Effects of Agronomic and Climatic Factors on the Spatial Distribution of Starch Content in Cultivated Barley on the Tibetan Plateau (Postprint)

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Abstract

To reveal the degree of influence of different environmental factors on the accumulation of grain starch content (GSC) in cultivated barley on the Tibetan Plateau, improve the relationship between spatial differentiation of barley GSC and environmental factors, and clarify the environmental effects on GSC of barley varieties in different regions of the Tibetan Plateau, this study investigated the distribution characteristics of GSC in cultivated barley on the Tibetan Plateau using data from 83 sample sites encompassing geographic, climate, soil, and agronomic factors. The results showed that: (1) In the horizontal geographic direction, the horizontal distribution of GSC in cultivated barley on the Tibetan Plateau generally exhibited a patchy interlaced distribution pattern and a spatial pattern of higher values in the south and lower values in the north, forming two high-value zones of cultivated barley GSC: one in south-central Tibetan Plateau centered at Lazi, Longzi, Doilungdêqên, Qüxü, Nyêmo, Tingri, Sakya, Dagzê, Dranang, Xigazê, Maizhokunggar, Gonggar, and Qonggyai in Tibet, and another in northeastern Tibetan Plateau centered at Gonghe, Guide, Haiyan, and Tongde in Qinghai; (2) In the vertical geographic direction, the variation in cultivated barley GSC displayed an "S" -shaped distribution pattern, i.e., above altitudes of 3300.0–3600.0 m, GSC gradually increased with increasing altitude, reaching its maximum between altitudes of 4200.0 m and 4500.0 m, after which it slightly decreased with further altitude increase; (3) The order of factors influencing cultivated barley GSC from greatest to least effect was: spike density > June mean diurnal temperature range > awn length > September mean temperature > January mean temperature > annual sunshine hours > 0°C accumulated temperature > May mean temperature > August mean diurnal temperature range > August mean temperature > June mean temperature > 10°C accumulated temperature > June mean monthly precipitation > May mean monthly precipitation > July mean relative humidity > August mean relative humidity > July mean temperature. These findings demonstrate that genotype exerts the greatest influence on cultivated barley GSC, followed by climate factors, while soil factors have insignificant effects on GSC. The primary agronomic factors affecting cultivated barley GSC are spike density and awn length, the main climate factors are diurnal temperature range during the jointing-heading stage and mean temperature during the grain filling-maturity stage, while sunshine and precipitation have relatively minor effects.

Full Text

Preamble

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Effects of Agronomic and Climatic Factors on the Spatial Distribution of Starch Concentration in Barley Cultivated on the Qinghai-Tibet Plateau

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Abstract

Starch concentration is an important quality trait of barley grain. In recent years, researchers have recognized that barley grain starch concentration (GSC) is influenced by both genetic factors and cultivation/environmental conditions. However, the relative effects of different environmental factors on barley GSC remain unclear. Moreover, previous studies have mostly been conducted at limited sites, and large-scale investigations of the relationship between cultivated barley GSC and environmental factors are lacking. The Qinghai-Tibet Plateau represents a crucial region for hull-less barley production in China, yet no systematic studies have reported on the relationship between barley GSC and environmental factors across this region.

This study investigated the spatial distribution of barley GSC across the Qinghai-Tibet Plateau using geographic, climatic, soil, and agronomic data from 83 sampling sites. The objectives were to identify the relative importance of different environmental factors affecting GSC, clarify the relationship between GSC distribution and environmental variables, and characterize the explicit environmental acclimation of barley varieties cultivated in different regions.

The results showed that: (1) GSC exhibited a macro-scale spatial distribution pattern along the horizontal gradient, characterized by staggered patches of varying values with a general trend of higher concentrations in the south and lower concentrations in the north. Two high-GSC regions were identified: the south-central plateau centered around Lazikongkar, Longzi, Duilongdeqing, Qushui, Nimu, Dingri, Sajia, Dazi, Zhanang, Shigatse, Mozhugongka, Gongga, and Qiongjie counties in Tibet; and the northeastern plateau centered around Gonghe, Guide, Haiyan, and Tongde counties in Qinghai Province. (2) Along the vertical gradient, GSC displayed an S-shaped distribution pattern, gradually increasing with altitude from 3300.0–3600.0 m, reaching maximum values between 4200.0 m and 4500.0 m, and then decreasing slightly at higher elevations. (3) The relative importance of environmental factors affecting barley GSC, in descending order, was: spike density > average diurnal temperature range in June > awn length > average temperature in September > average temperature in January > annual sunshine hours > average temperature in May > average diurnal temperature range in August > average temperature in August > average temperature in June > accumulated temperature (10°C) > average precipitation in June > average precipitation in May > average relative humidity in July > average relative humidity in August > average temperature in July. Genotype had the greatest impact on cultivated barley GSC, followed by climatic factors, while soil factors showed no significant effects. Spike density and awn length were the most important agronomic factors, whereas diurnal temperature range during the elongation-heading period and average temperature during the grain-filling and maturation period were the primary climatic factors. The effects of sunshine hours and precipitation were relatively minor. These findings support previous reports that barley GSC is mainly controlled by variety characteristics (i.e., genetic factors), although environmental factors also exert apparent effects.

Keywords: agronomic factor; climatic factor; barley; starch concentration; spatial distribution; Qinghai-Tibet Plateau

1. Study Area Overview

The study area encompassed the primary barley cultivation zones across the Qinghai-Tibet Plateau, spanning five provinces/autonomous regions: Tibet, Qinghai, Sichuan, Gansu, and Yunnan. Geographically, the region extends from 27°–38°N latitude and 79°–104°E longitude, with elevations ranging from 1500.0 m to 4500.0 m. The plateau features distinct vertical vegetation zones, including alpine meadow, montane coniferous forest, montane shrubland, and mountain grassland. Climatically, the region is characterized by an annual precipitation range of 150.0–890.0 mm, mean annual temperatures of -0.6–12.9°C, and annual sunshine hours totaling 3393 h. The specific locations of all sampling sites are illustrated in [Figure 1: see original paper].

2. Sample Collection and Analysis

2.1 Plant Sample Collection and Analysis

Sampling was conducted during the barley maturity period in 2014. A total of 83 representative sites were selected across different ecological cultivation zones based on the plateau's atmospheric temperature and precipitation patterns. Site selection prioritized uniformly growing, contiguous barley fields. At each site, five 20.0 m^2 sampling plots were established, from which 2000 g of barley grains were randomly collected. Prior to sampling, local farmers were consulted to document basic information including cultivated variety and fertilization practices. Conventional field measurements were performed on 20 individual plants per site. Starch content was determined using enzymatic hydrolysis following the national standard method (GB5009.9-85).

2.2 Soil Sample Collection and Analysis

Concurrent with plant sampling, soil samples were collected from the tillage layer (0–30.0 cm) at five random points within each plot. Samples were air-dried and analyzed for total nitrogen (semi-micro Kjeldahl method), organic matter (potassium dichromate oxidation), total and available phosphorus (molybdenum-antimony colorimetry), total and available potassium (atomic absorption spectrophotometry), and pH (potentiometric method).

3. Data Analysis and Processing

Spatial distribution maps of barley GSC were generated using ARCGIS 9.3 software. Statistical analyses were performed using SPSS software, including one-way ANOVA and least significant difference (LSD) tests for inter-group comparisons. Stepwise regression analysis was employed to establish relationships between GSC and geographic, climatic, soil, and agronomic factors. Random forest regression analysis was applied to comprehensively evaluate the relative importance of different factors affecting barley GSC across the plateau. Climatic data were obtained from the China Meteorological Data Service Center.

4. Results and Analysis

4.1 Horizontal Distribution Characteristics of Barley GSC on the Qinghai-Tibet Plateau

The horizontal distribution of barley GSC across the Qinghai-Tibet Plateau exhibited a patchy, mosaic pattern with a general south-high, north-low gradient. Two distinct high-value regions were identified: the south-central plateau region (centered around Lazikongkar, Longzi, Duilongdeqing, Qushui, Nimu, Dingri, Sajia, Dazi, Zhanang, Shigatse, Mozhugongka, Gongga, and Qiongjie counties in Tibet, spanning 29.0°–30.0°N and 87.0°–92.0°E) with an average GSC of (57.9762 ± 2.0447)%; and the northeastern plateau region (centered around Gonghe and Guide counties in Qinghai, spanning 35.0°–36.5°N and 100.0°–101.5°E) with an average GSC of (62.1635 ± 5.6130)%. The spatial distribution pattern is visually presented in [Figure 2: see original paper].

4.2 Vertical Distribution Characteristics of Barley GSC

Along the vertical gradient, barley GSC displayed an S-shaped distribution pattern. At elevations below 2700.0 m, GSC averaged (46.6973 ± 4.2364)% with substantial variation. Between 2700.0–3000.0 m, GSC decreased to (42.3189 ± 10.1330)%. From 3300.0–3600.0 m, GSC began to increase gradually, reaching its maximum value of (50.4275 ± 10.7836)% in the 4200.0–4500.0 m elevation band. Above 4500.0 m, GSC decreased slightly to (50.3392 ± 5.2206)%. The overall mean GSC across all elevations was (48.1675 ± 9.9556)%, with a coefficient of variation of 19.69%. Detailed distribution statistics across altitude gradients are provided in .

4.3 Relationships Between Barley GSC and Geographic Factors

Stepwise regression analysis yielded the following relationship between GSC and geographic factors (latitude X , longitude X , altitude X):

$$GSC = 26.7002 + 0.1311X - 0.1752X + 0.0040X$$

The equation indicates that GSC was positively correlated with longitude and altitude, but negatively correlated with latitude. However, based on standard error testing, this regression model did not achieve significance at the $= 0.05$ level, suggesting that geographic factors alone did not significantly influence barley GSC.

4.4 Relationships Between Barley GSC and Climatic Factors

A stepwise regression model incorporating multiple climatic factors was developed:

$$\begin{aligned} GSC = {} & 68.4096 + 0.0066X + 1.2481X + 12.2109X - 8.0992X + 12.6286X - \\ & 10.3583X - 7.3785X - 3.1067X - 3.0721X + 3.2766X - 0.2635X - 0.374X \\ & + 0.3262X - 0.4007X + 0.3652X - 0.245X - 1.8666X - 0.3538X + 0.293X \\ & + 0.3827X - 0.5219X - 0.3576X - 0.2426X + 0.8191X + 0.1716X - 0.3747X \\ & + 0.3728X + 0.3898X + 0.2890 \end{aligned}$$

Where variables represent various monthly temperature, precipitation, humidity, and sunshine metrics. The primary climatic factors influencing GSC were annual sunshine hours, May diurnal temperature range, June average temperature, August diurnal temperature range, June diurnal temperature range, June precipitation, August precipitation, and May diurnal temperature range. The model achieved significance at $= 0.05$, indicating that climatic factors significantly affected barley GSC. Specifically, GSC showed significant positive correlations with annual sunshine hours, May diurnal temperature range, June average temperature, and June precipitation, while exhibiting significant negative correlations with June diurnal temperature range, August average temperature, and accumulated temperature (10°C).

4.5 Relationships Between Barley GSC and Soil Factors

The stepwise regression model for soil factors was:

$GSC = 55.6769 - 7.1357X - 0.0260X$

Where X represents soil total potassium content and X represents available potassium content. The model indicates that GSC was negatively correlated with both soil potassium fractions. However, this regression equation did not pass significance testing at = 0.05, suggesting that soil factors did not significantly influence barley GSC.

4.6 Relationships Between Barley GSC and Agronomic Factors

The regression model for agronomic factors revealed:

$GSC = 1.7731 + 1.8331X - 3.8122X + 0.1279X + 1.0718X - 0.5077X + 0.1916X$

The primary agronomic factors affecting GSC were spike density and awn length. The model demonstrated that GSC increased with decreasing spike density and decreasing awn length. Partial correlation analysis showed that spike density and awn length were extremely significantly negatively correlated with GSC, while other agronomic traits showed no significant relationships. This regression model passed significance testing at = 0.01, indicating that agronomic factors had highly significant overall effects on barley GSC.

4.7 Comprehensive Analysis of Factor Effects

To determine the relative importance of factors showing significant effects, random forest regression analysis was performed on 27 variables. The results ranked factor importance as follows: spike density > June diurnal temperature range > awn length > July relative humidity > May precipitation > June precipitation > August relative humidity > August diurnal temperature range > annual sunshine hours > January temperature > May temperature > June temperature > August temperature > September temperature > accumulated temperature (0°C) > accumulated temperature (10°C). This analysis confirmed that spike density and awn length were the dominant agronomic factors, while diurnal temperature range during critical growth periods and temperature during grain filling were the primary climatic determinants of GSC variation across the plateau.

5. Conclusions and Discussion

The horizontal distribution of barley GSC on the Qinghai-Tibet Plateau exhibited a mosaic pattern with higher values in the south and lower values in the north, forming two major high-concentration centers in the south-central and northeastern regions. Vertically, GSC followed an S-shaped curve, peaking at elevations of 4200.0–4500.0 m after gradually increasing from 3300.0–3600.0 m, then declining slightly at higher altitudes. The comprehensive analysis revealed that the relative importance of factors affecting GSC, in descending order, was: spike density > June diurnal temperature range > awn length > July relative humidity > May precipitation > June precipitation > August relative humidity > August diurnal temperature range > annual sunshine hours > January temperature > May temperature > June temperature > August temperature > September temperature > accumulated temperature (0°C) > accumulated temperature (10°C).

Genotype emerged as the most influential factor, followed by climatic factors, while soil factors showed negligible effects. The key agronomic determinants were spike density and awn length, whereas the primary climatic influences were diurnal temperature range during the jointing-heading stage and average temperature during the grain-filling and maturation stage. Sunshine and precipitation effects were comparatively minor. These results align with previous findings that barley GSC is predominantly controlled by genetic factors, though environmental conditions also exert significant influence.

The study further revealed that GSC was significantly positively correlated with annual sunshine hours, May diurnal temperature range, June average temperature, and June precipitation, while showing significant negative correlations with June diurnal temperature range, August average temperature, and accumulated temperature (10°C). The correlation with soil nitrogen content was not significant. These findings are consistent with international studies demonstrating that elevated temperatures during grain filling reduce starch content, and that temperature stress during flowering affects both yield and quality parameters. The observed relationships support the conclusion that while barley starch content is primarily under genetic control, environmental factors—particularly temperature regimes during critical developmental stages—play a substantial modulating role.

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