Postprint of Ecological Zoning of Fiber Quality in Northwest Inland Cotton Region Based on GGE Analysis

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Abstract

This study selected 7 trial sites in the early-maturing cotton region and 10 trial sites in the early-to-medium-maturing cotton region of the Northwest Inland Cotton Area in China' s cotton regional trials from 2005 to 2014 as experimental environments for fiber quality regional distribution analysis. The GGE model was employed to generate biplots, investigating the interaction patterns between experimental environments and tested varieties for fiber quality traits in the Northwest Inland cotton region, discussing and delineating suitable ecological zones for trait selection of tested varieties, and examining correlations among fiber physical performance indicators based on GGE biplots, thereby providing a basis for regionalized cotton variety planting and ideal experimental environment selection in the Northwest Inland cotton region. The results indicated that: (1) Certain correlations existed among various cotton fiber quality traits, with spinning consistency index exhibiting extremely significant or significant positive correlations with length, strength, and uniformity index. (2) Fiber quality traits in the early-maturing group of the Northwest Inland cotton region could be divided into three ecological zones: premium cotton fiber ecological zone (Jinghe), ordinary premium fiber ecological zone (Xinjiang Production and Construction Corps Division 6 Changji, Wusu), and ordinary fiber ecological zone (Xinjiang Production and Construction Corps Division 7 125th Regiment, Xinjiang Production and Construction Corps Division 8 121st Regiment, Shihezi, and Dunhuang). (3) Quality traits in the early-to-medium-maturing group of the Northwest Inland cotton region could also be divided into three ecological zones from premium to ordinary: premium fiber ecological zone (Shache, Luntai, Bazhou, Kuqa, Shufu, Xinjiang Production and Construction Corps Division 1 Alar 13th Regiment, and Xinjiang Tahe 10th Regiment), ordinary premium fiber ecological zone (Mai gai ti and Xinjiang Production and Construction Corps Division 3 Kashgar), and ordinary fiber ecological zone (Aksu). Therefore, the early-maturing cotton region of Northwest Inland should emphasize the breeding of comprehensive premium fiber quality traits alongside early maturity, improving fiber length and strength. For the early-to-medium-maturing cotton region in southern Xinjiang, while focusing on selecting cotton varieties with suitable length and strength for machine harvesting, it is essential to precisely determine reasonable cotton harvesting periods to improve fiber maturity, but attention must be paid to reducing micronaire values, and optimizing planting regions to provide multi-level raw cotton materials for rational cotton utilization by textile enterprises.

Full Text

Preamble

Ecological Regionalization of Cotton Fiber Quality in the Northwest Inland Region Using GGE Analysis

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Abstract

This study analyzed the distribution characteristics of cotton fiber quality using data from 7 early-maturing and 10 early-medium maturing cotton trial sites in the Northwest Inland region of China during 2005–2014. The GGE model was employed to generate biplots for investigating genotype-by-environment interaction patterns for fiber quality traits, exploring suitable ecological zones for cultivar selection, and examining correlations among fiber physical properties. The results provide a basis for regionalized cotton variety cultivation and ideal test environment selection in the Northwest Inland region. Key findings include: (1) Significant correlations existed among fiber quality traits, with spinning consistency index showing highly significant or significant positive correlations with fiber length, strength, and uniformity index. (2) The early-maturing cotton region was divided into three ecological zones: a premium fiber quality zone (Jinghe), a common high-quality fiber zone (Sixth Agricultural Division of Xinjiang Production and Construction Corps in Changji, Usu), and a standard fiber zone (125th Regiment of Seventh Division, 121st Regiment of Eighth Division, Shihezi, and Dunhuang). (3) The early-medium maturing region was similarly divided into three zones: a premium fiber zone (Shache, Luntai, Bazhou, Kuqa, Shufu, 13th Regiment of First Division in Alar, and 10th Regiment of Tahe), a common high-quality zone (Maigaiti and Third Division Kashi), and a standard fiber zone (Aksu). Therefore, breeding efforts in the early-maturing region should prioritize comprehensive fiber quality improvement, particularly fiber length and strength. In the southern Xinjiang early-medium maturing region, cultivar selection should focus on length and strength suitable for mechanical harvesting, while optimizing harvest timing to improve fiber maturity and reduce micronaire values. This regionalization provides multi-level raw cotton materials to meet diverse textile industry requirements.

Keywords: Cotton (Gossypium hirsutum L.); Fiber quality; GGE biplot; Ecological regional division

Introduction

The Northwest Inland cotton region, dominated by Xinjiang, represents China' s largest cotton production area. Located west of the Liupan Mountains (north of 35°N and west of 105°E), it encompasses Xinjiang, the Hexi Corridor in Gansu, and areas along the Yellow River irrigation districts. The region offers distinct climatic advantages for cotton production, including dry conditions, abundant sunlight, strong solar radiation, extended sunshine hours, and large diurnal temperature variations—conditions superior to those in the Yellow River and Yangtze River cotton regions that facilitate stable cotton growth and boll opening with high economic yield coefficients. However, poor soil fertility and water scarcity constrain production development. The region is suitable for early-maturing, early-medium maturing upland cotton, and sea-island cotton cultivation. Xinjiang' s cotton production demonstrates outstanding scale advantages, making it an ideal cotton production base.

China' s cotton production has gradually shifted from southern and eastern regions to the northwest, with Xinjiang' s cotton yield ranking highest nationally. In terms of comprehensive fiber quality, Xinjiang cotton surpasses both other domestic regions and the national average. Nevertheless, modern textile technology demands increasingly higher fiber quality standards. Many textile enterprises have recently increased imports of Australian and American cotton due to considerations of raw cotton quality and cost, making quality improvement and efficiency enhancement critical objectives for Xinjiang cotton production.

While numerous cotton varieties have been approved in China in recent years, few achieve balanced excellence in length, strength, and fineness. In Xinjiang, climate conditions particularly limit fiber strength, representing the main factor restricting fiber quality grade improvement. This makes appropriate ecological zone division essential for cultivar adaptation. Historical regionalization efforts include Feng Zefang' s initial three-zone classification (Yellow River, Yangtze River, and South China cotton regions), later expanded to five zones in the 1950s (adding the northern extra-early maturing and Northwest Inland regions). Subsequent research has further subdivided Xinjiang into medium-maturing, early-medium maturing, early-maturing, and extra-early maturing sub-regions, while the Yellow River region has been divided into three fiber quality ecological sub-regions, and the Yangtze River region into "medium quality," "high length and strength," and "low micronaire" ecological zones.

Xu Naiyin utilized the "which-won-where" function of GGE biplots to cluster test locations with common best-performing varieties into single mega-environments, enabling targeted variety selection to improve breeding efficiency. Researchers including Yu Shirong, Wang Lei, and Crossa have conducted similarity-based cluster analyses of test environments. Ebdon, Yan, and Bradu developed the GGE (genotype main effect plus genotype-by-environment interaction) model integrated with biplot technology, resulting in the GGE Biplot Explorer software. This approach provides intuitive visualization and simple operation for analyzing principal component analysis (PCA) or singular value decomposition (SVD) results, making it ideal for variety trial analysis. The method has been successfully applied to crops including sugarcane, rapeseed, soybean, and wheat. Xu Naiyin et al. previously investigated ecological adaptability distribution of cotton varieties in the Yangtze River region using GGE models.

This study analyzed 17 test locations (7 early-maturing and 10 early-medium maturing) from national cotton regional trials in the Northwest Inland region during 2005-2014. Using the "environment-trait" function of GGE biplots, we divided the target region into relatively homogeneous variety ecological zones to improve selection accuracy for fiber quality traits and test environment evaluation. This regionalization provides theoretical support for cotton breeding target formulation, variety registration, regionalized cultivation, and rational cotton allocation for textile enterprises.

1.1 Experimental Design

Data were obtained from national cotton regional trials conducted in the Northwest Inland region from 2005 to 2014, including both early-maturing and early-medium maturing cotton groups. The early-maturing cotton trials were conducted at seven locations: Usu, Shihezi Academy of Agricultural Sciences, Jinghe, 121st Regiment of Eighth Division, 125th Regiment of Seventh Division, Sixth Division Changji in Xinjiang Production and Construction Corps, and Dunhuang in Gansu. The early-medium maturing trials were conducted at ten locations: Maigaiti, Shufu, Shache, Kuqa, 13th Regiment of First Division in Alar, Third Division Kashi, Luntai, Bazhou, 10th Regiment of Tahe in Alar, and Aksu. All trials employed randomized complete block designs with three replications and 20 m^2 plot sizes, with plant spacing varying according to target density. Field management followed local high-yield cultivation practices.

1.2 Measurements and Methods

At peak boll opening stage, 50 normally opened bolls from the middle fruiting branches were collected from each plot in all test locations. After sun-drying and ginning, the lint was used as fiber quality test samples. The Cotton Quality Supervision, Inspection and Testing Center of the Ministry of Agriculture conducted measurements using USTER HVI (High Volume Instrument) series equipment. Samples were conditioned for 48 hours at constant temperature and humidity [(20±2)°C, (65±3)% relative humidity] before testing. Eight fiber quality parameters were measured: upper half mean length, strength, micronaire, elongation, reflectance, yellowness, uniformity index, and spinning consistency index. Each sample was measured three times following GB/T 20392-2006 "Standard test methods for cotton fiber physical properties using HVI." Quality evaluation followed GB 1103.1-2012 "Cotton—Part 1: Saw ginned upland cotton" and GB 1103.2-2012 "Cotton—Part 2: Roller ginned upland cotton."

1.3.1 GGE Model Analysis

Fiber quality data from 17 test locations in the Northwest Inland region during 2005-2014 were analyzed using GGE Biplot software. Raw data were read into the program, and biplots were generated based on data centering and scaling methods. Principal component analysis was performed with test environment centering to create GGE biplots. The relationships among test environments were expressed through distances between environment markers and vector angles, while the relative positions of fiber quality traits and test environment markers revealed trait-environment interaction patterns. The spatial relationships between fiber quality indices and test environments in the coordinate system were used to evaluate quality performance across environments, delineate ecological zones, and assess correlations among quality traits. Vector angles between fiber quality traits indicated correlation strength: smaller angles represented stronger correlations, acute angles indicated positive correlations, obtuse angles indicated negative correlations, and right angles indicated no correlation. The cosine of the angle between two trait vectors equals their correlation coefficient. Xu et al. demonstrated that fiber quality phenotypic values in the Yangtze River region are controlled by genetic factors, environmental factors, and their interactions. The projection length of a test environment vector onto a quality trait vector indicated the phenotypic value magnitude for that trait in the corresponding environment, with longer projections representing higher values.

1.3.2 Geographic Factors of 17 Test Environments

The 2005-2014 national cotton regional trials in the Northwest Inland region primarily covered Xinjiang Uygur Autonomous Region and the Hexi Corridor in Gansu. The early-maturing cotton zone, located in northern Xinjiang and Gansu, comprised seven test locations, while the early-medium maturing zone in southern Xinjiang comprised ten locations. Geographic factors including location names, codes, longitude, latitude, and altitude are detailed in Table 1 .

2.1.1 Ecological Regionalization of Early-Maturing Cotton Fiber Quality

Based on comprehensive fiber quality performance of major indices across seven test environments from 2005–2014, GGE biplot "environment-trait" analysis was conducted to examine environmental effects on fiber quality and their interactions. As shown in Figure 1 [Figure 1: see original paper] and Table 2 , small vector angles indicated significant positive correlations between fiber length and uniformity index, breaking strength, micronaire, and spinning consistency index, while a negative correlation was observed with yellowness. Micronaire showed positive correlations with fiber length, uniformity, and strength, but negative correlation with yellowness. Fiber strength exhibited positive correlations with spinning consistency index, uniformity index, length, and reflectance, but negative correlation with yellowness. Spinning consistency index showed positive correlations with fiber length, strength, uniformity index, micronaire, and reflectance, but negative correlation with yellowness. The extremely small angle between spinning consistency index and fiber strength vectors, nearly overlapping, indicated a highly significant positive correlation, demonstrating that fiber strength contributes substantially to spinning performance. Therefore, improving fiber breaking strength is essential for enhancing spinning capacity in the early-maturing cotton region of Northwest Inland.

The spatial relationships among ecological zones in the early-maturing cotton region (Figure 1) revealed that Zone I was located opposite the micronaire vector direction, representing a low micronaire area. Zone II was positioned at the average location of all fiber quality vectors, indicating average comprehensive quality performance. Zone III aligned with the micronaire vector direction, representing a high micronaire region.

2.1.2 Cluster Analysis of Early-Maturing Cotton Test Environments

Based on test environment codes from the early-maturing cotton region (Table 1), GGE biplot analysis (Figure 1) and principal component-based clustering (Figure 2 [Figure 2: see original paper]) divided the seven test environments into three distinct fiber quality ecological zones. Zone I comprised Sixth Division Changji and Usu; Zone II contained only Jinghe; and Zone III included four locations: 121st Regiment of Eighth Division, 125th Regiment of Seventh Division, Shihezi, and Dunhuang. Cluster analysis of the first two principal component scores from the "environment-trait" GGE biplot was followed by

ANOVA to detect significant differences among zones and compare trait performance levels. Projection lengths of test locations onto trait vectors indicated performance levels, with longer projections representing higher values. Additionally, closer proximity between locations and trait vectors indicated better performance.

The spatial relationships further revealed that Zone I, located opposite the micronaire vector, was a low micronaire area. Zone II, positioned at the average of fiber quality vectors, showed average comprehensive quality, with small acute angles between spinning consistency index and strength, uniformity, and micronaire vectors, indicating superior performance in these traits and classification as an excellent fiber quality zone. Zone III exhibited greater perpendicular distances to quality trait vectors than other zones and aligned with the micronaire vector direction, representing a high micronaire region.

2.1.3 Characteristics of Early-Maturing Cotton Fiber Quality Zones

Mean values and significance tests for fiber quality indices across ecological zones are presented in Table 3 . No significant differences were observed among zones for strength, micronaire, elongation, or reflectance. Zone I showed higher strength than Zone III (non-significant) but significantly lower uniformity index than Zone II, indicating poor fiber uniformity. Zone II exhibited the highest strength and reflectance (non-significant), with significantly higher uniformity index and spinning consistency index than other zones. Fiber length was highest in Zone II, significantly different from Zone I but not from Zone III. Zone III showed intermediate performance for most traits.

The early-maturing cotton region was thus classified from premium to standard quality as follows: Zone II (Jinghe area) as the premium fiber ecological zone, with fiber length >30 mm, strength >31 cN · tex ^{1}, uniformity index >86%, micronaire at Grade A, and spinning consistency index >160, suitable for spinning 60 count yarn. Zone I (Sixth Division Changji and Usu) as the common high-quality zone, with length and strength >30, uniformity >84%, micronaire at Grade A, and spinning consistency index >150, suitable for 50 count yarn, requiring comprehensive trait improvement. Zone III (Dunhuang, 125th Regiment of Seventh Division, 121st Regiment of Eighth Division, and Shihezi) as the standard fiber zone, with length and strength 30, uniformity >85%, micronaire at Grade B, reflectance <80%, and spinning consistency index >150, classified as a common high micronaire zone where harvest timing should be optimized to avoid over-maturity and reduce micronaire while maintaining color grade.

2.2.1 Ecological Regionalization of Early-Medium Maturing Cotton Fiber Quality

Based on comprehensive performance of major fiber quality indices across ten test environments from 2005–2014, GGE biplot analysis examined environmental effects and interactions. Figure 3 [Figure 3: see original paper] and Table 4 show that spinning consistency index vectors had very small angles with fiber strength and length vectors, indicating highly significant positive correlations, and smaller angles with uniformity index, showing significant positive correlation. Large angles with micronaire and elongation indicated negative correlations. As a comprehensive fiber quality indicator, spinning consistency index depends primarily on fiber length, uniformity, and strength. The negative correlation with micronaire suggests that both immature and over-mature fibers adversely affect spinning performance. Micronaire showed a significant positive correlation with breaking elongation (very small angle) and negative correlations with strength, reflectance, and yellowness (large angles).

2.2.2 Cluster Analysis of Early-Medium Maturing Cotton Test Environments

Based on test environment codes (Table 1), GGE biplot analysis (Figure 3) and principal component clustering (Figure 4 [Figure 4: see original paper]) divided the ten test environments into three distinct fiber quality ecological zones. Zone I contained only Aksu; Zone II comprised Maigaiti and Third Division Kashi; and Zone III included seven locations: Shache, Shihezi University South Xinjiang Experiment Station (Luntai), Bazhou, Kuqa, Shufu, 13th Regiment of First Division in Alar, and 10th Regiment of Tahe, representing the main early-medium maturing cotton production area.

Spatial relationships revealed that Zone I was opposite to fiber length, strength, uniformity, and spinning consistency index vectors, indicating relatively poor comprehensive quality. Zone II aligned with the micronaire vector direction, representing a high micronaire area with other traits at average levels. Zone III aligned with fiber length, strength, uniformity, and spinning consistency index vectors, showing the best comprehensive quality. The longest projection onto the strength vector indicated highest strength values, with acute angles to length, uniformity, and spinning consistency index vectors demonstrating superior performance in these traits, and an obtuse angle to micronaire indicating lower values. Thus, Zone III represents the optimal fiber quality ecological zone, encompassing the broadest area and indicating good overall fiber quality in the Northwest Inland early-medium maturing cotton region.

The classification from premium to standard quality was: Zone III (Shache, Luntai, Bazhou, Kuqa, Shufu, 13th Regiment of First Division in Alar, 10th Regiment of Tahe) > Zone II (Maigaiti, Third Division Kashi) > Zone I (Aksu). Zone III, the premium fiber ecological zone, achieved the “double 30” standard with length >30.0 mm and strength >30.0 cN · tex [1], uniformity index >85.0%, micronaire at Grade B, and spinning consistency index >150, suitable for 50 count yarn. Zone II, the common high-quality zone, had length and strength slightly below 30 mm, uniformity >85%, micronaire at medium Grade B (relatively high), and spinning consistency index >140, suitable for 40 count medium yarn. Zone I, the standard fiber zone, showed lower comprehensive quality requiring improvement, particularly in length and strength.

2.2.3 Characteristics of Early-Medium Maturing Cotton Fiber Quality Zones

Mean values and significance tests for fiber quality indices are shown in Table 5 . Significant differences existed among zones for most traits. Zone I showed lower length, strength, uniformity index, and spinning consistency index than other zones, with significantly lower uniformity and spinning consistency and significantly higher yellowness, indicating poor comprehensive quality. Zone II exhibited intermediate values, with significantly higher uniformity and spinning consistency than Zone I and significantly higher micronaire than Zone III, representing medium fiber quality levels. Zone III showed the highest length, strength, uniformity, and spinning consistency, significantly higher than Zone I for length, uniformity, and spinning consistency, and significantly lower micronaire than Zone II, confirming it as the optimal fiber quality production zone.

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3 Discussion and Conclusion

China' s Northwest Inland cotton region encompasses vast areas with diverse ecological conditions. Scientific regionalization helps leverage environmental advantages to promote fiber production and utilization. Establishing superior production zones based on fiber quality performance and geographic distribution characteristics provides guiding significance for the industry. Southern Xinjiang primarily cultivates early-medium maturing types, while northern Xinjiang focuses on early-maturing types. Over the past decade, the early-maturing cotton area has expanded rapidly, particularly in northern Xinjiang due to global warming, with improved fiber quality achieved through water-saving irrigation, optimized fertilization, and advanced cultivation techniques.

This study demonstrates that fiber quality traits are interdependent, with spinning consistency index showing highly significant or significant positive correlations with length, strength, and uniformity index, consistent with Yu Yu' s findings. Therefore, cotton variety registration should evaluate not only fiber length, strength, and micronaire, but also consider uniformity index as a crucial quality determinant. We recommend including both uniformity index and spinning consistency index as reference criteria in variety registration processes.

Genotype-by-environment interaction in cotton variety trials is influenced by multiple factors including soil type, altitude, climate, and cultivation practices, causing substantial variation across years and locations. Cotton fiber quality indices correlate well with climatic factors (temperature, sunlight, precipitation, humidity). The Northwest Inland region, with abundant sunshine, low precipitation, and low relative humidity, represents an optimal area for premium cotton production, leading domestic quality rankings in fiber length, micronaire, and grade. However, varieties meeting the premium standard of >31.0 mm length, >32.0 cN · tex^{1} strength, and 3.7–4.2 micronaire for spinning 60 count yarn remain lacking.

Current variety registration standards in China evaluate cultivars based on average performance across target environments, representing a broad-adaptation selection approach. The Northwest Inland regional trial system is generally reasonable but requires adjustments to test location distribution and evaluation criteria, particularly adding more early-maturing trial sites to enhance effectiveness and scientific rigor of regionalization for more targeted variety selection, registration, and extension. Bilgin et al. applied GGE biplot "which-won-where" analysis to explore genotype-by-environment interaction patterns for yield-based selection. This study utilized the same approach based on fiber length, strength, micronaire, and spinning consistency index to delineate variety ecological zones, analyzing test environments located in the same optimal sector across multiple trials to establish quality-trait-based ecological regionalization. This regionalization provides decision support for breeding broad-adaptation and specifically-adapted cotton varieties and offers theoretical guidance for selecting ideal variety test environments.

In the northern Xinjiang region, the Jinghe area, with abundant sunshine, minimal precipitation, and low relative humidity, represents the optimal premium cotton production zone, characterized by excellent fiber maturity, fully developed length, optimal micronaire values, and good color grade to meet high-count yarn requirements. In the early-maturing cotton region, Sixth Division Changji and Usu are located in the optimal micronaire zone with good comprehensive quality. Dunhuang, 125th Regiment of Seventh Division, 121st Regiment of Eighth Division, and Shihezi should focus on reducing micronaire, improving length and strength—particularly strength, which tends to be lower in Xinjiang due to climatic conditions compared to other regions. Therefore, introducing and breeding varieties for the early-maturing region should emphasize comprehensive fiber quality improvement alongside early maturity, with particular attention to enhancing fiber strength.

The early-medium maturing region in southern Xinjiang was divided into three quality ecological zones: Zone III (Shache, Shihezi University South Xinjiang Experiment Station in Luntai, Bazhou, Kuqa, Shufu, 13th Regiment of First Division in Alar, 10th Regiment of Tahe), Zone II (Maigaiti, Third Division Kashi), and Zone I (Aksu). Based on this analysis, we recommend that the early-medium maturing region in southern Xinjiang should select varieties with appropriate length and strength for mechanical harvesting, precisely optimize harvest timing to improve fiber maturity while reducing micronaire, and establish optimized planting zones to provide multi-level raw cotton materials for textile enterprises. The early-maturing region should strengthen strength selection to meet higher requirements for modern mechanical harvesting technology, optimize planting layouts of existing varieties based on fiber quality ecological regionalization, and focus on breeding new varieties with superior comprehensive quality traits.

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