WTS.

4.2.2 Climate Factors The relationship between WTS and climate factors was established as:

$$WTS = 23.4949 - 19.2711 \times X_1 + 19.1457 \times X_4 - 0.7225 \times X_5 + 0.9636 \times X_2$$

where key climate factors included sunshine hours during tillering-elongation (X_1), average temperature during heading-maturation (X_4), and precipitation during heading-maturation (X_5). Partial correlation analysis showed significant positive correlations for sunshine hours during heading-maturation, average temperature during heading-maturation, diurnal temperature range during elongation-heading, and precipitation during heading-maturation, while sunshine hours during tillering-elongation showed significant negative correlation. The regression equation passed the significance test at $\alpha = 0.01$, indicating climate factors significantly affected WTS.

4.2.3 Soil Factors The relationship between WTS and soil factors was:

$$WTS = 50.1515 - 0.0013 \times X_5 - 0.0076 \times X_7$$

where soil available potassium content (X_7) showed significant negative correlation ($r = -0.2921$, $P < 0.05$). However, the regression equation did not pass the significance test at $\alpha = 0.05$, suggesting soil factors had no significant overall effect on WTS.

4.2.4 Comprehensive Factors Random forest regression analysis of seven significant variables revealed the importance order of factors affecting WTS: precipitation during heading-maturation > soil available potassium content > sunshine hours during tillering-elongation > average temperature during heading-maturation > sunshine hours during heading-maturation > diurnal temperature range during elongation-heading > longitude.

Table 4 Importance value of different influencing factors on WTS of cultivated barley

5. Conclusion and Discussion

This study demonstrates that the main climate factors affecting WTS in the Qinghai-Tibet Plateau are precipitation, sunshine hours, and temperature during the heading-maturation period, followed by soil factors (mainly available potassium) and geographic factors (mainly longitude). Under these environmental influences, WTS shows a patchy, staggered distribution pattern horizontally, forming two high-value regions centered in southwestern Tibet (Qushui-Dingri) and northeastern Qinghai (Haiyan-Gangcha). Vertically, WTS exhibits a double-peak pattern at 3600.0–3900.0 m and above 4500.0 m.

These findings align with studies showing that barley WTS is primarily controlled by genetic factors but also significantly affected by environmental conditions. However, they contrast with research from Mediterranean regions and northern Europe that found minimal environmental effects. The significant positive correlations between WTS and precipitation, sunshine hours, temperature during heading-maturation, and diurnal temperature range during elongation-heading are consistent with studies on European barley varieties, though some mechanisms remain unclear and require further investigation.

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Note: Figure translations are in progress. See original paper for figures.