CLIMATE QUALITY EVALUATION AND FINE ZONING OF GUANGXI SPECIALIZED FORAGE RICE "ZHONGZAO 39"
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广西专用饲料稻“中早 39”气候品质评价与精细化区划

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DOI: https://doi.org/10.35633/inmateh-73-43

Keywords: *Rice; Specialized Forage Rice; Climate Quality; Zoning*

ABSTRACT
Using the staged sowing experiment data and rice quality data of the specialized forage rice "Zhongzao 39"(hereinafter referred to as "Z-39") conducted in Nanning, Guangxi, combined with climate and geographic information data, the meteorological factors that play a key role in the formation of rice quality for the specialized forage rice "Z-39" are screened and determined. Based on the actual planting of specialize forage rice in Guangxi and the critical disaster causing indicators of "Z-39" specialize forage rice, the climate quality zoning index of "Z-39" is determined. GIS fine grid spatial simulation analysis method is used for refined spatial simulation analysis on key meteorological factors. The zoning indicator method and path analysis method are fully used for refined level zoning of the climate quality of Guangxi specialized forage rice "Z-39". It includes three levels: optimal, high-quality, and suboptimal. Ultimately, a refined zoning map for the climate quality of "Z-39" is developed, and the results are in line with the actual situation of forage rice cultivation in Guangxi. The aim is to provide a scientific basis for the rational planning and sustainable development of the specialized forage rice "Z-39" in Guangxi.

摘要
利用在广西南宁开展的专用饲料稻“中早 39”分期播种试验数据以及稻米品质数据，结合气候资料和地理信息数据，筛选确定对专用饲料稻“中早 39”稻米品质形成起关键作用的气象因子，结合广西专用饲料稻实际种植情况以及专用饲料稻“中早 39”致灾临界指标等，确定“中早 39”气候品质区划等级指标，并利用 GIS 细网格空间模拟分析方法对关键气象因子进行精细化空间模拟分析，综合利用区划指标及通径分析法，对广西专用饲料稻“中早 39”气候品质进行最优、优质和次优三个等级的精细化等级区划，研制出广西专用饲料稻“中早 39”稻米气候品质精细化区划图，分区结果符合广西饲料稻种植实际情况，以期为专用饲料稻“中早 39”在广西种植提供合理规划布局和可持续发展提供科学依据。

INTRODUCTION
Rice is the main grain crop in China. With the improvement of living standards, the pursuit of rice quality is also increasing. The quality of rice is a comprehensive trait, and its quality is not only influenced by its own genetic characteristics, but also meteorological conditions (*Sreenivasulu et al., 2022; Zahra et al., 2022*). During the growth and development period of rice, there are sensitive periods for multiple meteorological factors, during which changes in meteorological conditions can have varying degrees of impact on the quality of rice (*Mousa et al., 2024*). Specialized forage rice is a type of rice specially made into forage for animals (*Jang et al., 2024*). According to the different parts of use, forage rice can be divided into two categories: one is rice used to forage single stomach animals such as pigs and chickens, with the breeding goal centered on yield and nutrient content.

Another type is whole plant forage for herbivorous livestock, which is different from general rice breeding in that it targets the biological yield and nutrient content of the whole plant.

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With the continuous diversification of food types, the per capita consumption of rice is gradually decreasing, creating objective conditions and market demand for the development of forage rice. It is an inevitable trend for the future development of rice to appropriately reduce planting area for people's consumption according to demand, and then diversify the development of rice, and expand more on rice foraging. "Zhongzao 39" (hereinafter referred to as "Z-39") is a high-yielding, multi resistant, and medium maturing early indica rice variety. It is widely planted as early rice in double cropping rice regions such as Guangxi, Jiangxi, Hunan, and Anhui. The variety has a wide range of adaptability, high yield, excellent rice quality, and good resistance (*Han, 2012*). In recent years, "Z-39" has also been widely planted in Guangxi.

There are many reports on the relationship between rice quality and meteorological conditions around the world. Japan, South Korea, the United States and other countries have cultivated specialized forage rice varieties suitable for their own national conditions through advanced agricultural technology (Jang et al., 2022; Ma et al., 2024). However, due to various reasons, research on specialized forage rice in China has stagnated and fallen behind, and there is still no complete system of specialized forage rice varieties. Moreover, most studies are limited to the impact and related analysis of meteorological factors on the quality of edible rice or other agricultural products (*Cheng et al., 2022; Wakatsuki et al., 2024; Dong et al., 2024; Zhao et al., 2023a; Chen et al., 2024*), and there is still a gap in the study of the relationship between the quality of specialized forage rice and meteorological factors, as well as the formulation of meteorological indicators for rice quality. Therefore, based on the entire growth period of rice, taking the specialized forage rice "Z-39" as the test variety, the key meteorological factors that affect the quality of forage rice are analyzed to determine the climate quality evaluation technical indicators of "Z-39", and establish a climate quality evaluation model. Based on the climate indicators of rice quality, the rice planting areas in Guangxi are divided, aiming to provide a scientific basis for high-quality rice breeding and cultivation.

MATERIAL AND METHODS

Test location and materials

Guangxi is located in the low-latitude region of southern China, with a warm climate, abundant heat, abundant rainfall, rainy and hot seasons, abundant sunshine, and favorable climate resources for the development of rice. Guangxi has a long history of planting rice and is one of the main double cropping rice areas in China. Over the years, the planting area and yield of rice have ranked first among grain crops.

The experiment was conducted from March to August 2019 at the Agricultural College Farm of Guangxi University (N22 ° 48 ′, E108 ° 22 ′). The tested variety is the early indica forage rice "Z-39", with a total growth period of 114 days and a thousand grain weight of 28 g. This variety has excellent rice quality, good resistance, and all rice quality indicators have reached the 5th grade of the Ministry of Quality for Edible Rice Varieties (*Wu et al., 2015*).

Data source

The daily meteorological data was from 89 meteorological stations in Guangxi Zhuang Autonomous Region from 1960 to 2020, including average temperature, maximum temperature, minimum temperature, solar radiation, and rainfall. The data was sourced from the Guangxi Zhuang Autonomous Region Meteorological Information Center. The geographic information data also came from the Meteorological Information Center of Guangxi Zhuang Autonomous Region, mainly including 1:250000 Guangxi administrative boundaries and administrative points. The Guangxi Digital Elevation Model (DEM) data was sourced from geospatial data clouds, mainly including longitude, latitude, altitude, slope, and aspect, with a resolution of 100 × 100 m.

Experimental design

The staged sowing experiment was divided into 7 sowing periods, with an interval of 15 days between each sowing period. A random block arrangement design was used, with a small area of 12.5 m^2 (length 5.2 m x width 2.4 m), repeated three times. No walkway was left between the small communities, and a 60 cm wide walkway was left between the repetitions. The conventional method of seedling cultivation involved manual transplanting around the 4-leaf stage, with a row spacing of 30 cm x 13 cm and 3 seedlings per hole. 5 rows were transplanted in each plot, with 40 holes in each row and 600 seedlings in each split plot, moderate fertilization level. Other field management were carried out according to local high-yield practices.

Measurement projects and research methods

(1) Determination of growth period and rice quality

The main growth periods of the three test points were recorded, including sowing period, emergence period, transplanting period, full heading period, maturity period and full growth period. Heading period refers to the date when 50% of the plants in the region head out, and maturity period refers to the physiological maturity date when 95% of the rice in the region turns yellow. 3 kg rice samples were randomly selected from each rice plot for determination and analysis of rice quality indexes. The quality indicators of rice mainly include brown rice percentage (%), milled rice percentage (%), full milled rice percentage (%), chalky grain percentage, chalkiness degree, amylose content (%), alkali digestibility value, gel consistency, protein content (%), and hydrolyzed amino acids (*Zhao et al., 2022*). They are measured according to the method of GB/T 15683-2008 High Quality Rice.

(2) A Fine Grid Spatial Simulation Analysis Method based on GIS Technology

Using GIS technology and climate resource fine grid spatial simulation analysis method, based on the climate quality zoning indicators of the specialized forage rice "Zhongzao39", a spatial analysis model for the climate quality of Guangxi specialized forage rice "Zhongzao39" is established by comprehensively considering the effects of five factors: longitude, latitude, altitude, slope, and aspect. The inverse distance weight interpolation method is used to simulate and analyze the influencing factors in the indicators using a 100×100 m fine grid. Residual correction analysis is carried out to analyze the spatial refinement distribution of climate quality of Guangxi forage rice "Zhongzao39". The expression for the relationship between climate quality zoning indicators and geographical elements is as follows:

$$Y = f(\emptyset, \lambda, h, s, a) + \varepsilon \quad (1)$$

where:

Y represents the climatic quality zoning indicators of the specialized forage rice "Z-39"; φ, λ, h, s, and a respectively represent geographic elements such as latitude, longitude, altitude, slope, and aspect; ε is the residual term, called the comprehensive geographic residual.

(3) Path analysis method

There are two common methods for establishing indicator weights: subjective weighting and objective weighting (*Włodarczyk et al., 2023*). Subjective weighting methods can be divided into expert scoring, expert ranking, Analytic Hierarchy Process (AHP), Rank Sum Ratio (RSR), and more. Objective weighting methods include factor analysis, component analysis, and more (*Zhao et al., 2023b*). The method of path analysis is used to allocate the weights of meteorological factors in climate quality indicators. Path analysis is a method of connecting the correlation coefficient with the direct and indirect effects of two variables based on a linear regression equation. The path analysis theory shows that the simple correlation coefficient (r_{ny}) between any independent variable X_n and the dependent variable Y is the sum of the direct path coefficients (P_{ny}) of X_n and Y and the indirect path coefficients (P_{nj}) of all X_n and Y, that is, the total effect of X_n on Y. In the case where multiple independent variables interact to affect a dependent variable, each independent variable has a different degree of influence on the dependent variable. There are also cases where one independent variable affects the dependent variable through other independent variables. In path analysis, the calculation of path coefficient is difficult, but after linear regression calculation through software, the standard coefficient of the equation is the calculated path coefficient.

The simple correlation coefficient is the sum of the indirect path coefficient and the direct path coefficient, which is the result obtained during correlation analysis.

Related formulas are as follows:

The direct path coefficient P_{ny} of X_n and Y = standard coefficient

The indirect path coefficient of X_n and Y=correlation coefficient (r_{ny}) x direct path coefficient (P_{ny})

The decision coefficient $R2(n)=2\times P_{nY}\times r_{ny}-(P_{ny})^2$

P_{ny} is the direct path coefficient between the independent variable n and the dependent variable Y; R_{nj} is the correlation coefficient between the independent variable n and the independent variable j; R_{ny} is the correlation coefficient between the independent variable n and the corresponding variable Y.

RESULTS AND ANALYSIS

Screening and determination of major meteorological influencing factors

Forage rice has different requirements or breeding objectives based on its utilization location and purpose. For the rice used for forage, high rice yield (> 8250 kg/hm^2), high crude protein content (≥ 12%), and high roughening rate (≥ 80%) are required (*Zhang et al., 2008*). In this study, protein content and brown rice rate are used to represent the quality of forage rice.

Based on the field stage sowing experiment data, rice quality data, and meteorological data, the correlation between the quality indicators (protein content and brown rice rate) of forage rice "Z-39" and meteorological factors during each growth period is analyzed (as shown in Tables 1 and 2).

Table 1 shows that the protein content of forage rice "Z-39" is significantly correlated with the average temperature throughout the full growth period and the lowest temperature from sowing to transplanting. It is significantly correlated with the highest temperature, average temperature, daily solar radiation, and rainfall from transplanting to full heading period. It is significantly correlated with the highest temperature, lowest temperature, average temperature, daily solar radiation, and rainfall from sowing to full heading period. There is no significant correlation with the meteorological factors studied from full heading to maturity period and from transplanting to maturity period.

Table 1

Correlation between Protein Content of Specialized Forage Rice "Z-39" and Meteorological Factors at Different Growth Stages

Growth stage	Highest tempera-ture	Lowest tempera-ture	Average tempe-rature	Diurnal variation of temperature	Daily average solar radiation	Humidity	Rain-fall
Full growth period	0.456	0.474	0.483*	0.100	0.477	-0.266	-0.349
Sowing and transplanting period	0.418	0.557*	0.467	0.400	0.362	0.299	0.005
Transplanting and full heading period	0.782**	0.477	0.596**	0.444	0.569*	-0.467	-0.619**
Full heading and maturity period	0.334	-0.221	-0.363	-0.277	-0.228	-0.27	-0.022
Sowing and full heading period	0.514*	0.702**	0.519*	0.094	0.571*	-0.233	-0.523*
Transplanting and Maturity period	0.434	0.439	0.440	0.190	0.414	-0.291	-0.406

*Note: * indicates significant correlation at the 0.05 level (bilateral);** indicates significantly correlation at the 0.01 level (bilateral).*

Table 2

Correlation between brown rice rate of specialized forage rice "Z-39" and meteorological factors at different growth periods

Growth period	The highest tempe-rature	The lowest temperature	Average tempera-ture	Diurnal variation of temperature	Daily average solar radiation	Humi-dity	Rainfall
Full growth period	-0.177	-0.412	-0.357	0.382	-0.319	-0.044	0.276
Sowing and transplanting period	-0.253	-0.226	-0.256	-0.261	-0.394	-0.172	-0.169
Transplantation and full heading period	-0.098	-0.363	-0.261	-0.292	0.022	-0.422	0.055
Full heading and maturity period	-0.696*	-0.811**	-0.711**	-0.786**	-0.695**	0.406	0.434
Sowing and full heading period	-0.418	-0.270	-0.246	0.809**	-0.416	-0.467	-0.051
Transplantation and maturity period	-0.308	-0.567*	-0.423	0.351	-0.364	0.075	0.419

*Note: * indicates significant correlation at the 0.05 level (bilateral)** indicates significant correlation at the 0.01 level (bilateral).*

Table 2 shows that the brown rice rate of forage rice "Z-39" is not significantly correlated with the meteorological factors during the full growth period, from sowing to transplanting period, and from transplanting to full heading period. It is significantly negatively correlated with the highest temperature, the lowest temperature, average temperature, daily temperature range, daily solar radiation, and the lowest temperature range from transplanting to maturity period. It is highly positively correlated with the diurnal variation of temperature from sowing to full heading period.

Xie et al. (2010), Xu, et al. (2021) and *Yao et al. (2021)* believed that high temperatures during the heading and filling period of rice could reduce the brown rice rate, milled rice rate, and protein content, leading to a decrease in rice yield and quality. *Yang et al. (2023)* found that low temperatures during the booting, heading, and filling periods can reduce the full head rice rate and taste score of rice. Based on the above correlation analysis, eight main meteorological factors are selected and determined for the evaluation of climate quality in "Z-39": the highest temperature from transplanting to full heading period, the lowest temperature from sowing to full heading period, the rainfall from transplanting to full heading period, the average temperature from transplanting to full heading period, the maximum temperature from full heading to maturity period, the minimum temperature from full heading to maturity period, and the average temperature from full heading to maturity period, and diurnal variation of temperature from sowing to full heading period.

Construction of a single climate quality index model for rice quality

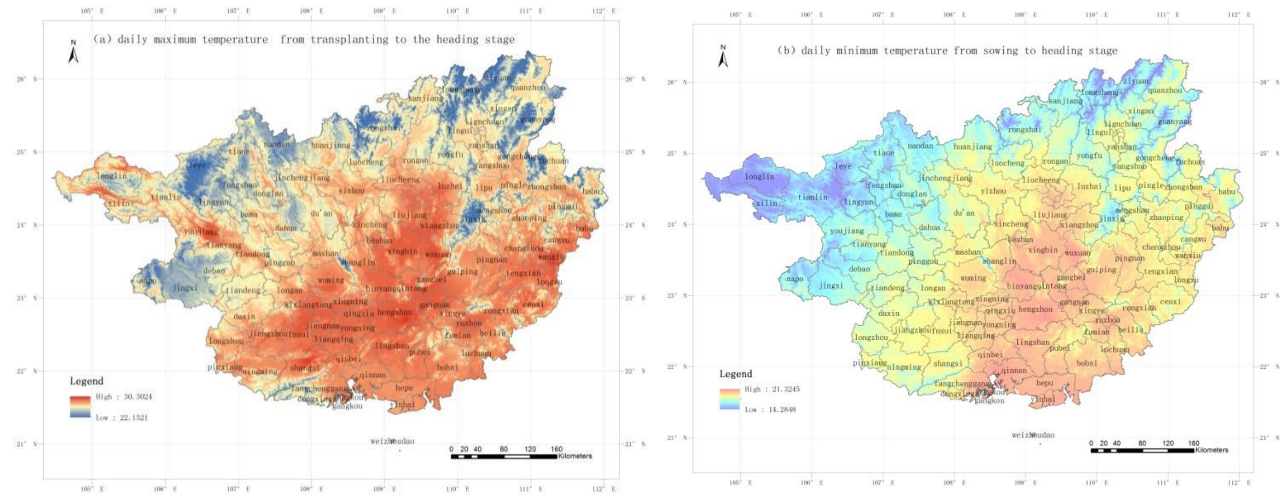
Stepwise linear regression, quadratic model, cubic model, and exponential distribution are used to fit and analyze the meteorological factors closely related to protein content and brown rice rate. Comparing the fitting effects of each model, the model with high fitting degree is selected to establish a single climate indicator model for the quality of forage rice "Zhongzao39". The model results are shown in Table 3.

Table 3

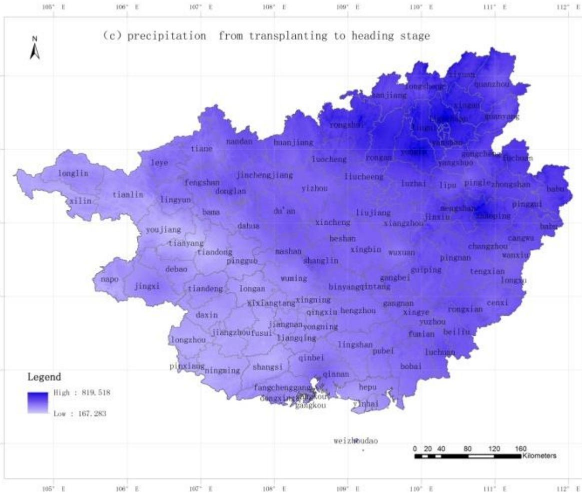
Climate model for single index quality of specialized forage rice "Z-39"

Quality index	Meteorological factors	Regression equations
Protein	The highest temperature from transplantation to full heading period	$Y = 0.029X_{2}\_T_{m}^{2} - 1.734X_{2}\_T_{m} + 32.786$
Protein	The lowest temperature from sowing to full heading period	$Y = 0.115X_{4}\_T_{i} + 4.457$
Protein	Rainfall from transplantation to full heading period	$Y = -0.003X_{2}\_R + 7.896$
Protein	Average temperature from transplantation to full heading period	$Y = 0.138X_{2}\_\ \bar{T} + 3.287$
Brown rice rate	The highest temperature from full heading to maturity period	$Y = 0.051X_{3}\_T_{m}^{2} - 3.767X_{3}\_T_{m} + 32.786$
Brown rice rate	The lowest temperature from full heading to maturity period	$Y = -0.136X_{3}\_T_{i}^{2} + 6.325X_{3}\_T_{i} + 5.987$
Brown rice rate	Average temperature from full heading to maturity period	$Y = -0.056X_{3}\_\ \bar{T}^{2} + 2.684X_{3}\_\ \bar{T} + 47.944$
Brown rice rate	Diurnal variation of temperature from sowing to full heading period	$Y = 73.05 + 0.712T$

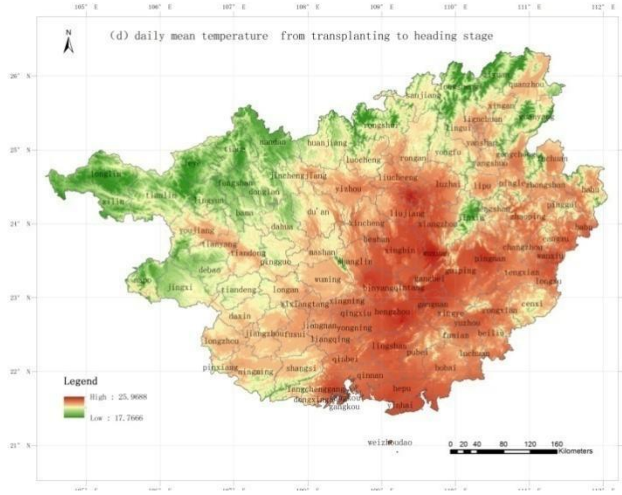
A spatial simulation analysis model is established for the 8 key meteorological factors and the 5 factors of longitude, latitude, altitude, slope and slope direction respectively. The residual correction of the model analysis structure is carried out to obtain the 100×100 m refined spatial distribution map of the 8 key meteorological factors (Fig.1).



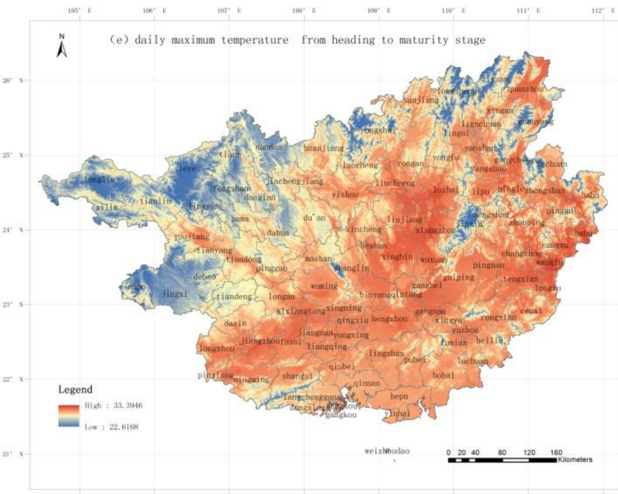
(a) The highest transplanting to full heading period (b) The lowest temperature from sowing to full heading period



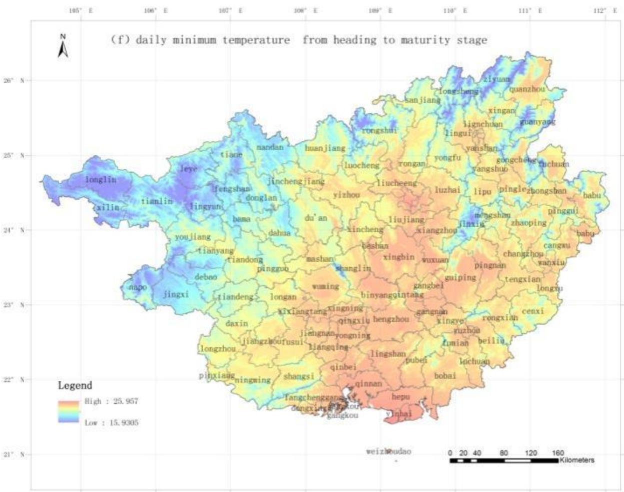
(c) Rainfall from transplanting to full heading period



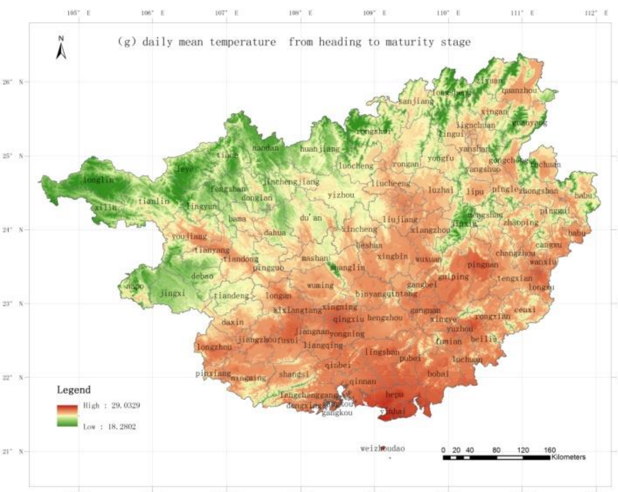
(d) Average temperature from transplanting to full heading period



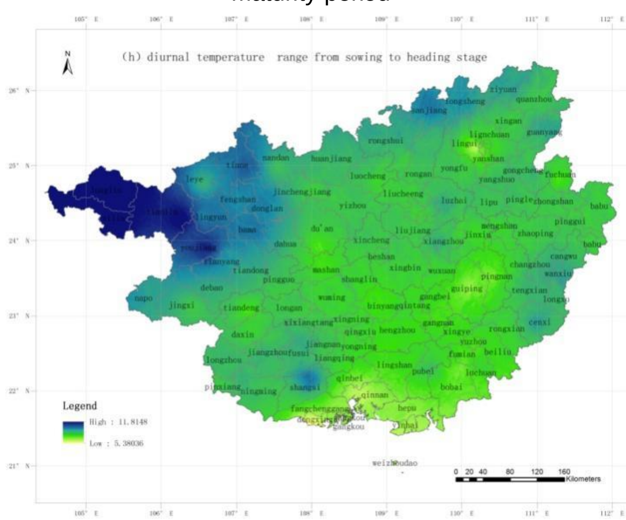
(e) The highest temperature from full heading stage to maturity period



(f) The lowest temperature from full heading stage to maturity period



(g) Average temperature from full heading stage to maturity period



(h) Diurnal variation of temperature from sowing to full heading period

Fig. 1 - Refined distribution map of Guangxi specialized forage rice "Z-39"

Establishing evaluation indicators for climate quality grading of rice

According to the requirements for the quality indicators of forage rice "Z-39", and taking into account the expert scoring method, combined with the climate background of rice cultivation in Guangxi, the critical disaster indicators for each growth stage of rice in Guangxi, and the analysis of suitable meteorological conditions for each growth period of "Z-39", the evaluation and grading indicators for the climate quality zoning of "Z-39" in Guangxi are determined (Table 4).

Table 4

Climate quality zoning index for specialized forage rice "Z-39"

Key meteorological factors	The highest quality area	High quality area	Secondary Quality Zone
The highest temperature from transplantation to full heading period (°C)	29-32	27.5-29	<27.5 >32
The lowest temperature from sowing to full heading period (°C)	>20.5	17.5-20.5	<17.5
Rainfall from transplantation to full heading period (mm)	400-500	500-630	>630 <400
Average from transplantation to full heading period (°C)	25-30	22.5-25	<22.5 >30
The highest temperature from full heading to maturity period (°C)	<31	31-32.5	>32.5
The lowest temperature from full heading to maturity period (°C)	22-24	20.5-22 24-26	<20.5 >26
Average from full heading to maturity period (°C)	23-26	21-23 26-27.5	<21 >27.5
Diurnal variation of temperature from sowing to full heading period (°C)	>9.8	-9.8	<7

Determining the weight of climate quality zoning indicators

The simple correlation coefficient, direct path coefficient, and indirect path coefficient between the quality of the special forage rice "Z-39" and key meteorological factors are integrated and calculated (Table 5). The weights of each factor based on a correlation coefficient weight of 40% and a direct path coefficient weight of 60% are calculated. According to calculations, the weights of the highest temperature from transplanting to full heading period (X1), lowest temperature from sowing to full heading period (X2), rainfall from transplanting to full heading period (X3), average temperature from transplanting to full heading period (X4), the highest temperature from full heading to maturity period (X5), the lowest temperature from full heading to maturity period (X6), average temperature from full heading to maturity period (X7), and diurnal variation of temperature from sowing to full heading period (X8) in the climate quality zoning of forage rice "Zhongzao39" are 18.3%, 13.8%, 6.4%, 23.9%, 9.5%, 7.5%, 14.6%, and 6%, respectively.

Table 5

Path analysis between the quality of specialized forage rice "Z-39" and meteorological factors

Key meteorological factors	Simple correlation coefficient	Direct path coefficient	Indirect path coefficient
X1	0.78	2.57	-1.79
X2	0.7	1.78	-1.08
X3	-0.62	-0.42	-0.2
X4	0.6	-3.94	4.54
X5	-0.7	0.92	-1.62
X6	-0.81	0.36	-1.17
X7	-0.71	-1.93	1.22
X8	0.81	0.07	0.74

Climate zoning of rice quality of Guangxi forage rice "Z-39"

Based on the climate quality zoning indicators and the spatial distribution of key meteorological factors of the special forage rice "Z-39", the spatial stacking function of GIS is used to stack the key meteorological factors with different weights corresponding to the zoning indicators at the same level. This result in a thematic map of the refined climate quality zoning of Guangxi specialized forage rice "Z-39" based on the stacking of key meteorological factors (Figure 2). As shown in Figure 2, the climate quality optimal zone, high-quality zone, and sub-optimal zone specialized forage rice "Z-39" account for 19.0%, 26.6%, and 54.4%, respectively.

The optimal areas are mainly distributed in most parts of central Guangxi, southeastern Guangxi, and northwestern Guangxi, including Huanjiang, Liuzhou, Liujiang, Luzhai, Shanglin, Binyang, Laibin, Xiangzhou, Wuxuan, Guigang, Fangchenggang, Xingye, Lingshan, Shangsi, Hepu, Pingnan, Cenxi, Cangwu and other counties (cities), as well as parts of Baise, Hechi, Hezhou, and Wuzhou. The thermal conditions in this area are suitable, and the matching of light, temperature, and water is optimal. Currently, the area for planting forage rice is the largest, especially in the Guizhong Basin area. If the planting time and structure are arranged reasonably, the specialized forage rice planted can achieve higher yield and better quality.

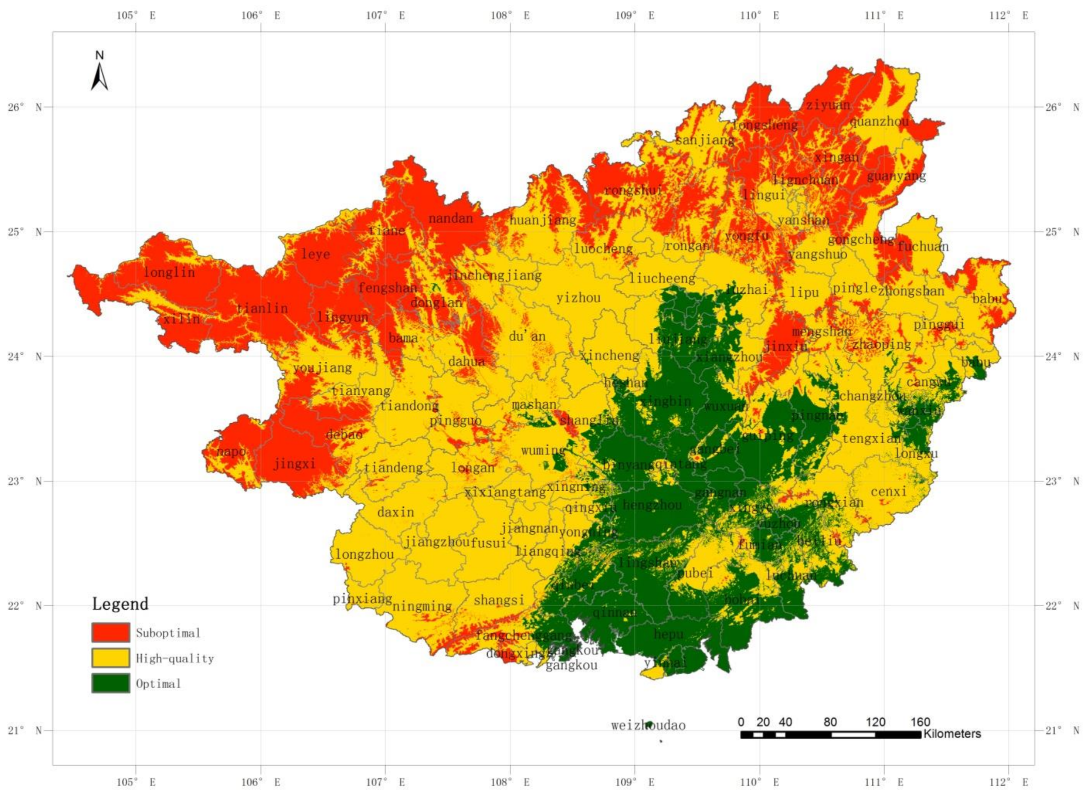


Fig. 2 - Fine climate quality zoning map of Guangxi specialized forage rice "Z-39"

The high-quality areas are mainly distributed in the southwest and northeast of Guangxi, as well as in some parts of cities such as Baise, Hechi, and Yulin. These areas need to cooperate with good field management measures, strengthen the prevention and control of diseases, pests, and meteorological disasters to harvest high-quality specialized forage rice.

The areas with sub-optimal climate quality are mainly distributed in northern Guangxi, western Guangxi, and southern Guangxi, including most counties (cities) such as Xilin, Longlin, Lingyun, Leye, Fengshan, Tian'e, Nandan, Longsheng, Resources, and Napo, as well as some counties (cities) such as Tianlin, Bama, Donglan, Rongshui, Guanyang, Jinxiu, Gongcheng, and Fangchenggang. Cold damage is more frequent in spring in the northern part of the area, while high temperature and heat damage is more likely to occur in the Baise area in the west. There are fewer areas for planting specialized forage rice in the south, which is generally not suitable for the cultivation of specialized forage rice and the improvement of rice quality.

DISCUSSIONS

(1) The key meteorological factors affecting the quality of special forage rice "Z-39". Temperature and light have a crucial impact on rice quality among various meteorological factors (*Lu et al., 2024*). Among them, temperature during the filling period, sunshine hours, and amylose content, brown rice rate, milled rice rate, full milled rice rate, and alkaline digestion value are negatively correlated (*Huang et al., 2021; Feng et al., 2024*). *Lv et al. (2021)* found that low temperature stress during the heading period can seriously affect the photosynthetic rate of rice, thereby reducing the polished rice rate and head milled rice rate. *Suung (2020)* and *Ahmed et al. (2015)* found that the content of amylose in rice usually decreases with increasing temperature.

This study uses staged sowing experimental data conducted in Nanning, Hengyang, and Nanchang, combined with local meteorological observation data for statistical analysis, the correlation between the rice quality elements (protein content, brown rice rate) of the specialized forage rice "Z-39" and meteorological factors in the full growth period of rice is analyzed. On this basis, eight meteorological factors that had significant correlation with rice quality factors and played a key role in rice quality of Z-39 were selected. The quality of rice is not only controlled by the genetic genes of the variety, but also by environmental factors, cultivation measures, and fertilization conditions (*Kashiwagi, 2021; Mahmood et al., 2024*). The study only analyzes and studies the climate factors that affect the specialized forage rice "Z-39". In actual production, various factors such as soil conditions, different cultivation methods, pest and disease effects, and planting management levels can also affect the quality of rice. Therefore, the next research needs to further systematically identify the demand of rice for climate resources under different influencing factors.

(2) Climate quality zoning and grading indicators for specialized forage rice "Z-39". Climate impact assessment of agricultural products is the study of the relationship between their quality and climate. Based on a climate quality assessment model and comprehensive evaluation, the climate quality level of agricultural products is determined (*Jin et al., 2015*). *Yang et al. (2022)* used Hubei's characteristic fragrant rice yellow felt as an example to construct a climate evaluation model for the quality of yellow felt and conduct quantitative evaluation. Based on the modeling results of the quality and key meteorological factors of "Z-39" rice, combined with the climatic characteristics of special forage rice cultivation, suitable meteorological conditions for each growth stage, especially the key growth stage, as well as restrictive meteorological conditions and disaster critical indicators, the climate grade index of rice quality planted in Guangxi for "Z-39" is determined, providing a reference for optimizing the layout of special forage rice cultivation in Guangxi.

(3) The climate quality classification of specialized forage rice "Z-39" in Guangxi. The promotion of agricultural products based on climate quality level zoning plays an important guiding role (*Yan et al., 2024*). The evaluation and zoning of climate quality levels, such as Dong Tibetan red rice in Hunan, green dates in Guangdong, and Wogan in Guangxi, have achieved certain benefits in crop promotion and meteorological services (*Chen et al., 2021; Tan et al., 2021*). Based on the climate quality zoning index of "Z-39", GIS spatial fine grid zoning method is used for fine grid spatial simulation analysis of key meteorological factors affecting rice quality. Then a refined climate quality zoning map for specialized forage rice "Z-39" is developed. The zoning results are divided into three zones: the best climate quality zone, the best climate quality zone, and the second best climate quality zone. The zoning results are more detailed and accurate, and also more in line with the actual distribution, providing a scientific basis for further optimizing the breeding layout.

CONCLUSIONS

This study focused on the specialized forage rice variety "Z-39" widely planted in Guangxi, and rice protein content and brown rice rate were selected as its quality evaluation indicators. The meteorological factors that played a key role in the quality elements of the specialized forage rice "Z-39" were: the highest temperature from transplanting to full heading period, the lowest temperature from sowing to full heading period, the rainfall from transplanting to full heading period, the average temperature from transplanting to full heading period, the highest temperature from full heading to maturity period, the lowest temperature from full heading to maturity period, the average temperature from full heading to maturity period, and diurnal variation of temperature from sowing to full heading period. The climate quality zoning indicators for the specialized forage rice "Z-39" were developed and the climate quality of specialized forage rice "Z-39" was classified. The optimal, high-quality, and sub-optimal climate quality areas accounted for 19.0%, 26.6%, and 54.4%, respectively. The optimal climate quality areas were mainly located in the central, southeastern, and northwestern regions of Guangxi.

ACKNOWLEDGEMENTS

China Meteorological Administration Joint Research Project on Meteorological Capacity Enhancement (22NLTSY013), National Agricultural Science and Technology Achievement Transformation Project (2014GB2E100281), Guangxi Science and Technology Key R&D Program Project (Guike AB17195037).

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