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Multi-Location Evaluation of Agronomic Performance and Yield Stability of Select Special Purpose Rice Lines in Luzon, Philippines

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Abstract

The increasing demand for high-quality and nutritionally enhanced rice has intensified interest in special purpose rice (SPR) such as aromatic, pigmented, and glutinous types. However, the productivity and adaptability of these rice types across diverse environments remain limited. This study evaluated the agronomic performance, yield, and adaptability of three CLSU-bred SPR lines—CLS1 (aromatic), CLS2 (pigmented), and CLS4 (glutinous)—across three major rice-producing areas in the Philippines (Pangasinan, Nueva Ecija, and Bulacan) during the 2022 wet season and 2023 dry season. Multi-location on-farm trials were conducted under farmer-managed conditions, and data on key agronomic traits and grain yield were collected. Combined analysis across environments was performed to assess genotype and environment effects. Results showed that agronomic performance and grain yield varied across locations and seasons, indicating strong environmental influence on SPR productivity. CLS1 and CLS2 consistently exhibited higher yield performance in irrigated environments, particularly in Nueva Ecija and Pangasinan, with yields reaching up to 6.20 t ha^{-1} and 7.42 t ha^{-1}. In contrast, all SPR lines showed reduced yield under rainfed conditions in Bulacan. CLS2 demonstrated relatively stable performance across environments, suggesting broader adaptability. These findings highlight the importance of environment-specific varietal selection and support the targeted deployment of SPR lines to enhance diversification and farmer income.

Introduction

Rice (*Oryza sativa* L.) remains the primary staple food in the Philippines and plays a central role in national food security, rural livelihoods, and agricultural development. Despite sustained production efforts, the country continues to face challenges in achieving self-sufficiency due to increasing population demand, climate variability, and limited natural resources (Philippine Statistics Authority, 2023). At the same time, consumer preferences are shifting toward rice types with superior grain quality, nutritional value, and specialty attributes, creating new opportunities for diversification and value addition within the rice sector.

Special purpose rice (SPR), including aromatic, pigmented, and glutinous types, represents a rapidly expanding high-value market segment. Aromatic rice is favored for its fragrance and eating quality; pigmented rice varieties are rich in bioactive compounds such as anthocyanins with potential health benefits, and glutinous rice plays an important role in traditional food systems and niche markets (Mbanjo et al., 2020; Tuaño et al., 2015). These specialty rice types often command premium prices, offering higher income potential for farmers compared to conventional white rice. However, SPR production remains constrained by relatively lower yield potential, longer maturity duration, and greater sensitivity to environmental stresses compared to improved inbred and hybrid varieties (Bandumula, 2018).

The economic importance of SPR extends beyond farm profitability to include its contribution to nutritional security and market diversification. Increasing health awareness among consumers has driven demand for pigmented and specialty rice in both domestic and export markets, positioning SPR as a strategic commodity for enhancing agricultural competitiveness. In major rice-producing regions such as Central Luzon, identifying suitable production environments and high-performing genotypes is essential to fully realize this market potential.

The performance of rice varieties, particularly specialty types, is highly influenced by environmental conditions. Optimal productivity of SPR is generally achieved under irrigated lowland ecosystems with adequate water supply, favorable soil fertility, and stable climatic conditions. However, certain pigmented and traditional rice lines have demonstrated adaptability under marginal or rainfed environments, suggesting opportunities for targeted deployment across diverse agroecosystems (Mbanjo et al., 2020; Van Nguyen & Ferrero, 2006). Matching genotypes to appropriate environments is therefore critical to maximize both yield and grain quality.

Recent studies highlight that abiotic stresses associated with climate variability—such as drought, flooding, and temperature extremes—are major constraints to rice production in Central Luzon. In Nueva Ecija, below-average rainfall and increasing temperature variability have been shown to induce crop stress, particularly in areas lacking irrigation, thereby affecting crop establishment and yield (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2022). Similarly, in Bulacan, both drought and flood events significantly reduce crop productivity, with more than half of farmers reporting yield losses exceeding 50% under drought conditions and substantial damage from flood events in low-lying areas (Agbay et al., 2023). Across Central Luzon, including Pangasinan, rice-growing areas are frequently exposed to extreme weather events such as typhoons and heavy rainfall, which contribute to recurring crop damage and yield instability. These conditions underscore the increasing vulnerability of rice systems to multiple abiotic stresses and highlight the need for resilient and adaptable rice varieties.

Given these challenges, one of the major limitations in expanding SPR production is the lack of location-specific performance data. Genotype × Environment (G×E) interactions play a critical role in determining the agronomic performance and yield stability of rice varieties under varying conditions of soil, water, and climate (Van Nguyen & Ferrero, 2006). Varieties that perform well in irrigated environments may not exhibit similar performance under rainfed or stress-prone conditions. Therefore, multi-location adaptability trials are essential to identify genotypes with either broad adaptability or specific adaptation to particular production environments.

In Central Luzon, where rice production systems range from irrigated lowland to rainfed ecosystems, the evaluation of newly developed SPR lines across diverse environments is crucial for guiding varietal recommendations and improving productivity. The development and deployment of SPR lines with enhanced yield potential, improved stress tolerance, and acceptable grain quality can help address current production constraints while meeting increasing market demand.

This study aimed to evaluate the agronomic performance and yield of selected CLSU-bred special purpose rice lines across multiple locations and seasons, and to assess their location-specific adaptability and market potential in major rice-producing areas of Central Luzon.

Materials and Methods

Study Sites and Experimental Conditions

Multi-location adaptability trials were conducted during the 2022 wet season (WS) and 2023 dry season (DS) in three major rice-producing areas in the Philippines: Tayug, Pangasinan; General Mamerto Natividad, Nueva Ecija, and Santa Maria, Bulacan. These locations represent varying production environments, including irrigated lowland systems (Tayug, Pangasinan, and General Mamerto Natividad, Nueva Ecija) and a predominantly rainfed ecosystem (Santa Maria, Bulacan). Differences in water availability, soil properties, and climatic conditions across sites provided a basis for evaluating location-specific performance of special purpose rice (SPR) lines.

Plant Materials

Representative lines of three SPR categories were used for adaptability, namely, CLS1 (aromatic), CLS2 (pigmented), and CLS4 (glutinous). Each location included a farmer-preferred inbred check variety (NSIC Rc 436, NSIC Rc 216, and NSIC Rc 160), which varied across sites depending on local practices and seed availability. These checks served as benchmarks for comparing the agronomic and yield performance of the SPR lines under farmer-managed conditions. Each study site used a check variety that is popularly planted in the area.

Experimental Design and Crop Establishment

The trials were conducted under a farmer-managed, non-replicated strip trial design in each location. In every site, the experimental area was divided into four adjacent plots of approximately equal size (~2,500 m^2 per entry), with each plot assigned to one of the three SPR lines and one check variety. Standard farmer practices for land preparation, crop establishment, fertilization, irrigation, and pest management were followed in each location to reflect realistic production conditions.

Seedlings were established either through direct seeding or transplanting depending on farmer practice. For transplanted systems, seedlings were raised in seedbeds and transplanted at approximately 14 days after sowing. Fertilizer application and crop protection measures were applied based on local recommendations and farmer discretion.

Soil sampling and analysis

Soil samples were collected using auger to a depth of 15 centimeters from five points in each location and placed in a bucket. Soil samples were then air dried and sieved at two mm mesh.

The soil samples were analyzed at the Regional Soils Laboratory, Department of Agriculture Regional Field Office III and at CRL Environmental Corporation-Environmental Testing Laboratory.

Data Collection

Agronomic data were collected from ten randomly selected sample plants per entry within each plot. The following parameters were measured: Plant height (cm): measured from the soil surface to the tip of the tallest panicle at maturity; Number of productive tillers: counted per plant at maturity; Panicle length (cm): measured from the panicle base to the tip; Spikelet fertility (%): determined as the percentage of filled grains over total spikelets per panicle. For the days to maturity, it was recorded as the number of days from sowing to approximately 80–85% grain maturity.

To enhance comparability across sites, grain yield was standardized to 14% moisture content and expressed in tons per hectare (t ha^{-1}). Environmental conditions, including irrigation availability and soil properties, were considered in interpreting genotype performance. While the non-replicated design reflects real-world farmer conditions, it limits the precision of statistical inference; thus, results are primarily intended to identify promising genotypes for further replicated trials.

Statistical Analysis

Due to the farmer-managed and non-replicated strip trial design employed at each site, statistical analysis was conducted using a combined analysis across environments, where each location–season combination was treated as a single environment.

A linear model was used to evaluate the effects of genotype (G), environment (E), and their interaction (G×E) on agronomic traits and grain yield:

$$Y_{ij} = \mu + G_i + E_j + (G\,X\,E)_{ij} + \epsilon_{ij}$$

where:

Y_{ij} = observed value of genotype i in environment j

μ = overall mean

G_i = effect of genotype

E_j = effect of environment

$(G\,X\,E)_{ij}$ = interaction effect

ϵ_{ij} = residual error

Given the absence of replication within environments, inferential statistical comparisons (e.g., LSD) were interpreted with caution. Emphasis was placed on descriptive statistics, including mean performance and variability across environments, to identify patterns of adaptability and stability among SPR lines.

Where applicable, comparisons among genotypes within environments were supported by observed trends rather than strict statistical significance testing. This approach is consistent with the exploratory nature of on-farm adaptability trials.

Results and Discussion

Environmental and Soil Influences on SPR Performance

Soil physicochemical properties across the three study locations are presented in Table 1. Soil samples collected during the fallow period from three rice production areas—Tayug, Pangasinan; General Mamerto Natividad, Nueva Ecija and Santa Maria, Bulacan—revealed marked differences in soil fertility status, nutrient availability, and physical characteristics. Total nitrogen (N) in all sites ranged from 0.08–0.14%, substantially below the optimum range of 1.50–3.00%, indicating potential nitrogen limitation for rice production if nutrient replenishment is not implemented. Available phosphorus (P) varied considerably, with Santa Maria exhibiting the highest concentration (85.54 ppm), while Tayug showed the lowest (2.30 ppm). Potassium (K) was adequate in Gen. Mamerto Natividad and Tayug but exceeded the normal range in Santa Maria (0.85 cmol kg^{-1}), suggesting greater nutrient reserves. Similar studies have shown that N, P, and K are among the most important indicators of rice soil fertility and directly influence crop productivity (Miura & Badayos, 2021; Linquist et al., 2022).

Table 1. Soil analysis from three adaptability trial locations

Area	General Mamerto Natividad	Tayug	Santa Maria	Normal Values	Reference
Macroelements		**Mean±Sem**			
N (%)	0.08 ± 0.03	0.11 ± 0.01	0.14 ± 0.02	1.50 – 3.00	(Khadka, et.al, 2016)
P (ppm)	9.12 ± 4.88	2.30 ± 0.58	85.54 ± 23.45	5.00 – 10.00	(Doberman & Fairhurst, 2000)
K (cmol/kg)	0.15 ± 0.02	0.16 ± 0.03	0.85 ± 0.04	0.15 – 0.45	(Doberman & Fairhurst, 2000)
S (ppm)	73.20 ± 11.67	132.07 ± 50.09	28.88 ± 11.59	5.00 – 20.00	(Suvillan, et.al)
Ca (cmol/kg)	5.48 ± 0.52	13.87 ± 1.42	14.80 ± 1.12	4	(Doberman & Fairhurst, 2000)
Mg (cmol/kg)	2.66 ± 0.27	6.00 ± 0.29	4.59 ± 1.52	3	(Doberman & Fairhurst, 2000)
Micronutrients					
Fe (ppm)	284.24 ± 22.83	158.66 ± 8.97	132.40 ± 10.79	60 – 300	(Mahender, et.al)
Mn (ppm)	114.72 ± 20.31	101.97 ± 8.64	296.62 ± 55.46	8 – 12	(Khadka, et.al, 2016)
Zn (ppm)	1.39 ± 0.32	2.42 ± 0.43	5.68 ± 2.24	1 – 3	(Khadka, et.al, 2016)
Cu (ppm)	5.78 ± 0.54	7.97 ± 0.24	20.98 ± 2.57	0.8 – 1.2	(Khadka, et.al, 2016)
Soil Properties					
Sand (%)	52.61 ± 2.98	28.19 ± 2.22	30.36 ± 2.89		
Silt (%)	28.19 ± 2.22	41.83 ± 1.69	25.62 3.57		
Clay (%)	30.36 ± 2.89	29.97 ± 1.06	48.92 ± 2.39		
Texture Class	Sandy clay loam	Clay Loam	Clay		
Other Parameters					
pH	5.50 ± 1.27	6.37 ± 0.12	5.94 ± 0.25	7	(Khadka, et.al, 2016)
OM (%)	2.00 ± 1.69	3.31 ± 0.25	3.48 ± 0.25	1.5 – 3.00	(Khadka, et.al, 2016)
CEC (cmol/kg)	10.29 ± 3.57	17.79 ± 0.27	20.39 ± 0.64	13 – 25	
N03 (mg/kg)	1.30 ± 0.54	0.15 ± 0.05	2.42 ± 0.15	20 – 40	
Phosphate (mg/kg)	382.80 ± 33.63	325.20 ± 50.51	1556.60 ± 268.57	200 – 1500	

Secondary nutrients, particularly sulfur (S), calcium (Ca), and magnesium (Mg), were generally above critical levels, indicating favorable conditions for nutrient cycling and plant development. Micronutrient analysis revealed adequate iron (Fe) concentrations across sites; however, manganese (Mn) and copper (Cu) greatly exceeded the reference values, particularly in Santa Maria, while zinc (Zn) ranged from adequate to excessive. Elevated micronutrient levels may enhance nutrient availability but could also indicate potential nutrient imbalances under prolonged cultivation. Soil pH ranged from 5.50 to 6.37, indicating moderately acidic conditions typical of many rice-growing soils. Acidic soils can influence nutrient solubility and availability, particularly phosphorus and micronutrients (Widowati & Sukristyonubowo, 2012).

Textural analysis classified the soils as sandy clay loam (Gen. Mamerto Natividad), clay loam (Tayug), and clay

(Santa Maria). The higher clay content in Santa Maria (48.92%) corresponded with greater cation exchange capacity (CEC = 20.39 cmol kg^{-1}), reflecting improved nutrient retention. Soil texture and CEC are recognized as major determinants of nutrient availability and rice nutrient uptake in paddy systems (Ye et al., 2024). Organic matter (OM) ranged from 2.00–3.48%, indicating moderate organic matter accumulation despite the fallow period. Previous studies reported that OM, pH, and CEC are reliable indicators of soil quality and fertility in rice ecosystems (Cedeño, 2019). Overall, the results suggest that while the three sites possess favorable levels of several macro- and micronutrients, nitrogen deficiency and nutrient imbalance remain potential constraints. Site-specific nutrient management strategies, particularly N supplementation and balanced fertilization, were observed to optimize special purpose rice productivity.

Agronomic Performance Across Environments

The agronomic traits of the SPR lines varied considerably across locations and seasons, reflecting strong environmental influence and genotype-specific responses. The pigmented line CLS2 consistently produced a higher number of productive tillers across most environments, indicating a strong tillering ability that contributes to yield potential. Meanwhile, the aromatic line CLS1 exhibited superior panicle length and plant height in irrigated environments, traits often associated with improved biomass accumulation and grain filling capacity.

However, these advantages were less pronounced under rainfed conditions, particularly in Santa Maria, where all genotypes exhibited reduced growth performance. Delayed maturity and reduced tiller formation observed in this location suggest that water limitation and climatic stress negatively affected crop development. This highlights the sensitivity of SPR lines, particularly aromatic types, to suboptimal environmental conditions.

Grain Yield Performance and Genotype × Environment Interaction

Grain yield showed clear variation across environments, demonstrating the importance of genotype × environment (G×E) interaction in determining SPR productivity. The highest yields were consistently recorded in irrigated environments, particularly in Nueva Ecija and Pangasinan, where CLS1 and CLS2 achieved yields exceeding 6.0 t ha^{-1} during both seasons. These results indicate that both lines possess strong yield potential when grown under optimal water and soil conditions.

In contrast, yield performance in Santa Maria was substantially lower across all genotypes, with values generally below 4.0 t ha^{-1}. This reduction can be attributed to the absence of irrigation and exposure to environmental stresses such as erratic rainfall, strong winds, and temperature fluctuations. The magnitude of yield decline across all lines in this environment underscores the limiting effect of water availability on SPR productivity.

Among the evaluated genotypes, CLS2 demonstrated relatively stable yield performance across both favorable and moderately stressed environments, suggesting broader adaptability. This stability may be associated with the inherent resilience of pigmented rice lines, which have been reported to perform better under less favorable conditions. In contrast, CLS1 exhibited higher yield potential but greater sensitivity to environmental stress, indicating specific adaptation to irrigated systems.

Trade-off Between Yield and Functional Quality

While glutinous line CLS4 consistently produced lower grain yield compared to CLS1 and CLS2, its agronomic performance remained acceptable across environments. This suggests its suitability for niche markets where grain quality and culinary properties are prioritized over yield. Similarly, the pigmented line CLS2 offers added value due to its high content of bioactive compounds, including anthocyanins and phenolics, which are associated with antioxidant activity and potential health benefits.

This highlights an important trade-off in SPR production: yield versus functional and market value. Although some SPR lines may not match the yield of conventional varieties, their premium pricing and nutritional advantages provide opportunities for increased farmer income and market diversification.

Implications for SPR Deployment in Major Rice Growing Areas

The observed variation in performance across environments emphasizes the need for location-specific varietal recommendations. CLS1 and CLS2 are best suited for irrigated lowland systems, where their yield potential can be fully expressed. In contrast, production in rainfed environments requires either improved management practices or the development of more stress-tolerant SPR lines.

The strong influence of environmental conditions on yield stability further highlights the importance of continued multi-location testing. Such evaluations are essential for identifying genotypes with either broad adaptability or specific adaptation, thereby improving the efficiency of varietal deployment.

Table 2. Period of planting and harvesting activities across three locations of the adaptability trials of four special purpose rice lines during the wet and dry season.

	Sowing		Transplanting		Harvesting		No. of days from sowing to harvesting	
	WS	DS	WS	DS	WS	DS	WS	DS
Tayug	06/14/2022	11/03/2022	-	11/28/2022	10/17/2022	02/28/2023	125 days	118 days
Gen. Mamerto Natividad	06/21/2022	12/02/2022	07/06/2022	12/25/2022	10/18/2022	03/30/2023	120 days	119 days
Santa Maria	07/11/2022	01/14/2023	08/08/2022	02/10/2023	11/16/2022	05/05/2023, 05/26/2023	129 days	133 days

Agronomic and yield performance of SPR in wet and dry seasons

Agronomic data means all the information that includes phenotypic data, like plant height, productive tillers, panicle length, and other physical attributes of rice and other plants. Crop yield is the measurement of the amount of agricultural production; it is often used to measure grains or cereal and other agricultural crops.

Table 3. Agronomic performance and grain yield of selected SPR lines in Tayug, Pangasinan during the 2022 wet season (WS) and 2023 dry season (DS)

	Plant height (cm)		Productive tillers		Panicle Length (cm)		Spikelet fertility (%)	Grain yield (tons/ha)	
Entry	WS	DS	WS	DS	WS	DS	WS	WS	DS
Check (NSIC Rc 218)	-	88.0	-	15	-	22.80	-	-	5.4
CLS1 (Aromatic)	136.5	104.8	11	16	28	25.40	67.81	2.78	5.3
CLS2 (Pigmented)	142.1	93.8	14	20	24.4	20.6	71.70	4.00	7.47
CLS4 (Glutinous)	-	97	-	14	-	26.80	-	-	2.39

WS = Wet Season; DS = Dry season
Values represent mean observations from farmer-managed plots
Missing values (-) indicate data not recorded
Grain yield adjusted to 14% moisture content

In the Tayug area, the check variety used was NSIC Rc 218 for both seasons. During the wet season (WS) only two lines were used, and three lines were used in the dry season (DS). The agronomic data of plant height shows that the tallest was CLS2 with 142.1 cm in WS and CLS1, which measured 104.8 cm (Table 3). The line that produced the greatest number of productive tillers was CLS2, both in WS and DS. In terms of panicle length, CLS1 has the longest with about 28cm in WS and CLS4 in DS. CLS2 exhibited higher spikelet fertility (71.70%) compared to CLS1 under wet season conditions. In terms of grain yield in both seasons, CLS2 produced the highest yield of 4 ton/ha and 7.47 ton/ha in respective seasons compared to the other lines and check variety.

The second location, in Gen. Mamerto Natividad (Table 4), the check variety used was NSIC Rc 218. The SPR lines used in both seasons were CLS1, CLS2, and CLS4. In terms of plant height, CLS2 was the tallest with 131.7 in WS and 109.9 in DS. In productive tillers, CLS2 produced 18 tillers, which is the highest in WS, and CLS4 has an increase of 6 tillers compared to 24. In terms of panicle length, CLS4 was the longest in WS, and the check variety was the longest in DS. The spikelet fertility is CLS1 with 84.89% in WS. Concerning the grain yield, CLS1 is the most productive in WS with a total of 6.20 ton/ha in WS and 7.42 ton/ha in DS.

Table 4. Agronomic performance and grain yield of selected SPR lines in in Gen. Mamerto Natividad, Nueva Ecija during the 2022 wet season (WS) and 2023 dry season (DS)

	Plant height (cm)		Productive tillers		Panicle Length (cm)		Spikelet fertility (%)	Grain yield (tons/ha)	
Entry	WS	DS	WS	DS	WS	DS	WS	WS	DS
Check (NSIC Rc 218)	-	86.85	-	21	-	24.10	-	-	-
CLS1 (Aromatic)	110.7	109.5	15	27	20.3	26.8	84.89	6.20	7.42
CLS2 (Pigmented)	131.7	109.9	18	19	18	23.7	73.51	3.29	6.95
CLS4 (Glutinous)	125.8	102.85	13	24	26.6	26.5	67.03	3.29	6.25

The results of agronomic and grain yield data in Santa Maria are the following. The tallest among the other lines in WS was CLS1 and CLS2 in DS. In terms of productive tillers, CLS2 and CLS9 had the highest numbers in WS and DS, respectively, and were consistently higher than other lines. CLS2 has the highest spikelet fertility with 79.46%. The line that produced the highest grain yield in WS was 3.83 ton/ha of CLS1, and in DS was 2.02 ton/ha of CLS2. The result of yield in this area was significantly different compared to other locations; this may be due to the lack of a water irrigation system and extreme environmental conditions, such as strong winds and heavy rainfall. In addition, this condition also caused a decrease in the grain quality of the harvested crop.

White aromatic rice varieties, such as those from the "Jasmine" line, have consistently shown high adaptability in the Philippine context; in this case, CLS1's genetic background is Jasmine. According to Lacerna et al. (2022), trials demonstrated that these varieties exhibit robust growth and yield potential even under varying moisture conditions. They reported an average yield of 4.5 tons per hectare, making them a preferable choice for farmers aiming for both quality and quantity in rice production.

Whereas pigmented rice lines, particularly red and black varieties, present unique advantages and challenges. The study of Mbanjo et al. (2020) revealed that while pigmented rice often yields slightly less than aromatic varieties—averaging 3.5 tons per hectare—they possess superior drought resistance and nutritional benefits due to higher anthocyanin content. This makes them valuable in enhancing food security and health within the community, as they are typically cultivated under less favorable conditions.

Glutinous rice lines, such as those used for traditional delicacies, have also been subjected to adaptability trials. A study conducted by Zhang et al. (2026) indicated that glutinous rice, despite having lower overall yields (approximately 3 tons per hectare), performs well in specific localities where traditional farming practices prevail. Its high market value compensates for lower yields, making it a viable option for farmers focused on niche markets.

Table 5. Agronomic performance and grain yield of selected SPR lines in Sta. Maria, Bulacan during the 2022 wet season (WS) and 2023 dry season (DS)

	Plant height		Productive tillers		Panicle Length (cm)		Spikelet fertility (%)	Grain yield (tons/ha)	
Entry	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**WS**	**DS**
Check (NSIC Rc 218)	-	124.10	-	30	-	27.10	-	-	1.79
CLS1 (Aromatic)	117.8	125.5	16	18	25.3	29.00	79.46	3.83	1.79
CLS2 (Pigmented)	113.7	128.0	18	29	26.6	25.65	76.85	2.54	2.02
CLS4 (Glutinous)	99.8	127.6	16	17	25.7	27.70	77.20	2.72	0.65
Check (CLS9 Glutinous)	-	94.8	-	31	-	24.90	-	-	1.79

In addition to the multilocation testing of the selected SPR lines, bioactive compound analysis of pigmented lines was performed. The pigmented rice line CLS2 exhibited notable levels of bioactive compounds, including a high total anthocyanin content (135.29 mg C3G g^{-1}), along with appreciable total phenolic (0.95 mg GAE g^{-1}) and flavonoid contents (2.49 mg RHE g^{-1}), which collectively contributed to its measurable antioxidant activities as indicated by DPPH (1.36 mg TE g^{-1}), ABTS (1.28 mg TE g^{-1}), and ferric reducing antioxidant power (2.46 mg TE g^{-1}). These findings indicate that CLS2 is a rich source of natural antioxidants that can help mitigate oxidative stress and reduce the risk of chronic diseases, including cardiovascular and metabolic disorders (Mbanjo et al., 2020). The high anthocyanin content, a defining characteristic of pigmented rice, has been associated with anti-inflammatory and anti-diabetic properties (Shao et al., 2014). Furthermore, pigmented rice varieties are often linked to a relatively lower glycemic index compared to polished white rice, meaning they are digested and absorbed more slowly, resulting in a gradual increase in blood glucose levels and improved glycemic control (Frei, Siddhuraju, & Becker, 2003). This slower glycemic response makes CLS2 a promising functional food option, particularly for individuals with diabetes or those at risk of developing metabolic syndrome.

Overall, the performance of the evaluated special purpose rice lines varied across environments, reflecting the influence of location-specific conditions on agronomic traits and yield. The aromatic line CLS1 consistently demonstrated strong yield potential and adaptability in irrigated areas such as Tayug and General Mamerto Natividad, while the pigmented line CLS2 exhibited competitive performance across both favorable and moderately stressed conditions, indicating broader adaptability. In contrast, the glutinous line CLS4 showed comparatively lower yield but maintained acceptable agronomic performance, suggesting suitability for niche production systems. Reduced performance across all lines in Santa Maria further underscores the impact of water limitation and environmental stress on SPR productivity. These findings highlight the importance of environment-specific varietal selection and provide a basis for targeted recommendations.

Conclusion

The study demonstrated a strong environmental influence on the performance of SPR lines. CLS1 and CLS2 showed superior yield in irrigated systems, while reduced productivity was observed under rainfed conditions. These findings support the targeted deployment of SPR lines based on environmental suitability. Continued multi-location evaluation is recommended to refine varietal recommendations and improve yield stability.

Ethical Statement

Prior to the establishment of the adaptability trials, Memoranda of Agreement (MOAs) were executed with the participating Local Government Units (LGUs) and farmer cooperators. All activities were done in close coordination with the Municipal Agriculture Offices (MAOs) and identified farmer-cooperators. These agreements ensured that all stakeholders were informed of the objectives, responsibilities, and expected outcomes of the project.

Conflict of Interest Statement

The authors declare no conflict of interest related to the conduct and publication of this research. All procedures followed were in accordance with institutional and ethical standards, and there were no financial or personal relationships that could have influenced the outcomes of this study.

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Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this manuscript, the author(s) used ChatGPT to assist in improving the clarity, grammar, readability, and technical tone of selected sections of the text. All AI-generated suggestions were carefully reviewed, verified, and revised by the author(s) as necessary. The author(s) assume full responsibility for the accuracy, integrity, and final content of this publication.

Data Availability

The data supporting the findings of the study are confidential and not available for public disclosure.

Author Contributions

FMNG: Conceptualization, Methodology, Validation, Data Curation, Review and Editing, Supervision and Project administration; **MCMF:** Conceptualization and Writing the outline; **MZPH:** project administration and data curation; **JTG:** project administration and data curation; **ZDC:** investigation and data curation; **KJAT:** investigation and data curation; **XPJ:** writing original draft, data curation and visualization; **ECA:** project administration and supervision; **MMS:** project administration.

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