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RESEARCH

Agro-Morphological Diversity of White Roselle (*Hibiscus sabdariffa* var. *altissima*) for Climate Change Adaptation in Burkina Faso

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Abstract

Climate change intensifies the variability of agroclimatic conditions in sub-Saharan Africa, threatening food security through increased droughts, rainfall gaps, and soil degradation. In this context, endogenous adaptation approaches based on local resources, such as White Roselle (*Hibiscus sabdariffa* var. *altissima*), are strategic due to their hardiness and dual food and textile uses. This study aims to characterize the agro-morphological diversity and performance stability of ten local white roselle cultivars from Burkina Faso to identify genotypes best adapted to contrasting climatic environments. The experiment was conducted over two agricultural seasons, dry and wet, in three locations with distinct ecological conditions. A randomized complete block design with three replications was implemented. Thirteen agro-morphological traits were measured. Data were analyzed using multifactor ANOVA, Tukey's HSD test for pairwise comparisons, calculation of the amir index, and stability analyses based on Finlay-Wilkinson and Ammi methods. Results showed a significant influence of cultivar and site factors. Kongkrou, Nikiema, and Konde exhibited good performance and high stability. Bakaridjan and Bala were more sensitive to environmental variations. These findings highlight the importance of valorising local cultivars in breeding strategies for resilient agriculture in West Africa.

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Statement of Sustainability: The present work supports the achievement of Sustainable Development Goals (SDGs) by investigating the genetic and agro-morphological diversity of crops, particularly in identifying resilient genotypes capable of adapting to environmental stresses. By characterizing local cultivars and optimizing agricultural practices, this research fosters sustainable farming systems, with a particular emphasis on enhancing food security in the face of climate change. The findings show the role of local biodiversity in addressing climate challenges, reducing dependency on external inputs, and promoting ecological sustainability in West African agriculture.

1. Introduction

Climate change in Sub-Saharan Africa is increasingly marked by the intensification of extreme weather events, including prolonged droughts, flooding, erratic rainfall patterns, and disruptions in the agricultural calendar (Serdeczny et al., 2017). These changing conditions exacerbate the vulnerability of agricultural systems, posing a significant threat to food security across the region (Kantamaneni et al., 2020). In addition, the ongoing degradation of soils, loss of fertility, erosion of cultivated biodiversity, and the emergence of new pests and diseases further compound the challenges faced by farmers (Amankona and Kabenomuhangi, 2024). Precipitation irregularities, in particular, constitute a serious threat to crops, especially those that are sensitive to water availability during crucial growth stages (Wakjira et al., 2024). In light of these challenges, the identification of plant species that can tolerate or adapt to these extreme climatic conditions is critical for ensuring agricultural resilience and food security (Akinkuolie et al., 2025). One such promising species is the white roselle (*Hibiscus sabdariffa* L. var. *altissima*), known for its robust resistance to abiotic stresses, low soil requirements, and wide temperature tolerance ranging from 20 to 35°C throughout the growing season

(Ankrah et al., 2018). Beyond its agronomic benefits, white roselle also offers considerable nutritional and medicinal value. Its leaves are commonly used as a leafy vegetable in traditional cuisine, while medicinally, they are utilized for treating various ailments, including scurvy, coughs, respiratory issues, and constipation (Islam et al., 2016). Despite its advantages, the behavior of white roselle under the current climatic pressures remains insufficiently studied (Hinojosa-Gómez et al., 2018).

This study aims to assess the genetic and agro-morphological diversity of local white roselle genotypes in terms of their drought tolerance, yield stability, and adaptability to the diverse climatic conditions found across West Africa. The specific objectives of the study include evaluating the diversity of genotypes based on their performance under drought and other environmental factors, analyzing the stability of yields under various climatic conditions, and identifying the most resistant and adaptable genotypes for sustainable agricultural practices. The hypotheses arising from these objectives are as follows: genotypes originating from distinct climatic zones will show significant differences in terms of drought tolerance and yield stability, influenced by both genetic and environmental factors. Furthermore, certain genotypes will demonstrate enhanced resilience and stability under fluctuating climatic conditions, making them more suitable for climate change adaptation.

2. Materials and Methods

2.1. Plant Material

The plant material used consisted of 10 cultivars originating from five regions in Burkina Faso. The cultivars studied are listed in Table 1.

Table 1. Fundamental agro-morphological characteristics of the cultivars studied.

Cultivar	Height (cm)	Fiber quality	Vigor
Bala	250–300	Good, long	High
Kondé	180–220	Medium	Medium
Kongkrou	220–260	Very good	High
Souroukoudingan	200–240	Good	High
Yirini	190–210	Medium to good	Medium
Gando	230–280	Excellent	Strong
Zangou	160–190	Medium	Medium
Nikiéma	240–270	Good	High
Saba	200–220	Medium	Medium
Bakaridjan	210–240	Very good	High

2.2. Methodology

The study was conducted over two consecutive agricultural years, with trials carried out during both the dry and wet seasons to evaluate cultivar performance under varied climatic conditions. Experiments were conducted in three locations in Burkina Faso, each characterized by distinct agro-climatic features. A map illustrating the geographic locations of the three experimental sites is presented in Figure 1. These sites differ in altitude, soil type, and climatic conditions, notably average annual temperature and precipitation levels (Table 2).

Table 2. Abiotic characteristics of the experimental sites.

Sites	Province	Altitude (meters)	Climate	Average temperature	Precipitation	Soil type
Laye	Kourwéogo	340	Semi-arid, dry, and hot	29 °C	634 mm	Tropical ferruginous soils
Dapélogo	Oubritenga	293	Semi-arid, hot, and dry	29.1 °C	627 mm	Sandy-loam soils
Absouya	Oubritenga	271	Semi-arid, dry, and hot	29 °C	618 mm	Soils rich in organic matter

2.3. Experimental Design

A randomized complete block design (RCBD) was implemented to minimize the effect of environmental variations on the observed results. This type of design allows a rigorous comparison of different treatments, here represented by the cultivars, while accounting for field heterogeneity (Coe and Nokoe, 2025; Serrano et al., 2025). The experiment included three replications, which enhances data reliability by ensuring reproducibility of results (Frévent, 2025). Each block represented one replication and contained all ten cultivars studied, for a total of thirty experimental units.

Seedlings were sown on uniformly prepared beds measuring 2 meters in length. Spacing between rows and plants was maintained according to agronomic standards for the cultivated species, to ensure good aeration, uniform light exposure, and optimal plant development (Rai et al., 2011). This design allowed precise evaluation of the agro-morphological performance of the different cultivars under similar conditions.

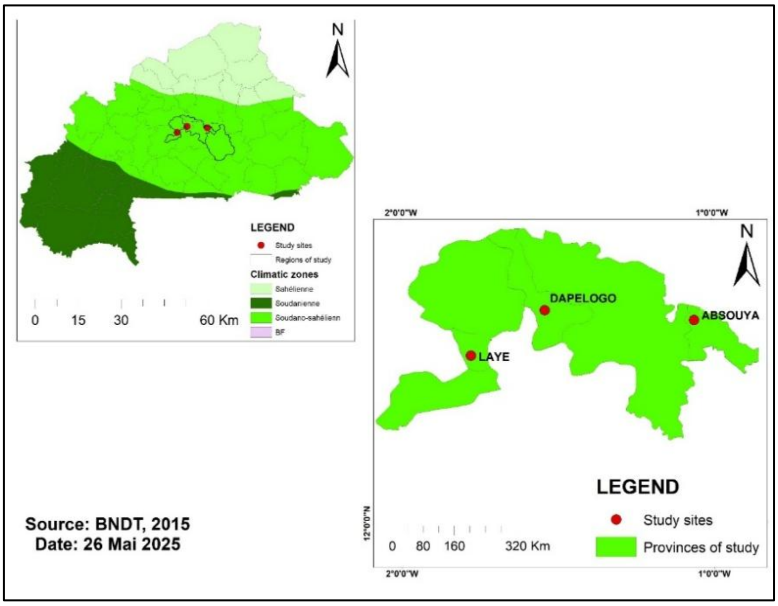

Figure 1. Map showing the experimental sites for White Roselle (*Hibiscus sabdariffa* var. *altissima*).

2.4. Parameters Measured

The parameters observed in this study were: flowering date (DFL), number of days to flowering (NJF), average number of stems per plant (NMT), number of main branches (NRP), plant height (HPT), length of the largest leaf (LOC), collar diameter (DIC), number of capitula per plant (NCP), percentage of plant survival (PSC), fresh leaf yield (RDC), average seed weight (PMG), seed production per plant (PGP), and seed yield (RDG). These various agro-morphological traits allow evaluation of the overall performance of the genotypes studied under trial conditions.

2.5. Statistics and Data Analysis

Collected data were first compiled using Microsoft Excel 2019, then statistically analyzed using R software (version 4.4.3). A descriptive analysis was conducted for each measured agro-morphological trait (mean, standard deviation, minimum, and maximum). An analysis of variance (ANOVA) was performed to assess the effects of the factors cultivar, site, season, year, as well as their interactions on the studied traits. The multiple comparisons were performed using the Tukey HSD test to identify significant differences between the group means. Additionally, a Multivariate Yield Index Analysis (AMIR) was conducted to integrate all measured traits into a single global synthetic index. This index was developed to summarize the overall agro-morphological performance of each cultivar by combining all thirteen traits. It allows for the ranking of genotypes based on productivity, vigor, earliness, and environmental adaptability. Each variable was standardized (mean-centered and scaled) using the formula :

$$Z_{ij} = \frac{X_{ij} - \overline{X}_j}{\sigma_j}$$

Zij is the standardized value of trait j for genotype i, x̄j is the mean, and σ is the standard deviation of trait j. The AMIR index for each genotype was calculated as follows:

$$AMIR_i = \sum_{j=1}^{n} w_j \cdot Z_{ij}$$

The weights (wj) were extracted from the first principal component of a Principal Component Analysis (PCA) performed on the standardized variables, following the approaches of (Mendeş, 2009) and (Mbaluka et al., 2022). n is the total number of traits. The result is a synthetic score enabling the overall comparison of cultivars. Finally, to explicitly link agronomic performance and adaptation to climate change, a stability analysis of yields was carried out using the Finlay and Wilkinson method. This approach evaluated the sensitivity and stability of cultivars according to environmental variations by analyzing the yield response of each genotype relative to the mean productivity index of the environments.

3. Results

3.1. Impact of Cultivar, Site, and Year Factors

The variable ReDG is significantly influenced by the factors Cultivar and Site. A significant effect was observed for the variable ReDC in relation to the factor Year. The factors Cultivar and Site exert a significant influence on the variable PtGP. Regarding the variable PSC, a significant effect was detected with the same factors. The variable PMG also shows a significant response to the factors Cultivar and Site. Significant effects are associated with the variable NRP for the factors Cultivar and Site. For the variable NMT, the analyses reveal significance with the factor Cultivar. There is a significant association between the variable NJF and the factor Cultivar. The variable NCP is significantly influenced by the factors Cultivar and Site. A significant effect was observed for the variable LOC in relation to the factor Cultivar. The factors Cultivar and Site exert a significant influence on the variable HP. Concerning the variable DUFL, significance was detected with the factors Cultivar and Site (Figure 2).

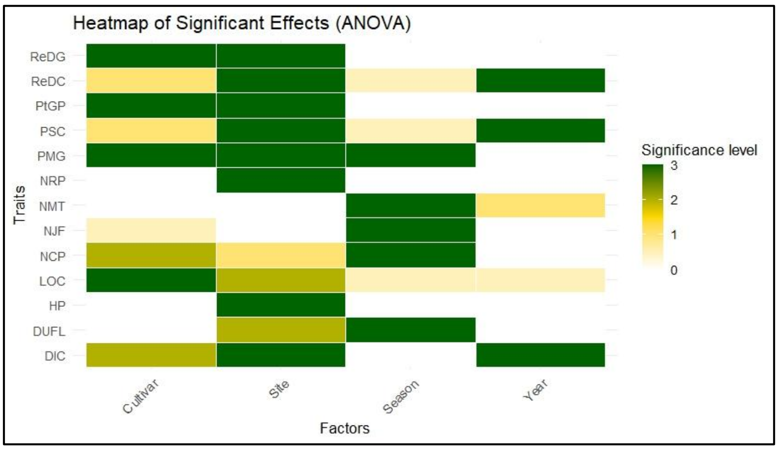

Figure 2. Analysis of variance of the studied cultivars.

3.2. Performance Variations of Genotypes

Table 3 presents the most prominent values among a broader set of results, highlighting the most significant differences between genotype-environment condition pairs. These differences were determined using the Tukey test, which identifies significantly distinct pairs. Nikiema and Saba show a constant difference of 1.0000000 in several comparisons, suggesting no notable variation between experimental conditions for these genotypes. The highest difference, 398.0335, was observed between the conditions Bakaridjan:Dapélélogo:Humide:2024 and Bakaridjan:Absouya:Humide:2023, indicating a marked variation between these two cultivation conditions. The lowest difference, 0.0000021, was recorded for the pair Bala:Laye:Humide:2023-Bala:Absouya:Humide:2023, reflecting an extremely low variation between these two environments.

Table 3. Performance Differences Between Genotypes Under Different Climatic Conditions in 2023 and 2024.

Pair	Difference
Bakaridjan:Dapélélogo:Humide:2023-Bakaridjan:Absouya:Humide:2023	186.455
Bala:Dapélélogo:Humide:2023-Bakaridjan:Absouya:Humide:2023	239.270
Bala:Absouya:Seche:2024-Bala:Absouya:Humide:2023	64.53083
Konde:Absouya:Seche:2024-Bala:Absouya:Humide:2023	117.3275
Nikiema:Dapélélogo:Seche:2023-Bakaridjan:Absouya:Humide:2023	95.8569
Bakaridjan:Dapélélogo:Humide:2024-Bakaridjan:Absouya:Humide:2023	398.0335
Konde:Laye:Seche:2024-Bakaridjan:Absouya:Humide:2023	275.0505
Kongkrou:Laye:Seche:2024-Bakaridjan:Absouya:Humide:2023	264.8438

The value of 264.8438 corresponds to the difference observed between the conditions Kongkrou:Laye:Seche:2024 and Bakaridjan:Absouya:Humide:2023. Finally, the difference of 239.270 measured for the genotype Bala between the conditions Dapélélogo:Humide:2023 and Absouya:Humide:2023 reflects performance variation between two specific cultivation environments. Similarly, the difference of 117.327 observed for the genotype Konde between the conditions Absouya:Seche:2024 and Absouya:Humide:2023 highlights a notable difference between these two environments, one being dry and the other humid.

3.3. Distribution of Mean AMIR indices by Cultivar

The cultivar Kongkrou has a mean index of 1.48. For the cultivar Nikiema, its mean index is estimated at 0.99. The cultivar Saba shows a mean index of 0.75. A mean index of 0.70 is recorded for the cultivar Konde. The cultivar Zangou registers a mean index of 0.30. Regarding the cultivar Souroukoudingan, the mean index is -0.36. The cultivar Yirini obtained an average value of -0.40. A value of -0.43 was observed for the cultivar Gando. The cultivar Bala is characterized by a mean index of -0.80. Finally, the mean index measured for the cultivar Bakaridjan is -2.25 (Figure 3).

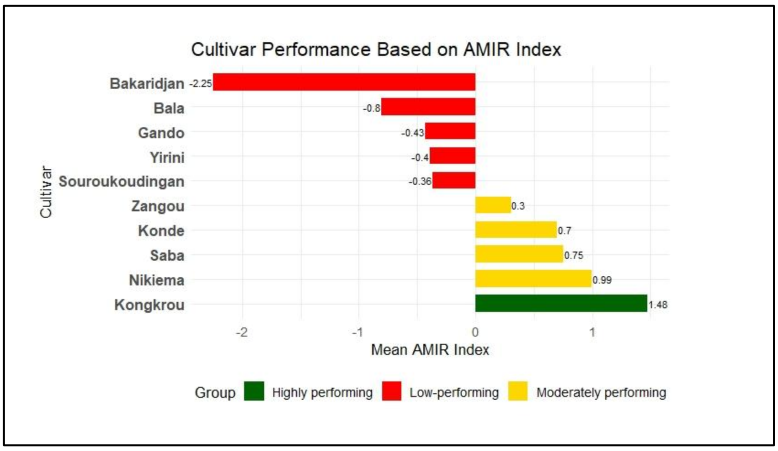

Figure 3. Performance ranking of cultivars.

3.4. Response of Cultivars to Environmental Variability

The graph illustrates the stability analysis of ten cultivars (Bakaridjan, Bala, Gando, Konde, Kongkrou, Nikiema, Saba, Souroukoudingan, Yirini, and Zangou) using the Finlay-Wilkinson regression method. The x-axis represents the environmental index, defined as the mean AMIR (aggregated performance index) for each environment. The y-axis shows the observed AMIR values for each cultivar × environment combination. For each cultivar, a regression line was fitted to model the genotype's response to environmental condition variations. The colored points correspond to individual observations, reflecting performances obtained in each tested environment. Cultivar names are listed in the legend to facilitate comparison of their respective behaviors. Results reveal that most cultivars have positive regression slopes, indicating improved performance under more favorable environmental conditions. However, the intensity of this response (slope) and the dispersion of points around the regression lines vary notably among genotypes. Some cultivars, such as Bakaridjan, Nikiema, Saba, and Konde, show regular linear trends with low dispersion, suggesting good stability in their performances.

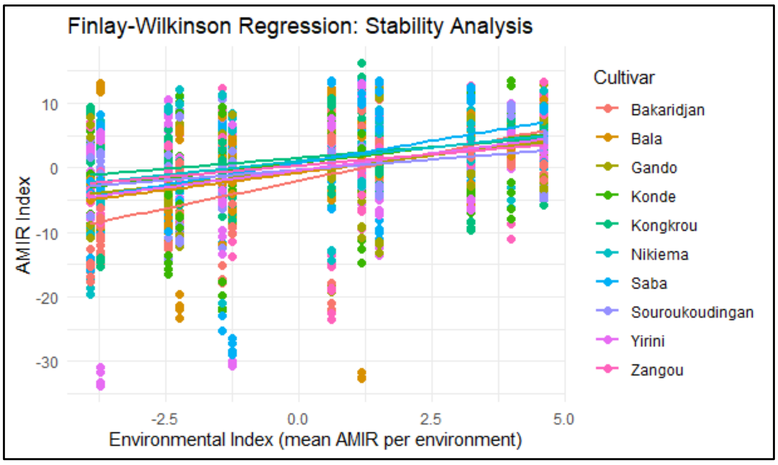

Figure 4. Response of cultivars to different environments.

Conversely, genotypes like Bala and Souroukoudingan display greater variability, with sometimes negative extreme values, indicating increased sensitivity to environmental effects. Overall, this graph simultaneously visualizes the stability (point dispersion) and responsiveness (regression slope) of different cultivars to environmental variability (Figure 4). These contrasting profiles provide a valuable basis for guiding varietal selection decisions, especially favoring genotypes that are both high-performing and stable across diverse agroecological contexts.

3.5. Evaluation of Seasonal Stability of Cultivars

The analysis focuses on ten cultivars evaluated by the AMIR index according to the seasonal index. The x-axis represents the seasonal index, which mainly ranges between -0.3 and +0.3. The y-axis shows the AMIR index for each observation, with values ranging from approximately -30 to +12. Each point represents the performance of a cultivar during a given season. The regression lines per cultivar indicate the trend of the AMIR index in relation to the seasonal index. The regression slopes are generally low, some close to zero. Cultivars Bakaridjan, Nikiema, Saba, and Kongkrou show nearly horizontal lines. Other cultivars, such as Souroukoudingan and Bala, display greater point dispersion and steeper slopes. Extreme AMIR values are noted, particularly for Zangou and Gando, with negative indices reaching -30. Data are mainly clustered around two seasonal index values near -0.25 and +0.25 (Figure 5).

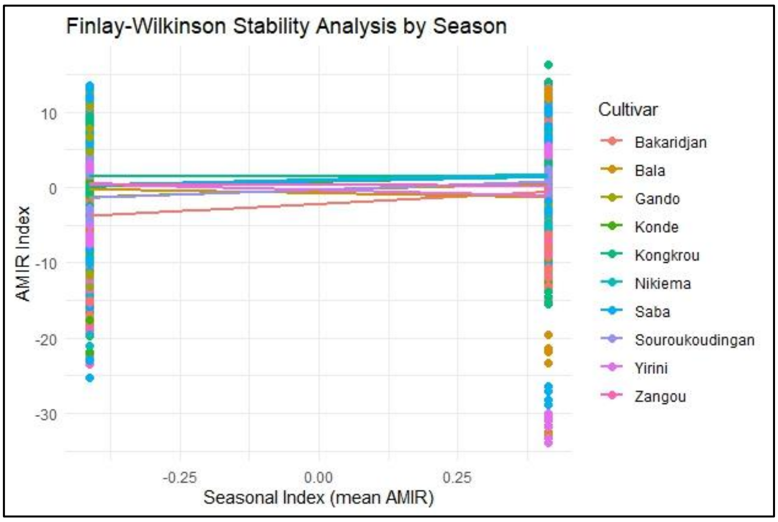

Figure 5. Response of cultivars to different seasons in Burkina Faso.

3.6. Distribution of Cultivars According to Seasons

The rainy season is positioned in the upper left part of the graph, with a negative value on the PC1 axis and a positive value on the PC2 axis. Conversely, the dry season is located in the lower right area, characterized by a positive value on the PC1 axis and a negative value on the PC2 axis. The cultivars are dispersed throughout the space defined by the two axes. Bakaridjan appears at the far left with a strongly negative score on PC1. Souroukoudingan and Gando are also located on the left side of the graph, in the upper part. Nikiema, Konde, Saba, and Kongkrou occupy the upper right area, with positive coordinates on both axes. Zangou is found in the lower right half, near the horizontal axis. Finally, Bala and Yirini are located in the lower quadrant, with negative scores on the vertical axis and close to zero on the horizontal axis (Figure 6).

4. Discussion

The heatmap analysis revealed a significant influence of the factors Cultivar and Site on the majority of the agro-morphological traits evaluated, including ReDG, PtGP, PSC, PMG, NRP, NCP, HP, and DUFL. This observation reflects both substantial genotypic variability and a sensitivity of these traits to the agroecological conditions specific to the experimental sites, as highlighted in several studies on genotype × environment interactions (Hailemariam Habtegebriel, 2022; Gauch, 2013). In contrast, the factor Year only affected a few traits, such as ReDC and DIC, suggesting that interannual variations were limited or that these traits exhibit temporal stability (Mühleisen et al., 2014). The factor Season, however, had a marginal effect, indicating either a small amplitude of seasonal contrasts or a certain tolerance of the genotypes to seasonal climatic variations (Gela et al., 2023).

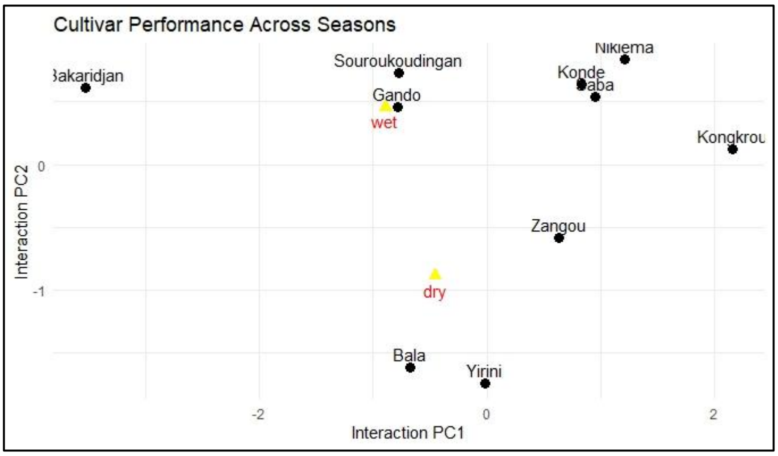

Figure 6. Adaptability of cultivars to the two seasons.

The results from the ANOVA showed significant differences between genotypes and environmental conditions for several of the measured traits. These differences were further explored using a Tukey test. The test revealed that the genotype Nikiema, as well as Saba, shows remarkable stability in their performance across different experimental conditions. This stability may be a sign of increased resilience to environmental variations, a characteristic sought for the development of varieties adapted to climate change. Conversely, other genotypes exhibited marked performance variations between different experimental conditions. These differences can be attributed to variations in abiotic factors such as temperature and humidity. The AMIR index was used to classify cultivars based on their overall performance, revealing three distinct groups. The first group, comprising Kongkrou, Nikiema, Saba, Konde, and Zangou, stands out with positive indices, indicating good adaptation to the experimental conditions. The second group, including Souroukoudingan, Yirini, and Gando, shows moderate performance, while the third group, consisting of Bala and Bakaridjan, displays significantly negative indices, indicating poor overall performance. The Finlay-Wilkinson approach applied to the stability analysis revealed differentiated behaviors among cultivars in response to seasonal variations. Most genotypes have regression slopes close to zero, indicating relative stability regardless of conditions. This stability is particularly pronounced in Nikiema and Kongkrou, making these cultivars strong candidates for agricultural systems exposed to high climatic variability (Mühleisen et al., 2014). In contrast, Souroukoudingan and Bala show higher sensitivity, characterized by steeper slopes and a significant dispersion in performance, indicating specific but unstable adaptation (Fox et al., 1990). Notable performance declines, particularly in Zangou and Gando in certain environments, highlight the importance of jointly evaluating stability and average performance (Ferreira et al., 2023). The AMMI analysis allowed for distinguishing genotypes based on their relative performance under contrasting conditions (Khan et al., 2024). Some cultivars, such as Bakaridjan, Souroukoudingan, and Gando, were found to be specifically adapted to the wet season, demonstrating better performance under favorable water conditions (Wu et al., 2023). In contrast, Nikiema, Konde, Saba, Kongkrou, and Zangou showed enhanced stability and productivity during the dry season, suggesting an ability to tolerate more severe water stress (Ruttanaprasert et al., 2025). The results of the Tukey test confirm these trends, with some genotypes showing significant performance differences between the dry and wet seasons, reflecting a specific adaptation to contrasting environments (Sarr et al., 2024). This result emphasizes the importance of considering seasonal variability in varietal selection strategies. The genetic diversity observed in local genotypes, combined with the stability of certain cultivars in response to climatic variations, represents a key lever for adaptation to climate change (Heslop et al., 2025). Some cultivars clearly position themselves in zones associated with either season, suggesting specific adaptation to contrasting environments, while others occupy intermediate positions, indicating phenotypic plasticity that allows them to maintain acceptable performance in diverse ecological contexts (Sultan, 2003). This genetic heterogeneity, highlighted by the Tukey test and AMMI analysis, can be leveraged in participatory breeding programs and the dynamic management of cultivated biodiversity, taking into account farmers' preferences and local constraints (Mancini et al., 2017).

5. Conclusion

The study conducted on ten local cultivars of White Roselle (*Hibiscus sabdariffa* var. *altissima*) revealed significant agro-morphological variability, indicative of differentiated adaptation potential to current climatic constraints in Burkina Faso. The Amir index, combined with stability analyses (Finlay-Wilkinson, Ammi), enabled the identification of genotypes combining both good agronomic performance and relative stability across seasons. Cultivars Kongkrou, Nikiema, Saba, and Konde notably stand out for their ability to maintain satisfactory yield in contrasting environments, while others, such as Bakaridjan and Bala, show marked sensitivity to environmental variability. These results confirm the relevance of endogenous approaches based on local genetic diversity to support climate change adaptation strategies.

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Supplementary Information Availability: Not applicable.

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