

EFFECTS OF DIFFERENT PLANTING REGIONS ON YIELD COMPONENTS AND GRAIN QUALITY OF RICE VARIETY ‘TONGXI 953’

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Abstract

To assess the regional adaptability of high-quality japonica rice ‘Tongxi 953’ in Jilin Province, field experiments were conducted during 2023–2024 in four major rice-producing areas in central and eastern Jilin. Yield and grain quality were systematically analyzed. Changchun had significantly more effective panicles per mu, spikelets per panicle, and higher seed-setting rate than other regions, with no significant difference in 1000-grain weight. The two-year average yield ranged from 7829.8 to 8902.7 kg ha⁻¹, with Changchun highest and Tonghua lowest; the highest yield was about 13.7% greater than the lowest. Ecological regions significantly affected processing and appearance quality, which were optimal in Tonghua, with chalky grain rate below 10% and head rice rate reaching 73.6%. Amylose content and gel consistency differed among regions, whereas alkali spreading value, transparency, and taste value were relatively stable. Overall, ‘Tongxi 953’ showed high yield in Changchun and superior quality in Tonghua. These results provide a scientific basis for regional deployment and extension of this cultivar in Jilin Province.

Key words: Rice; ‘Tongxi 953’; Regional adaptability; Yield components; Grain quality

Introduction

Jilin Province is located in the core of the high-quality rice-growing region in Northeast China. Its central black soil belt falls within the world’s golden rice cultivation zone (40°–45°N), which is particularly suitable for the production of high-quality japonica rice (Farooq *et al.*, 2022). As a major grain production base in China, Jilin Province boasts unique geographical and climatic conditions conducive to the development of high-quality japonica rice. However, significant differences in natural climatic factors, including temperature, precipitation, and sunlight, exist among different regions of Jilin Province. These differences lead to distinct regional characteristics and thus result in considerable variations in rice yield and phenotypic traits (Yan *et al.*, 2024). As environmental conditions significantly influence the agronomic traits and yield performance of ‘Tongxi 953’ (Farooq *et al.*, 2022; Yan *et al.*, 2024), matching varietal characteristics with local ecological conditions is essential to fully exploit the production potential of this rice cultivar.

With rising living standards, the demand for high-quality rice has increased steadily (Miao *et al.*, 2025). However, each high-quality rice variety has an optimal extension region where its inherent quality and yield potential can be fully expressed (C. Wang *et al.*, 2025). Therefore, identifying the optimal planting region is essential for improving the economic and social benefits of cultivar promotion.

‘Tongxi 953’ is a newly released mid-late maturing japonica rice cultivar in Jilin Province (Jishendao 20241017). It has a 143-day growth period, strong tillering

ability, and a compact plant type. It out-yielded ‘Akita Komachi’ by 7.6% in regional trials and meets the Grade 2 high-quality edible rice standard (head rice rate 73.2%, taste value 85.0). It shows moderate resistance to leaf blast and sheath blight. These traits distinguish it from older japonica varieties in Jilin and support its potential for differentiated regional deployment.

Similar multi-location studies on japonica rice in Northeast China have reported comparable regional variation. (Farooq *et al.*, 2022) found that yield of four japonica cultivars differed by up to 20.53% between Harbin and Qiqihar, while chalkiness was higher at Qiqihar. (Yan *et al.*, 2024) reviewed yield and quality status of erect-panicle japonica rice in northern China and noted that regional deployment is critical for optimizing both traits. These studies support the need for regional adaptability evaluation of newly released cultivars such as ‘Tongxi 953’.

To evaluate the regional adaptability of this cultivar, this study was conducted in four mid-late maturing rice-producing regions, including Jilin City, Changchun City, and Siping City in central Jilin Province, as well as Tonghua City in eastern Jilin Province. We hypothesized that yield would be highest in Changchun due to more favorable temperature conditions during tillering and grain filling, whereas grain quality would be best in Tonghua due to more stable grain-filling temperatures. The specific objectives were to (i) compare the yield components and grain quality of ‘Tongxi 953’ across the four planting regions, and (ii) identify the optimal region for high-yield and high-quality production. These findings are expected to provide a scientific basis for regional deployment and extension of high-quality rice varieties in Jilin Province.

Methodology

Experimental materials: The experimental material was rice variety ‘Tongxi 953’, a mid-late maturing rice variety in Jilin Province. It had a growth period of 143 days, and its grain quality met the specified requirements for Grade 2 high-quality edible rice in accordance with the Quality Standards for Edible Rice Varieties issued by the Ministry of Agriculture.

Experimental design: The experiment was laid out in a single-factor completely randomized design, consisting of four rice cultivation locations: Changchun (Changchun Academy of Agricultural Sciences, CC), Jilin (Jilin City Academy of Agricultural Sciences, JL), Siping (Rice Research Institute, Jilin Academy of Agricultural Sciences, SP), and Tonghua (Tonghua Academy of Agricultural Sciences, TH). The study was conducted under field conditions for two consecutive years. At each site, the same field was used in both years, but the arrangement of replicate plots was re-randomized each year. Each year, four planting regions were evaluated with three replications per region, yielding 12 plots per year. Across the two years, the four planting regions and two years were combined into eight treatments (4 regions×2 years), and all treatments were analyzed together using one-way ANOVA. Each plot was 50 m long and 4 m wide, with an area of 200 m². A 1-m-wide protective border was set around the experimental field. Seedlings were raised in mid-April and transplanted in late May at 30–35 days old, with a spacing of 30 cm×20 cm and 3–4 seedlings per hill. Nitrogen (N), phosphorus (P₂O₅), and potassium (K₂O) were applied at rates of 170 kg ha⁻¹, 50 kg ha⁻¹, and 75 kg ha⁻¹, respectively. All other field management practices were consistent with local conventional cultivation procedures.

Yield and yield components: At the harvest stage, 30 hills were sampled from each plot for the measurement of yield components. After air-drying, plant and grain traits were examined, including panicle number per hill, 1000-grain weight, grain number per panicle, and seed-setting rate. In addition, a separate 5 m² area within the same plot was harvested to determine actual grain yield. Thus, the 30 hills and the 5 m² harvest area were sub-samples taken from the same plot.

Milling quality of rice: After harvest, the paddy rice was naturally air-dried in a cool and ventilated area until its moisture content stabilized at approximately 14%. Under local conditions, this process took approximately 3 months because of the low temperature and high humidity during the drying period. Subsequently, 300 g of paddy rice was randomly selected from each replicate of each treatment. After removing impurities and unfilled grains, the samples were dehulled using a brown rice machine (Model: Satake TM-05, Satake, Japan) to determine the brown rice percentage. The brown rice was further polished with a laboratory milling machine (Model: Satake Pearlest) to determine the milled rice percentage and head rice percentage. All determinations were performed in accordance with the milling quality specifications specified in the Chinese National Standard GB/T 17891-2017 High-quality Paddy. Each measurement was conducted in triplicate, and the average value was recorded.

Appearance quality of rice: After impurity removal from the same batch of air-dried samples, 100 intact grains were randomly selected to measure grain length and grain width, and the length-width ratio was calculated. Chalkiness degree and chalky grain rate were determined by manual identification and counting according to the method described in GB/T 17891-2017. Each treatment was measured in triplicate, and the results were expressed as the mean value.

Eating quality of rice: Physicochemical indexes: Amylose content was determined by iodine colorimetry according to GB/T 15683-2008 Determination of amylose content in rice. Gel consistency was measured in accordance with GB/T 22294-2008 Inspection of grain and oils - Determination of gel consistency in rice.

Sensory evaluation: According to GB/T 15682-2008 Inspection of grain and oils - Sensory evaluation method for cooking and eating quality of paddy and rice, five trained panelists conducted a comprehensive scoring (total score 100) for cooked rice in terms of odor, appearance and structure, palatability, taste, and texture of cooled rice. All determinations were repeated three times, and the average values were used for analysis.

Data analysis: Experimental data were organized and preliminarily calculated using Microsoft Excel 2010, and statistically analyzed with IBM SPSS Statistics 27.0. Measurement data were expressed as mean ± standard deviation. One-way ANOVA followed by Duncan's multiple range test was used to analyze the significance of differences among treatments at $p < 0.05$. Significant differences between treatments were labeled with different lowercase letters at the 0.05 probability level.

Results

Annual mean air temperature in different planting regions: Jilin Province has a temperate monsoon climate, with most areas having an annual mean temperature of 3–5°C, active accumulated temperature of 2700–3600°C, and annual precipitation of 550–910 mm (H. Li *et al.*, 2018). Rice yield and quality depend on growth processes, which are closely affected by climatic conditions. Rice in Jilin is mainly grown from sowing and seedling raising in April to maturity in October. As shown in Figures 1 and 2, monthly mean temperatures differed among the four planting regions and between the two years. In April 2023, mean temperatures were below 10°C in all regions, but rose to 11°C or above in April 2024. In May, temperatures declined in both years, especially in TH. From June to September, temperatures were generally similar among regions, with some fluctuations. A summary of monthly mean temperatures is provided in Table 1.

In June 2023, temperatures were similar across regions, but decreased in 2024 except in SP. In July 2023, CC and JL reached the highest temperature (24.5°C), followed by TH and SP, all above 24°C. CC's July temperature remained stable, JL's decreased by 1°C, and other regions rose to 24.5°C in the second year. In August and September 2023, regional temperatures were uniform at 22.5°C and 18.5°C, respectively. In August 2024, temperatures increased, with TH being the highest. In September 2024, temperatures dropped compared with 2023: TH was the highest, JL and CC were moderate and equal, and SP was the lowest.

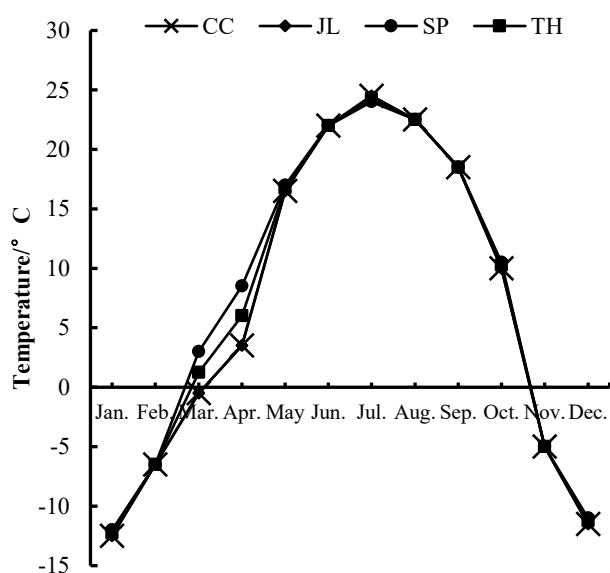


Fig. 1. Monthly mean air temperature in the four planting regions in 2023.

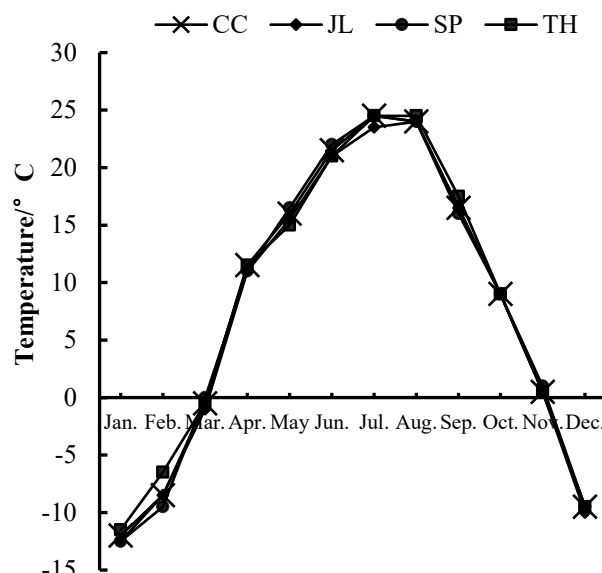


Fig. 2. Monthly mean air temperature in the four planting regions in 2024.

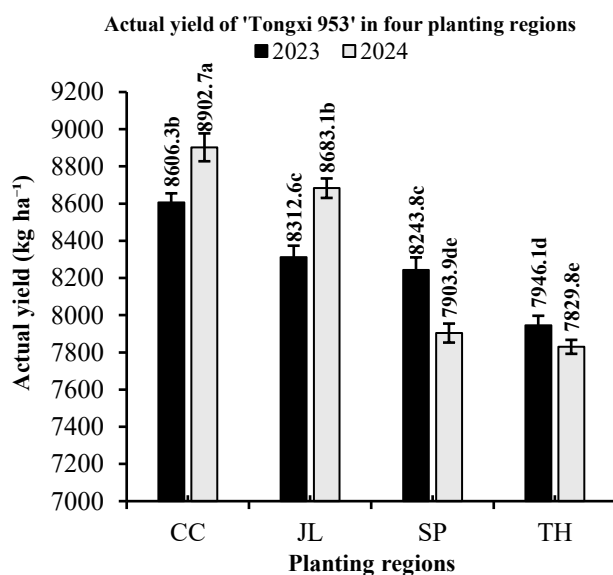
Table 1. Monthly mean air temperature (°C) in the four planting regions in 2023 and 2024.

Planting region	City	Year	Mar. (°C)	Apr. (°C)	May (°C)	Jun. (°C)	Jul. (°C)	Aug. (°C)	Sep. (°C)	Oct. (°C)
Central	CC	2023	-0.5	3.5	16.5	22	24.5	22.5	18.5	10.0
	JL	2023	-0.5	3.5	16.5	22	24.5	22.5	18.5	10.0
	SP	2023	3.0	8.5	17	22	24	22.5	18.5	10.5
Eastern	TH	2023	1.25	6.0	16.8	22	24.3	22.5	18.5	10.3
Central	CC	2024	-0.5	11.5	16.0	21.5	24.5	24.0	16.5	9.0
	JL	2024	-1.0	11.0	15.5	21.0	23.5	24.0	16.5	9.0
	SP	2024	0.0	11.0	16.5	22.0	24.5	24.0	16.0	9.0
Eastern	TH	2024	-0.5	11.5	15.0	21.0	24.5	24.5	17.5	9.0

Effects of different planting regions on yield and yield components: Rice yield is determined by multiple factors, which can be mainly summarized into four basic components: panicle number per unit area, grain number per panicle, seed-setting rate, and 1000-grain weight (He *et al.*, 2024). As shown in Table 2, the rice variety 'Tongxi 953' grown in different planting regions exhibited the same growth period of 143 days across both years. The 1000-grain weight showed no significant differences among planting regions or years, and was not affected by regional or annual climatic variations. However, effective panicle number per mu, grain number per panicle, and seed-setting rate differed significantly among the eight treatments (four regions $\times$ two years). Effective panicle number per mu in CC was the highest and significantly higher than in other regions in both years, while that in TH was the lowest and significantly lower than in other regions. Effective panicle number in JL and SP was similar in 2023 with no significant difference. From 2023 to 2024, effective panicle number per mu increased slightly in CC, rose significantly in JL, and remained relatively stable in other regions.

Grain number per panicle differed significantly among regions in 2023: CC was the highest, followed by JL, SP, and TH (the lowest). In 2024, CC remained the highest and TH the lowest, with no significant difference between JL and SP. Grain number per panicle in TH remained the lowest with no obvious change between years, decreased

slightly in SP, and declined significantly in CC and JL. Seed-setting rate varied among regions within the same year and between years for the same region. In both years, seed-setting rate followed the order: CC > JL > SP > TH, and decreased significantly over the two years.

Fig. 3. Actual yield of 'Tongxi 953' in four planting regions in 2023 and 2024. Data are means $\pm$ SD. Different letters above bars indicate significant differences at $p < 0.05$.

In 2023, actual yield was the highest in CC and the lowest in TH, with no significant difference between JL and SP. In 2024, CC still had the highest yield and TH the lowest. In 2023, yield in TH was significantly lower than in CC and JL, while SP was not significantly different from JL. In 2024, yields in SP and TH were significantly lower than those in CC and JL. Compared with 2023, actual yield increased significantly in CC and JL in 2024, but decreased obviously in SP and TH. In both years, the actual yield among regions ranked in the order: CC > JL > SP > TH. Meanwhile, the seed-setting rate in all regions showed a significant decreasing trend over the two years (Fig. 3).

Effects of different planting regions on milling quality of ‘Tongxi 953’:

The main indices of rice milling quality include brown rice rate, milled rice rate, and head rice rate. As shown in Table 3, planting region and year had significant effects on the milling quality of rice. For brown rice rate, TH was the highest in both years and increased significantly over the two years, reaching 83.8% in 2024—the highest value among all treatments, which was significantly higher than that in other regions in the same year. CC ranked second to TH and was significantly higher than JL and SP in the same year. Meanwhile, brown rice rate in CC, JL, and SP decreased significantly over the two years. For milled rice rate, values in SP and TH were similar and significantly higher than those in JL and CC, which were also close to each other. No obvious changes in milled rice rate were observed among regions over the two years. For head rice rate, TH remained the highest in both years and was significantly higher than CC, JL, and SP. Head rice rate showed no obvious changes in TH and SP over the two years, but increased significantly in CC and JL.

Effects of different planting regions on appearance quality of ‘Tongxi 953’:

The appearance quality of rice mainly includes grain length, length-width ratio, chalky grain rate, and chalkiness degree. As shown in Table 4, no significant differences were observed in grain length and length-width ratio among regions or years. The chalky grain rate in TH (eastern region) was the lowest and significantly lower than in other regions in both years, with no obvious changes over the two years, indicating good stability. In 2023, SP had the highest chalky grain rate,

significantly higher than other regions, followed by CC and JL, which showed slight differences between each other. In 2024, the chalky grain rate increased significantly in all regions except TH, especially in CC, where it increased markedly and reached the maximum value among all treatments across the two years.

The chalkiness degree in CC was the highest and significantly higher than in other regions in both years, while that in TH was the lowest and significantly lower than in other regions. Both CC and TH maintained stable chalkiness degrees with no significant changes over the two years. In 2023, the chalkiness degree in SP was slightly lower than that in CC but significantly higher than that in JL. In 2024, the chalkiness degree in JL increased slightly, while that in SP decreased significantly, resulting in a slightly higher value in JL than in SP.

Effects of different planting regions on cooking and eating quality of ‘Tongxi 953’:

Cooking and eating quality is the most important indicator in the evaluation system for high-quality edible rice (P. Li *et al.*, 2022). As shown in Table 5, in 2023, the amylose content of ‘Tongxi 953’ in CC and TH was similar and significantly higher than that in JL and SP, which showed no significant difference between each other. In 2024, the amylose content was similar between CC and JL, and showed no significant difference between SP and TH, both of which were significantly higher than those in CC and JL. There were no significant differences in amylose content between JL and TH across the two years. The content decreased significantly in CC and increased significantly in SP over the two years.

In 2023, gel consistency was the highest in TH, showed no significant difference between CC and SP, and was the lowest in JL. In 2024, gel consistency showed no significant difference between JL and TH, both slightly higher than those in CC and SP (which also showed no significant difference). Gel consistency increased slightly in JL over the two years and decreased slightly in other regions. There were no significant differences in alkali spreading value, transparency, or overall taste value among regions in either year, and no obvious changes were observed across the two years.

Table 2. Effects of different planting regions on yield components of ‘Tongxi 953’ in two years.

Planting region	City	Year	Growth period (days)	Effective panicles ($\times 10^4 \cdot \text{hm}^{-2}$)	Grains per panicle	Seed-setting rate (%)	1000-Grain weight (g)	Actual yield ($\text{kg} \cdot \text{hm}^{-2}$)
Central	CC	2023	143.0 $\pm$ 0.0a	21.7 $\pm$ 0.2ab	145.3 $\pm$ 4.7a	90.0 $\pm$ 0.3a	25.1 $\pm$ 0.2a	8606.3 $\pm$ 49.2b
	JL	2023	143.0 $\pm$ 0.0a	20.5 $\pm$ 0.2c	137.7 $\pm$ 3.5b	87.9 $\pm$ 0.6b	25.0 $\pm$ 0.1a	8312.6 $\pm$ 61.2c
	SP	2023	143.0 $\pm$ 0.0a	20.1 $\pm$ 0.3c	130.0 $\pm$ 1.0c	87.3 $\pm$ 0.2bc	25.1 $\pm$ 0.2a	8243.8 $\pm$ 67.2c
Eastern	TH	2023	143.0 $\pm$ 0.0a	19.6 $\pm$ 0.3d	123.7 $\pm$ 3.1d	86.9 $\pm$ 0.6cd	25.0 $\pm$ 0.2a	7946.1 $\pm$ 50.8d
Central	CC	2024	143.0 $\pm$ 0.0a	22.1 $\pm$ 0.2a	136.0 $\pm$ 2.6b	87.8 $\pm$ 0.4b	25.2 $\pm$ 0.5a	8902.7 $\pm$ 74.9a
	JL	2024	143.0 $\pm$ 0.0a	21.4 $\pm$ 0.1b	126.0 $\pm$ 2.7cd	87.1 $\pm$ 0.1c	24.9 $\pm$ 0.2a	8683.1 $\pm$ 52.4b
	SP	2024	143.0 $\pm$ 0.0a	20.2 $\pm$ 0.4c	125 $\pm$ 1.0cd	86.4 $\pm$ 0.1de	24.9 $\pm$ 0.1a	7903.9 $\pm$ 51.1de
Eastern	TH	2024	143.0 $\pm$ 0.0a	19.5 $\pm$ 0.4d	121.3 $\pm$ 1.5d	85.9 $\pm$ 0.3e	24.8 $\pm$ 0.1a	7829.8 $\pm$ 37.5e

Note: Data are presented as mean $\pm$ standard deviation. Different lowercase letters within the same column indicate significant differences among treatments according to Duncan’s multiple range test at $p < 0.05$. CC: Changchun; JL: Jilin; SP: Siping; TH: Tonghua. The same applies below

Table 3. Effects of different planting regions on milling quality of ‘Tongxi 953’ in two years.

Planting region	City	Year	Brown rice rate (%)	Milled rice rate (%)	Head rice rate (%)
Central	CC	2023	82.9 ± 0.2bc	73.5 ± 0.6b	71.5 ± 0.5c
	JL	2023	82.6 ± 0.3cd	73.3 ± 0.3b	71.7 ± 0.6c
	SP	2023	82.7 ± 0.3cd	74.3 ± 0.3a	72.5 ± 0.4b
Eastern	TH	2023	83.2 ± 0.2b	74.4 ± 0.6a	73.6 ± 0.6a
Central	CC	2024	82.7 ± 0.3cd	73.5 ± 0.4b	72.7 ± 0.6b
	JL	2024	82.5 ± 0.2de	73.6 ± 0.4b	73.0 ± 0.4ab
	SP	2024	82.2 ± 0.1e	74.5 ± 0.4a	72.7 ± 0.6b
Eastern	TH	2024	83.8 ± 0.1a	74.6 ± 0.4a	73.6 ± 0.4a

Table 4. Effects of different planting regions on appearance quality of ‘Tongxi 953’ in two years.

Planting region	City	Year	Grain length (mm)	Length-width ratio	Chalky grain rate (%)	Chalkiness degree (%)
Central	CC	2023	4.9 ± 0.0a	2.1 ± 0.0a	11.5 ± 0.3cd	2.8 ± 0.1a
	JL	2023	4.9 ± 0.0a	2.1 ± 0.0a	11.1 ± 0.2d	2.3 ± 0.1c
	SP	2023	4.9 ± 0.0a	2.1 ± 0.0a	12.5 ± 0.2b	2.7 ± 0.2ab
Eastern	TH	2023	4.9 ± 0.0a	2.1 ± 0.0a	9.8 ± 0.2e	2.1 ± 0.1d
Central	CC	2024	4.9 ± 0.0a	2.1 ± 0.0a	13.4 ± 0.3a	2.8 ± 0.1a
	JL	2024	4.9 ± 0.0a	2.1 ± 0.0a	11.9 ± 0.7c	2.5 ± 0.1bc
	SP	2024	4.9 ± 0.0a	2.1 ± 0.0a	13.3 ± 0.2a	2.3 ± 0.1c
Eastern	TH	2024	4.9 ± 0.0a	2.1 ± 0.0a	9.4 ± 0.2e	2.0 ± 0.1d

Table 5. Effects of different planting regions on cooking and eating quality of ‘Tongxi 953’ in two years.

Planting region	City	Year	Amylose content (%)	Gel consistency (mm)	Alkali spreading value (scale)	Transparency (scale)	Taste value (score)
Central	CC	2023	17.4 ± 0.4a	77.3 ± 0.6ab	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
	JL	2023	16.6 ± 0.4b	76.0 ± 1.0b	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
	SP	2023	16.5 ± 0.5b	76.3 ± 2.1ab	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
Eastern	TH	2023	17.5 ± 0.4a	78.3 ± 1.5a	7.0 ± 0.0a	1.0 ± 0.0a	85.3 ± 0.6a
Central	CC	2024	16.7 ± 0.3b	76.0 ± 1.0b	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
	JL	2024	16.7 ± 0.4b	77.0 ± 0.0ab	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
	SP	2024	17.3 ± 0.2a	75.7 ± 1.2b	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a
Eastern	TH	2024	17.5 ± 0.4a	77.7 ± 0.6ab	7.0 ± 0.0a	1.0 ± 0.0a	85.0 ± 0.0a

Pearson correlation analysis was performed to examine the relationships between monthly mean temperature and yield and quality traits (Table 6). No significant correlations were detected

Table 6. Pearson correlations between monthly mean temperature (April–September) and yield and quality traits of ‘Tongxi 953’ (n=8).

Trait	Apr.	May	Jun.	Jul.	Aug.	Sep.
Actual yield	−0.035	−0.056	−0.161	−0.274	−0.032	−0.160
Head rice rate	0.639	−0.425	−0.522	−0.225	0.522	−0.304
Chalky grain rate	0.310	0.289	0.217	−0.098	−0.133	−0.548
Amylose content	−0.057	−0.166	0.009	0.442	0.143	0.042
Taste value	−0.266	0.342	0.276	0.014	−0.371	0.350

Note: All correlation coefficients were not significant at $p < 0.05$. $n = 8$ site-year combinations (4 planting regions × 2 years)

Discussion

Effects of different planting regions on yield and yield components: Rice yield components are positively correlated with yield. Effective panicle number and total grain number per panicle show a significant positive correlation with yield, while seed-setting rate exhibits an extremely significant positive correlation with yield (Zou *et al.*, 2023). To achieve high yield, the coordinated development of effective panicle number, grain number per panicle, seed-setting rate, and 1000-grain weight is

essential (He *et al.*, 2024; Hu *et al.*, 2024; S. Li *et al.*, 2013; Xu *et al.*, 2015; Zhang *et al.*, 2022). However, when the same rice variety is planted in different regions, its yield can vary considerably due to the influences of climate and other environmental conditions. Air temperature in different planting regions affects rice growth stages differently, which in turn influences rice yield components and ultimately the actual grain yield.

Low temperature during the tillering stage inhibits rice tillering, reduces tiller number, and decreases effective panicle number (Guo *et al.*, 2025). Either low or high

temperature from booting to flowering can delay heading, suppress and degrade spikelet differentiation, cause pollen abortion and abnormal development of reproductive organs, resulting in reduced seed-setting rate and grain number. High temperature during grain filling shortens the filling duration and leads to incompletely filled grains, whereas low temperature delays grain filling and increases the number of empty and shriveled grains (Fu *et al.*, 2008). The relatively stable increase in temperature during the tillering stage in CC may have promoted rice tillering and thus may have contributed to the higher number of effective panicles. Meanwhile, the higher temperature at the same period in 2024 accelerated early tillering, leading to a further significant increase in yield, which compensated for the yield reduction caused by the decrease in seed-setting rate. Relatively low temperatures in SP and JL in 2024 during the same period may have inhibited rice tillering. In TH, large temperature fluctuations and low temperatures in the early tillering stage suppressed tillering, resulting in the lowest number of effective panicles among all regions.

From booting to heading and flowering, the average temperature in CC remained stable at 22.5~24.5°C with a suitable diurnal temperature range. Such climatic conditions favored spikelet differentiation and reproductive organ development, thereby increasing grain number per panicle and seed-setting rate. Abnormally high temperatures in TH may have inhibited pollen development, possibly contributing to the reduced seed-setting rate. In 2024, temperatures during the grain-filling stage were lower than in 2023. The lower temperature may have slowed the grain-filling rate, delayed the filling process, increased the number of empty and shriveled grains, and reduced the seed-setting rate. We hypothesize that this contributed to the lower seed-setting rate. The 1000-grain weight showed no significant differences among regions or years, indicating that it was mainly controlled by genetic factors rather than regional or annual environmental conditions. Overall, the eight treatments (four regions $\times$ two years) differed significantly in rice growth during the developmental stages and consequently in actual yield. The yield differences were closely associated with variation in effective panicle number, grain number per panicle, and seed-setting rate, indicating that these yield components were the main contributors to the regional yield differences. This suggests that climatic conditions during tillering and grain filling played an important role in determining yield potential in this region.

Effects of different planting regions on the processing quality of rice variety ‘Tongxi 953’: Rice processing quality represents the deepening and expansion of grain production, serving as an intermediary link connecting primary products with the consumer market. It falls within the scope of the food industry and is closely related to agriculture, industry, and circulation sectors. Processing quality directly affects the commercial value of rice, and its development is closely related to national welfare and people's livelihoods (Mohidem *et al.*, 2022). Rice milling quality is not only influenced by the genetic characteristics of varieties but also by environmental factors in different regions. Head rice rate is the most important factor in rice processing quality and is affected by multiple factors, among which the average temperature during the grain-filling period has the greatest impact (Siebenmorgen *et al.*, 2013).

The relatively favorable temperature conditions during grain filling in TH may have contributed to better endosperm development and grain plumpness, which are important for achieving a high head rice rate. This suggests that regions with stable grain-filling temperatures may have an advantage in processing quality. Although temperatures in this region were low in March, they increased significantly in April, potentially promoting the accumulation of effective accumulated temperature during the tillering stage. From August to September, temperatures approached the optimal range for the rice grain-filling period, favoring endosperm development and plumpness, thereby enhancing the head rice rate. In contrast, CC and JL experienced a sharp temperature drop in September following high temperatures in August, which may have shortened the grain-filling period, resulting in significantly lower head rice rates compared to TH. The head rice rate in CC and JL increased slightly in 2024, possibly due to a modest temperature rise in August that accelerated the grain-filling process and promoted grain plumpness and starch accumulation. However, the temperature decline in September may have led to insufficient maturity in some grains, causing a slight decrease in brown rice rate. SP showed stable processing quality performance across the two years.

Effects of different planting regions on the appearance quality of rice variety ‘Tongxi 953’: The appearance quality of rice is determined by the combined effects of varietal genetic characteristics and regional environmental conditions. The main factors influencing rice appearance quality are grain length, chalky grain rate, and chalkiness degree (Q. Wang *et al.*, 2020). The opaque portion in the rice endosperm is referred to as chalkiness, which is caused by the loose and irregular arrangement of starch granules, manifesting as an opaque phenotype in the endosperm. Rice with chalkiness is prone to breakage during milling and produces more cracks in grains during cooking, directly affecting the appearance quality and commercial value of rice (Singh *et al.*, 2005). Chalky grain rate and chalkiness degree, as core indicators for evaluating rice appearance quality, serve as the primary basis for grading in rice trade, also known as commercial quality or market quality (Yun *et al.*, 2016). Chalkiness is a complex quantitative trait controlled by multiple genes and is susceptible to environmental conditions (Paul *et al.*, 2020). Unsuitable temperature conditions during the grain-filling period can increase the incidence of chalkiness.

It can be seen from the experimental results that: There were no significant differences in grain length and length-width ratio of ‘Tongxi 953’ among regions in both years, indicating that climatic variations in different planting regions had little effect on these traits, which may be mainly related to genetic factors. In TH, the temperature fluctuation during the grain-filling period was relatively small, which may have promoted uniform starch deposition and limited chalkiness development. This is consistent with the superior appearance quality observed in TH and suggests that stable grain-filling temperatures are beneficial for limiting chalkiness. In the other regions, the average temperature during the grain-filling period in 2024 was lower than that in 2023 and also lower than the two-year average temperature in TH, resulting in an increased chalky grain rate. We

hypothesize that low temperatures may have inhibited endosperm cell division, amyloplast proliferation, and growth, leading to smaller amyloplast volumes and enlarged intercellular spaces, which loosened the internal grain structure and increased chalkiness. Overall, chalky grain rate and chalkiness degree differed significantly among the eight treatments (four regions $\times$ two years).

Effects of different planting regions on the cooking and eating quality of rice variety ‘Tongxi 953’: Rice is primarily consumed as food, making cooking and eating quality a major aspect of rice quality evaluation. The cooking and eating quality of rice is the most complex of all rice quality traits. In China, several physicochemical properties, including amylose content, alkali spreading value, gel consistency, transparency, and taste value, are still commonly used to reflect the cooking and eating quality of rice (Xiong *et al.*, 2002). In TH, high temperatures during the heading stage may have accelerated grain filling and shortened the starch accumulation period, possibly leading to increased amylose content, harder cooked rice texture, and reduced palatability. In CC, the large diurnal temperature range during the grain-filling period favored the accumulation of amylopectin, reduced the proportion of amylose, and enhanced the stickiness, elasticity, and aroma of cooked rice. The stability of alkali spreading value and transparency across regions and years suggests that these traits are less sensitive to environmental variation and are more strongly controlled by genetic factors. Therefore, they may be less useful for distinguishing regional quality differences in this cultivar.

The taste value, which reflects the overall sensory quality of cooked rice, remained stable across regions and years (85.0–85.3). This stability was accompanied by relatively small variations in amylose content (16.5–17.5%) and gel consistency (75.7–78.3 mm). In general, low to intermediate amylose content and intermediate to long gel consistency are associated with softer, stickier, and more palatable cooked rice. The relatively low amylose content and intermediate gel consistency observed in ‘Tongxi 953’ are consistent with its high taste value. Although amylose content was slightly higher in TH (17.5%) and gel consistency was slightly lower in SP (75.7 mm in 2024), these differences did not lead to significant changes in taste value, suggesting that the eating quality of this cultivar is largely genetically controlled and buffered against environmental variation. The stable sensory scores indicate that ‘Tongxi 953’ can maintain good eating quality across different planting regions in Jilin Province. However, because the sensory panel consisted of only five trained panelists, these results should be interpreted with caution, and larger-scale sensory evaluation is recommended for future studies.

Environmental factors beyond temperature: Although temperature is a major driver of rice growth and quality, other environmental factors such as precipitation, sunshine duration, and soil fertility can also influence yield and grain quality. In this study, these factors were not systematically measured across the four sites. Therefore, the ecological interpretation presented here focuses mainly on temperature, and the roles of precipitation, sunshine duration, and soil fertility remain to be tested. Future studies that integrate these factors would provide a more holistic understanding of regional adaptability in ‘Tongxi 953’.

Limitations: This study has several limitations. It was limited to two years, four sites, and a single cultivar. Daily temperature data were not available, so stage-specific temperature effects should be treated as hypotheses rather than confirmed causal relationships. Precipitation, sunshine duration, and soil fertility were not systematically measured, and their effects remain to be tested. Since the original raw replicate values for yield and quality traits are no longer available, the main effects of region and year and their interaction were not separately partitioned, and effect sizes could not be estimated. Monthly temperature data were fully retained and are presented in Figure 1 and Table 1. Future multi-year, multi-site studies with a two-factor design and detailed climatic and soil data are needed to further quantify the contributions of region, year, and their interaction.

Conclusion

Based on the two-year experimental results from four major production areas in Jilin Province—Changchun (CC), Jilin (JL), Siping (SP), and Tonghua (TH)—the rice variety ‘Tongxi 953’ exhibited significant regional adaptability differences in both yield and quality. In terms of yield, the variety performed best in Changchun, with the highest effective panicles per unit area, grains per panicle, and seed-setting rate, ultimately achieving the highest actual yield, ranked as CC > JL > SP > TH. Regarding rice quality, the grain produced in Tonghua showed the best comprehensive performance in processing quality (brown rice rate, head rice rate) and appearance quality (chalky grain rate, chalkiness degree). In contrast, the core indicators of cooking and eating quality (alkali spreading value, transparency, taste value) remained relatively stable across all production areas, with no significant differences. In summary, if high yield is the primary objective, the Changchun area is the most suitable region for promotion; if quality is the priority, the Tonghua area offers greater advantages. These findings provide a critical basis for the differentiated promotion and industrial application of ‘Tongxi 953’ in Jilin Province.

For practical extension, we recommend prioritizing Changchun for high-yield production and Tonghua for high-quality production of ‘Tongxi 953’. However, it should be noted that the official registration of ‘Tongxi 953’ excludes Tonghua from its recommended adaptation area due to its susceptibility to panicle blast. This exclusion is based on disease risk rather than quality. Under proper disease management, Tonghua produced grain with the best processing and appearance quality in this study and may therefore be considered for high-quality production when blast control is ensured.

For breeding programs, the stable eating quality and broad regional adaptability of ‘Tongxi 953’ suggest that it could serve as a valuable parent for developing new japonica varieties with stable quality across diverse environments. For policy implications, differentiated extension policies are recommended to support high-yield production in central Jilin and high-quality production in eastern Jilin, which could enhance the overall competitiveness of the rice industry in Jilin Province. Further multi-year and multi-site validation is needed to refine these recommendations and support differentiated extension policies in Jilin Province.

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