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Performance of six genotypes of *Hibiscus sabdariffa* L. under cultural practices and jassids influence

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Abstract: Roselle (*Hibiscus sabdariffa* L.), a plant in the Malvaceae family, is of vital importance because its leaves, calyxes and seeds are all consumed. However, this species is still absent from genetic improvement programs in Burkina Faso. The aim of this study was to gain a better understanding of its genetic potential and how this potential is expressed under agro-ecological intensification conditions in a real environment. To do this, six genotypes were tested with cropping practices such as organic fertilization and sowing densities. Qualitative and quantitative traits were measured, as well as the susceptibility of genotypes to attacks by jassids. The results revealed differences in the color, shape and physiological characteristics of the plants. Genotypes differed in growth cycle length, with HSE6 showing a shorter cycle and HSE1 a longer cycle. HSE4 and HSE5 were identified as the most productive. Cultivation practices had a significant influence: a sowing density of 0.4 m x 0.6 m and fertilization with poultry droppings (6000 kg/ha) gave the best performance. Conversely, the absence of fertilization adversely affected plant growth. Assessment of the damage caused by jassids shows uniformity of attack, with damage rates ranging from 26% to 50%. The impact of jassids should be studied in greater depth and more resistant genotypes should be explored.

1. Introduction

Traditional African vegetables, especially leafy vegetables, make a very

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important contribution to the human diet because they are rich in minerals and vitamins. They therefore contribute to the resilience of populations to food and nutritional insecurity (Kahane *et al.,* 2005; Dansi *et al.,* 2008). However, these vegetables have been marginalized and under-exploited with the introduction of exotic vegetables from temperate regions such as lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*) and leek (*Allium porrum*) (Abukutsa-Onyango, 2010).

These vegetables include roselle (*Hibiscus sabdariffa* L.), a plant of the Malvaceae family widely grown in several tropical regions and distinguished by two botanical varieties: *Hibiscus sabdariffa* var. *Sabdariffa*, commonly known as Roselle, and *Hibiscus sabdariffa* var. *Altissima* known as Mesta. It is a very important plant in terms of diet, as almost all its parts are consumed (Hama-Ba *et al.,* 2017). The purple-red calyxes are used to produce 'bissap' in Wolof, a drink much appreciated by the local population. In the past, Roselle was grown by women on small areas and mainly in association with other cereal crops or pulses for self-consumption (Ouoba *et al.,* 2016).

Nowadays, roselle is attracting growing interest because of its significant economic potential for producers and processors and its nutritional and therapeutic benefits (Cissé *et al.*, 2009). Despite its many advantages, roselle cultivation in Burkina Faso faces a number of challenges, including a lack of varieties with high yield potential and cultivation practices adapted to the new environmental conditions imposed by climate change. Climate change has posed new challenges for agriculture in tropical regions, with rising temperatures having a negative impact on crop production due to limited water availability, resulting in sub-optimal fruiting (Gornall *et al.,* 2010). Also, the increase in humidity and temperature has made crops more vulnerable to infestations of insect pests that thrive in these conditions, resulting in the expansion of their geographical ranges and an increased risk of insect pest infestations on plants (Naeem-Ullah *et al.,* 2020). It was in such a hostile environment that, during the 2022/2023 wet season agricultural campaign, the Plant Protection Directorate made the chilling report of the appearance in Burkina Faso of a jassid species [*Amrasca biguttula* (Ishida) (Hemiptera: Cicadellidae)]. Over 617,000 hectares of cotton were infested, with huge losses. Other crops such as roselle and okra were also attacked, and the damage was spectacular (Sawadogo *et al.,* 2023).

These many new constraints mean that production of this crop is unable to meet market demand, despite the growing popularity of the crop. Faced with the need to optimize yields while preserving ecosystems, agro-ecological intensification is emerging as a promising solution. The selection of genotypes with high yield potential adapted to the new environmental conditions, in particular parasitic and abiotic pressure, combined with agro-ecological intensification practices in agrosystems, is therefore necessary to relaunch bissap production in Burkina Faso. However, few studies have been carried out to assess the reaction of different *Hibiscus sabdariffa* genotypes to this approach in a Sudano-Sahelian environment. This is why knowledge of the genetic potential and the expression of this potential under agro-ecological intensification conditions in a real environment is becoming an important step in the development of innovative technological packages to increase the productivity of bissaps in Burkina Faso. Hence the interest of this study, which aims to assess the variability and agromorphological performance of the most widely grown genotypes in Burkina Faso in a real environment.

2. Materials and Methods

Site of study

This study was carried out at the Center for Environmental, Agricultural and Training Research (CREAF) in Kamboinsé (Ouagadougou) during 2024-2025 agricultural season. Geographical coordinates are 12°28 N latitude and 1°32 W longitude, with an altitude of around 296 m above sea level. The site is located in the northern Sudanese zone, with a long dry season from November to May and a short rainy season from June to October (Thiombiano and Kampmann, 2010). Average temperatures vary between 27°C and 31°C in the cold and hot periods respectively. During the 2024-2025 season of the trial, total rainfall was 970.7 mm. The Kamboinsé soils are classified as leached tropical ferruginous soils with a silty-clay or silty-sandy texture.

Plant material

The plant material used for this experiment consisted of six roselle genotypes. Five genotypes (HSE1 HSE2, HSE3, HSE4, and HSE5) came from

Burkina Faso and one genotype (HSE6) from Niger.

Experimental design

The experiment was arranged in a split-split-plot design with three replicates, spaced 1.5 m apart. Each replicate comprised two sowing densities [0.40×0.40 m (D1) and 0.60×0.40 m (D2)] which constituted the main plots. For D1, each main plot consisted of six sub-plots measuring 2×4 m, whereas for D2 each main plot consisted of six sub-plots measuring 3×4 m, giving a total of 12 sub-plots per replicate. Each sub-plot comprised six rows corresponding to the six genotypes, with 11 planting hills per row. The spacing between main plots and between sub-plots was 1.0 m and 0.8 m, respectively. Fertilization treatments (Table 1) were randomly assigned to the plots. The sowing was done with 6 holes per planting row, followed by thinning to one plant per hole at 21 days after sowing. The plots were regularly weeded as needed. Due to the early cessation of rainfall, supplementary irrigation was provided as needed until harvest.

Table 1 - Fertilizer regimes applied in the experiment

Fertilizer code	Description
F0	Unfertilized control
F3000	Poultry manure applied at 3000 kg ha^{-1}
F4000	Poultry droppings graded at 4000 kg/ha
F5000	Poultry droppings graded at 5000 kg/ha
F6000	Poultry droppings graded at 6000 kg/ha
ASS	Intercropping with bambara groundnut (*Vigna subterranea*)

Data collection

A total of 25 variables were recorded. The choice of variables and data collection periods were based on some previous studies (Sharma *et al.*, 2016; Ouangraoua, 2023), and on the use of the roselle descriptor (Daudu *et al.*, 2019). These variables were classified into qualitative and quantitative variables. The various measurements were taken on five plants per row.

Qualitative parameters

Harvesting was carried out at physiological maturity. Qualitative traits were evaluated either in the field or after harvest, depending on the organ and trait considered. Vegetative traits, including leaf color, petiole color, leaf shape, leaf pubescence, stem color, stem pubescence, calyx color, calyx shape and calyx pubescence, were visually assessed in the field at maturity. Flower color was visually observed at the flowering stage. Seed traits, namely seed shape, seed color, and seed pubescence, were assessed after harvest using an optical microscope. All color-related traits were evaluated by direct visual observation and were based roselle descriptor (Daudu *et al.*, 2019).

Quantitative parameters

Twelve quantitative traits were considered into three groups according to phenology, physiology and agronomic parameters. For phenology-related parameters, days to 50% flower bud formation (FBF50), days to first flowering (FFLO), days to 50% flowering (FLO50), and days to 50% calyx maturity (MAT50) were recorded. Physiological and agronomic parameters were measured on five plants per line and concerned plant height (PlanH), stem diameter (DiaSt), number of branches (NBR), calyx length (LogCal), calyx width (WiCal) as physiological parameters and the number of calyx per plant (CalP), dry calyx yield (YieCal) and seed yield (YieSd) as agronomic parameters. Yield was estimated using the formula:

$$\text{Rdt (kg/ha)} = [(10000\ \text{m}^2\ /\text{density}) \times (\text{weight (calyx or seed)} / \text{NBR})]/1000$$

Assessment of jassids damage on Hibiscus sabdariffa genotypes

Foliar damage caused by jassids on *Hibiscus sabdariffa* genotypes was assessed using a foliar damage scoring scale as proposed by Simon *et al.* (2018): 0= no foliar damage; 1= 25% of leaves damaged; 2= 26-50% of leaves damaged; 3= 70% of leaves damaged; 4= 100% of leaves damaged; 5= complete defoliation.

Statistical analysis

The data collected were entered and processed in Excel 2016. An analysis of variance (ANOVA) was performed using XLSTAT 2019 software to identify the traits that discriminate between genotypes. Means were compared using the Student Newman Keuls test with a threshold of 5%. Relationships between quantitative characteristics were estimated using the Pearson correlation matrix. Structuring of agromorphological diversity was estimated by principal component analysis (PCA) followed by hierarchical ascending classification using Ward's aggregation method and Euclidean distance at the 5% threshold. These analyses of variance highlighted the influences of the various factors (genotypes, fertilization and sowing density) and their interactions on the agronomic performance of the genotypes studied.

3. Results

Variability of qualitative traits among roselle genotypes

The six genotypes showed high leaf variability (Table 2). In fact, these genotypes showed five different leaf characteristics: acute green leaves, not pubescent; rounded green leaves, not pubescent; rounded violet-green leaves, not pubescent; acute violet-green leaves, not pubescent; and rounded light green leaves, pubescent (Fig. 1). The petioles of these leaves were either red, deep red, light red or light green. They had four types of stems which were either red, deep red, light red or light green with or without pubescence. The calyxes of all the genotypes were pubescent and were either long or short. The difference between the calyxes of the different genotypes was basically in their color. Calyxes were either red, light red, deep red or white (Fig. 1). Flowers coloration exhibited considerably variability, ranging from violet with purple pigmentation at the base to dark violet with purple pigmentation at the base, including intermediate forms such as pale violet with basal purple pigmentation as well as pale yellow flowers (Fig. 1). The seeds were all pubescent, angular or kidney-shaped and black or brown in color (Table 2).

Table 2 - Frequency distribution of qualitative traits among the six roselle genotypes

Qualitative parameter	Category	Frequency (%)
Leaf color	Green-violet	33.33
	Green	50.00
	Light green	16.67
Leaf shape	Rounded	50.00
	High	50.00
Leaf pubescence	No	83.33
	Yes	16.67
Stem color	Red	33.33
	Light red	16.67
	Deep red	33.33
	Light green	16.67
Stem pubescence	No	83.33
	Yes	16.67
Petiole color	Red	33.33
	Light red	16.67
	Deep red	33.33
	Green	16.67
Calyx shape	Long	83.33
	Short	16.67
Calyx color	Red	33.33
	Light red	16.67
	Deep red	33.33
	White	16.67
Calyx pubescence	Yes	100
Seed color	Brown	66.67
	Black	33.33
Seed shape	Reniform	33.33
	Angular	66.67
Seed pubescence	Yes	100
Flower color	Pale violet with purple pigmentation at the base	16.66
	Violet with purple pigmentation at the base	50.00
	Pale yellow	16.66
	Deep violet with purple pigmentation at the base	16.66

Fig. 1 - Variability of floral organs and leaves in the six genotypes: a = rounded, non-pubescent violet-green leaves; b = acute, non-pubescent violet-green leaves; c = acute, non-pubescent green leaves; d= rounded, non-pubescent green leaves; e = violet flower with purple pigmentation at the base; f = pale violet flower with purple pigmentation at the base; g = pale yellow flower; h = dark violet flower with purple pigmentation at the base; i = red calyx; j = light red calyx; k = dark red calyx; l = white calyx.

The colour of the leaves varied from green to purple-green, with green leaves predominating (50%), while the shape of the leaves was evenly distributed between rounded and tall shapes (50%

each). The majority of genotypes (83.33%) did not exhibit leaf pubescence, reflecting a general tendency towards glabrescence. With regard to the stem, marked variability in pigmentation was observed, with shades ranging from light red to dark red, while green stems remained in the minority. As with the foliage, non-pubescence dominates (83.33%). At the floral level, most genotypes (83.33%) had a long calyx, a dominant morphological characteristic within the studied group. The colour of the calyx showed wide variability, with a strong predominance of red hues (red, light red and dark red accounting for 83.33%), while white calyxes were rare (16.67%). On the other hand, calyx pubescence was a constant characteristic, observed in all genotypes (100%). Seed characteristics also revealed some diversity: brown was the dominant colour (66.67%), followed by black (33.33%), while angular shapes (66.67%) were more common than kidney-shaped ones (33.33%). Finally, flower color showed considerable variability, with purple pigmentation at the base (50%) being predominant, whereas lighter or darker shades (pale purple, deep purple or pale yellow) were less frequent.

Variability of quantitative traits among roselle genotypes

Figure 2 shows the results of the mean separation for the traits determining the growth cycle of the six genotypes, namely the timing of flower bud appearance, flowering and calyx maturity, Significant differences were observed for all variables ($p<0.0001$).

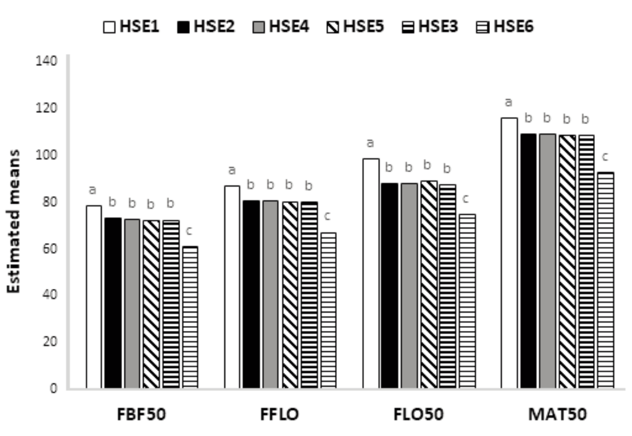

Fig. 2 - Variability in phenological traits of roselle genotypes. FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity.

HSE6 was the earliest maturing genotype, with mean values of 61 days to 50% flower bud formation (FBF50), 75 days to first flowering (FFLO), and 92 days to 50% calyx maturity (MAT50). Genotype HSE1 had the latest flower bud formation (78 days), flowering (98 days) and calyx maturity (116 days). Genotypes HSE2, HSE3, HSE4 and HSE5 had intermediate periods of flower bud formation (72 days), flowering (88 days) and calyx maturity (108 days).

The results of mean separation for physiological traits are shown in figure 3. Highly significant differences were observed for all traits ($P<0.0001$). The highest plant height (PlanH) and stem diameter (DiaSt) were reordered for genotype HSE4, with mean values of 86.9 cm and 11.2 mm, respectively, whereas the lowest values were observed in genotype HSE6 (71.2 cm and 9.4 mm, respectively). In terms of capsules size, genotype HSE1 had the longest capsules (46.4 mm) but the smallest diameter (22.8 mm). In contrast, genotype HSE6 showed the widest (25.9 mm) and shortest capsules (42.2 mm). Genotype HSE2 was the most branched with an average of 23.6 branches per plant, while genotype HSE6 was the least branched, with an average of 17.3 branches per plant.

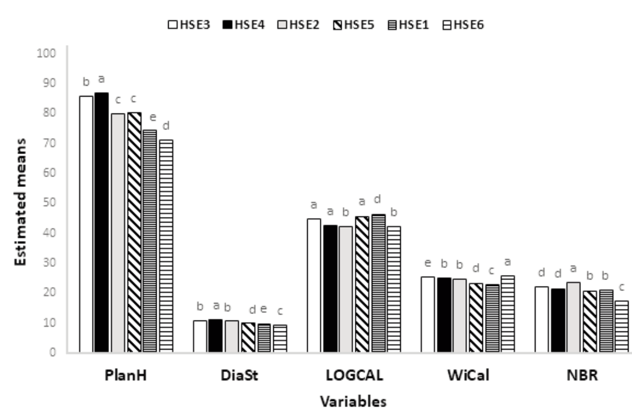

Fig. 3 - Variability in physiological traits of roselle genotypes. PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches.

Mean separation for agronomic traits are given in figure 4. Significant difference among the six genotypes were observed for the average number of capsules per plant (CalP) and grain yield ($p<0.0001$). For the number of capsules per plant (CalP), genotypes HSE1 and HSE6 obtained the highest and lowest values, with values of 14.72 and 8.85 respectively. For seeds yield (YieSd), the highest and lowest values were obtained by genotypes HSE5 (156.36 kg/ha) and HSE1 (98.29 kg/ha). Dry calyx yield (YieCal) showed no significant difference between genotypes.

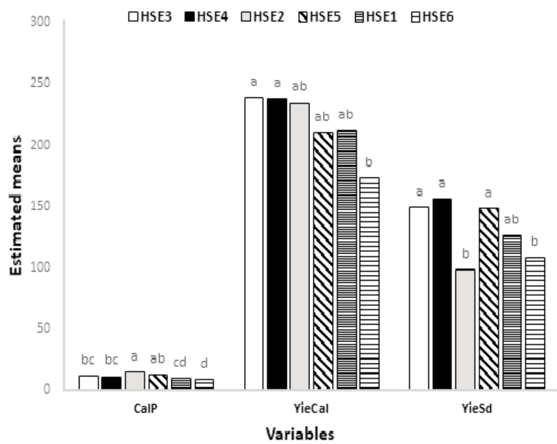

Fig. 4 - Variability in agronomic traits of roselle genotypes. CalP= number of capsules per plant; YieCal= dry calyx yield; YieSd= seed yield.

Structuring phenotypic variability

The results of the principal component analysis (PCA) indicated the contribution of each variable to the formation of the axes (Fig. 5, Table 3). Projection of the variables onto the F1/F2 plane (Fig. 5) showed that the first two axes explained 86.76% of the total variability (Fig. 5). Thus, the F1 axis, with 61.80% of the total

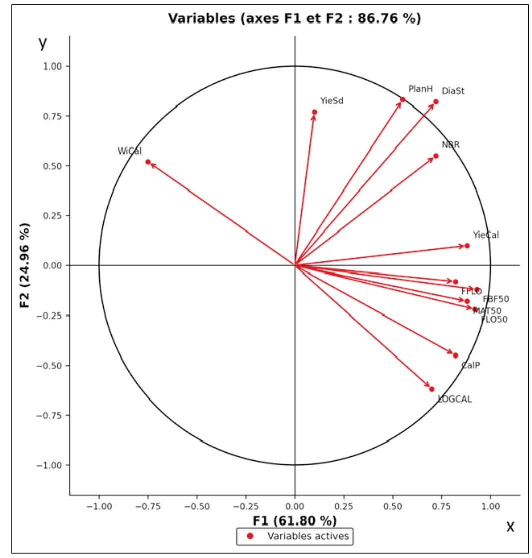

Fig. 5 - Projection of variables in the PCA F1/F2 plane. FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity; PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches per plant; CalP= number of calyx per plant; YieCal= dry calyx yield; YieSd = seed yield.

inertia, associates days to bud formation (FBF50) (r=0.972), days to appearance of the first flower (FFLO) (r=0.980), days to 50% flowering (FLO50) (r=0.928), days to 50% calyx maturity (MAT50) (r=0.982), the number of branches per plant (NBR) (r=0.554), calyx width (WiCal) (r=0.609), the number of capsules per plant (CalP) (r=0.650), and calyx yield (YieCal) (r=0.824). The F1 axis is therefore the productivity axis and the axis that defines the cycle.

Table 3 - Value of the cosines squared linking the twelve quantitative characteristics and the PCA factor

Variables	F1	F2	F3	F4	F5
FBF50	**0.972**	0.005	0.012	0.010	0.001
FFLO	**0.980**	0.006	0.007	0.007	0.001
FLO50	**0.928**	0.060	0.006	0.006	0.000
MAT50	**0.982**	0.004	0.005	0.009	0.001
PlanH	0.214	**0.654**	0.040	0.083	0.010
DiaSt	0.290	**0.684**	0.006	0.008	0.011
LOGCAL	**0.349**	0.339	0.227	0.061	0.024
WiCal	**0.609**	0.265	0.038	0.082	0.006
NBR	**0.554**	0.255	0.089	0.000	0.102
CalP	**0.650**	0.117	0.121	0.082	0.030
YieCal	**0.824**	0.007	0.092	0.011	0.066
YieSd	0.063	**0.599**	0.105	0.217	0.016

FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity; PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches per plant; CalP= number of calyx per plant; YieCal= dry calyx yield; YieSd= seed yield.

The F2 axis, which accounts for 24.96% of total inertia, has a positive association with height (r=0.654) and stem diameter (DiaSt) (r=0.654). This axis can be described as a growth axis.

Structure of the diversity of the six genotypes studied

Hierarchical and ascending classification (HEC) was used to structure the genotypes into 4 groups (Fig. 6). The first group consisted of HSE1, which is characterized by a to a longer growth cycle of 120 days after sowing and a large number of calyxes (14.720). The second group, made up of two genotypes, HSE2 and HSE3, was characterized by a cycle of 108 days, an average stem height of 79.943 cm and an average number of bolls of 12.310, with an average yield of 209.838 kg/ha of calyx. The third group was made up of two genotypes, HSE4 and HSE5, which were particularly characterized by their high calyx yield (237.500 kg/ha). The fourth and final group was characterized by its very early ripening days, low number of bolls (8.848) and low yield (173.206).

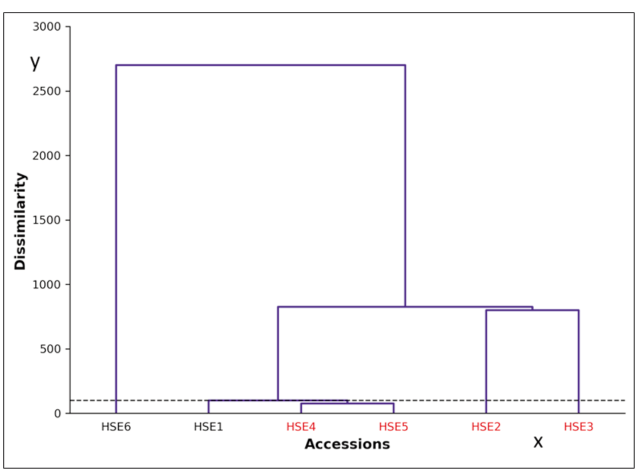

Fig. 6 - Genotype dendrogram.

Influence of cultural practices on genotypes performances

Analysis of variance indicated no significant effect of fertilization on phenological parameters at the 5% level. In contrast, fertilization had a significant effect on physiological traits, specifically plant height, stem diameter, and number of branches (Fig. 7) and agronomic traits (Fig. 8). The dose of 6000 kg/ha of poultry droppings (F6000) recorded the greatest height (87.703 cm) and diameter (11.517 mm), while the dose of 5000 kg/ha of poultry droppings (F5000) recorded the highest number of branches (23.263). On the other hand, the lowest values for height,

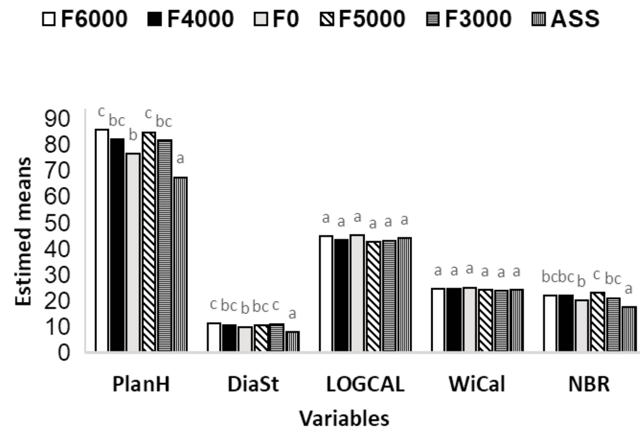

Fig. 7 - Performance of six genotypes for physiological traits under different organic fertilization regimes. PlanH= plant height ($p< 0.0001$); DiaSt= stem diameter ($p<0.0001$); LOGCAL= calyx length ($p= 0.74$); WiCal= calyx width ($p= 0.885$); NBR= number of branches ($p<0.0001$).

diameter and branching were observed in intercropping with Bambara groundnut (ASS), with values of 67.676 cm, 8.165 mm and 17.660 respectively. As for the length and width of the capsules, no significant differences were observed in any of the treatments.

The F6000 treatment resulted in the highest calyx and seed yields, reaching 256.973 kg ha^{-1} and 151.833 kg ha^{-1}, respectively (Fig. 8). Conversely, intercropping with Bambara groundnut treatment produced the lowest yields, with calyx and seed yields of 143.248 kg ha^{-1} and 89.178 kg ha^{-1},

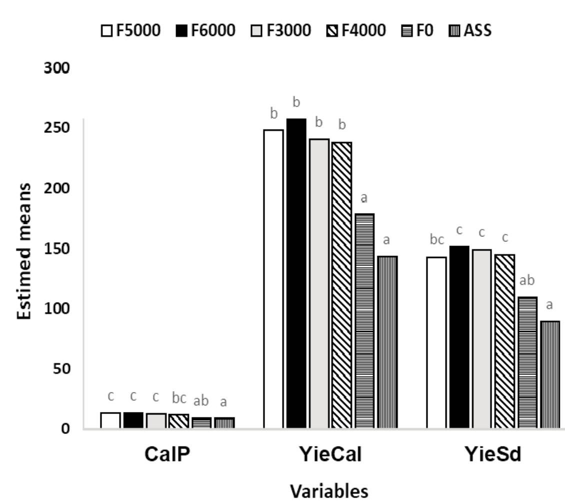

Fig. 8 - Performance of six genotypes for agronomic traits under different organic fertilization regimes. CalP= number of calyx per plant ($p< 0.0001$); YieCal= dry calyx yield ($p=0.000$); YieSd= seed yield ($p=0.000$).

respectively. Similarly, the average number of capsules per plant was maximized under F5000 and F6000 (13.5), whereas the lowest value was recorded under intercropping with Bambara groundnut (8.710).

Effect of sowing density on genotypes performances

Analysis of variance showed that sowing density had no significant effect on phenological parameters related to days to 50% flower bud formation (FBF50), days to first flowering (FFLO), days to 50% flowering (FLO50), days to 50% calyx maturity (MAT50) which showed respective p-values of 0.694, 0.524, 0.382 and 0.487. These results show that sowing density did not influence the duration of the growth cycle of the genotypes studied. In contrast, sowing density significantly affected several physiological traits (Fig. 9). Higher density (D2) resulted in greater calyx length and width, as well as a higher number of branches per plant, while plant height and stem diameter were not significantly influenced by density. Overall, plants grown at D2 exhibited more vigorous vegetative development.

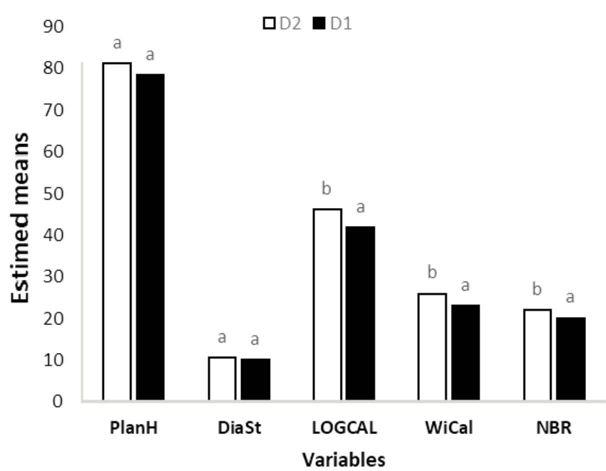

Fig. 9 - Effect of plant density on physiological parameters. PlanH= plant height (p=0.139); DiaSt= stem diameter (p=0.117); LOGCAL= calyx length (p< 0.0001); WiCal= calyx width (p< 0.0001); NBR= number of branches (p=0.004); G= genotype; D= sowing density.

Sowing density also had a significant impact on agronomic performance. The higher density (D2) consistently produced superior results, with an increased number of bolls per plant and higher calyx and seed yields compared with the lower density. These results indicate that increasing sowing density improved yield-related traits without affecting the phenological development of roselle genotypes.

For all agronomic parameters for the results of analyses of variance revealed significant differences between sowing densities at the 5 % threshold. Separation of the averages shows that the best yields were obtained with density D2, with values of 13.146 for the number of bolls, 243.789 kg/ha for calyx yield and 149.614 kg/ha for seed yield (Fig. 10).

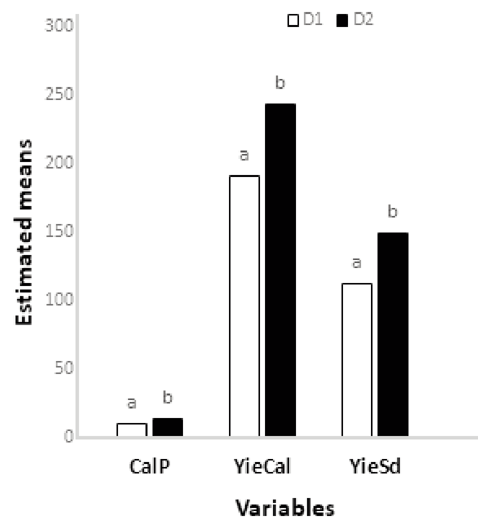

Fig. 10 - Effect of plant density on physiological parameters. PlanH= plant height (p=0.139); DiaSt= stem diameter (p=0.117); LOGCAL= calyx length (p< 0.0001); WiCal= calyx width (p< 0.0001); NBR= number of branches (p=0.004); G= genotype; D= sowing density.

Interactions between different factors

The analysis of variance revealed both significant and non-significant interactions between genotypes and fertilization regimes across the studied parameters (Table 4). Significant interactions were observed for flowering traits (FBF50, FFLO, and FLO50), maturity (MAT50), plant height (PlanH), stem diameter (DiaSt), number of branches per plant (NBR), number of bolls, and grain yield, indicating that the response to fertilization varied among genotypes and, conversely, that genotype performance depended on the fertilization regime. In contrast, calyx yield and calyx dimensions (length and width) did not show significant interactions.

Concerning genotype × sowing density interaction, significant interactions between genotypes and sowing densities were detected for all the parameters analyzed (Table 5), demonstrating that genotype responses were strongly influenced by plant density and vice versa.

As for fertilization regime × sowing density interaction, the interaction between fertilization regime and sowing density resulted in both

Table 4 - Analysis of variance of the genotype × fertilization regime interaction

Parameters	Source	DoF	Sum of squares	Mean square	Frequency	Pr > F
FBF50	Gen *X* Fert	35	6005.12	171.57	32.70	< 0.0001
FFLO	Gen *X* Fert	35	7706.04	220.17	37.64	< 0.0001
FLO50	Gen *X* Fert	35	11052.15	315.78	23.31	< 0.0001
MAT50	Gen *X* Fert	35	11135.43	318.15	84.09	< 0.0001
PlanH	Gen *X* Fert	35	17225.73	492.16	3.57	< 0.0001
DiaSt	Gen *X* Fert	35	383.68	10.97	3.16	< 0.0001
LOGCAL	Gen *X* Fert	35	1769.19	50.55	0.82	0.753
WiCal	Gen *X* Fert	35	548.78	15.68	0.77	0.820
NBR	Gen *X* Fert	35	1792.78	51.22	2.71	< 0.0001
CalP	Gen *X* Fert	35	1929.29	55.12	2.37	0.000
YieCal	Gen *X* Fert	35	720263.63	20578.96	1.42	0.073
YieSd	Gen *X* Fert	35	368666.82	10533.34	2.30	0.000

FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity; PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches per plant; CalP= number of calyx per plant; YieCal= dry calyx yield; YieSd= seed yield.

Table 5 - Analysis of variance of the genotype × sowing density interaction

Parameters	Source	DoF	Sum of squares	Mean square	Frequency	Pr > F
FBF50	G *X* D	11	5856.90	532.45	99.40	< 0.0001
FFLO	G *X* D	11	7547.93	686.17	115.58	< 0.0001
FLO50	G *X* D	11	10515.37	955.94	65.54	< 0.0001
MAT50	G *X* D	11	11084.87	1007.71	281.01	< 0.0001
PlanH	G *X* D	11	8228.68	748.06	4.51	< 0.0001
DiaSt	G *X* D	11	99.22	9.02	2.02	0.028
LOGCAL	G *X* D	11	1994.32	181.30	3.40	0.000
WiCal	G *X* D	11	758.76	68.98	4.067	< 0.0001
NBR	G *X* D	11	1044.64	94.97	4.67	< 0.0001
CalP	G *X* D	11	1483.35	134.85	5.93	< 0.0001
YieCal	G *X* D	11	312840.40	28440.04	1.93	0.038
YieSd	G *X* D	11	193779.50	17616.32	3.60	0.000

FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity; PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches per plant; CalP= number of calyx per plant; YieCal= dry calyx yield; YieSd= seed yield.

significant and non-significant effects on the evaluated traits (Table 6). Significant interactions were found for plant height (PlanH), stem diameter (DiaSt), number of branches per plant (NBR), number of calyx per plant (CalP), calyx length (LOGCAL), calyx width (WiCal), calyx yield (YieCal), and seed yield (YieSd). Conversely, phenological traits related to the crop cycle - namely flowering (FBF50, FFLO, FLO50) and maturity (MAT50) - were not significantly affected by this interaction.

Susceptibility of genotypes to jassid attack

The symptoms observed with jassid attacks on the different genotypes of *H. sabdariffa* are essentially yellowing of the leaves from the edges (Fig. 11a), inward rolling of the leaves (Fig. 11a), production of small leaves (Fig. 11b), stunted growth (Fig. 11b) and reddening of the leaves (Fig. 11c). The severity of leafhopper attacks on roselle varied from 2.5 for genotype HSE1 to 2.91 for genotype HSE6 (Table 7). These results show a uniformity of jassid attacks,

Table 6 - Analysis of variance of the fertilization regime × sowing density interaction

Parameters	Source	DoF	Sum of squares	Mean square	Frequency	Pr > F
FBF50	Fert *X* D	11	49.57	4.51	0.13	1.000
FFLO	Fert *X* D	11	57.37	5.21	0.12	1.000
FLO50	Fert *X* D	11	203.81	18.53	0.28	0.988
MAT50	Fert *X* D	11	99.54	9.05	0.16	0.999
PlanH	Fert *X* D	11	10380.25	943.66	6.08	< 0.0001
DiaSt	Fert *X* D	11	320.24	29.11	8.63	< 0.0001
LogCal	Fert *X* D	11	1992.87	181.17	3.40	0.000
WiCal	Fert *X* D	11	587.67	53.42	3.00	0.001
NBR	Fert *X* D	11	1076.85	97.89	4.85	< 0.0001
CalP	Fert *X* D	11	1560.98	141.91	6.35	< 0.0001
YieCal	Fert *X* D	11	626126.15	56920.56	4.30	< 0.0001
YieSd	Fert *X* D	11	230782.33	20980.21	4.45	< 0.0001

FBF50= days to 50% flower bud formation; FFLO= days to first flowering; FLO50= days to 50% flowering; MAT50= days to 50% calyx maturity; PlanH= plant height; DiaSt= stem diameter; LOGCAL= calyx length; WiCal= calyx width; NBR= number of branches per plant; CalP= number of calyx per plant; YieCal= dry calyx yield; YieSd= seed yield.

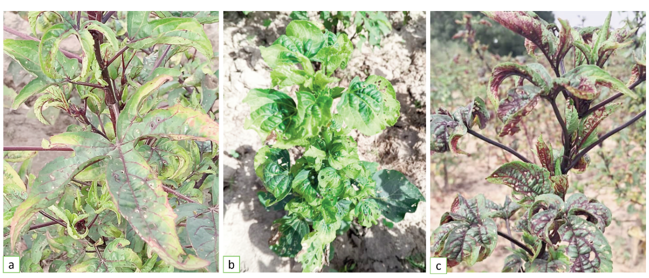

Fig. 11 - Symptoms of jassid attacks on roselle. a) yellowing of leaves from the edges and inward rolling of leaves; b) stunted growth and production of small leaves; c) reddening of leaves.

Table 7 - Severity of jassid attacks on roselle

Genotypes	Severity index
HSE6	2.91
HSE4	2.87
HSE2	2.86
HSE3	2.83
HSE5	2.77
HSE1	2.49

with damage rates ranging from 26 to 50 % of leaves damaged.

4. Discussion and Conclusions

A number of qualitative and quantitative variables enabled clear discrimination among the six roselle genotypes. These genotypes were distinguished by the colouring of their aerial organs (red and green), the shape of their leaves, their calyxes and their seeds. Similar discriminating traits have been reported by Konaté (2024) and Ouangraoua (2023) for *Hibiscus sabdariffa* accessions. This diversity of color and shape could be due to the ploidy of the species, as it is an allotetraploid plant (Salehi *et al.*, 2022). According to Combes Gavalda (2015), allotetraploid plants have great genetic diversity, due to their origin from interspecific hybridization followed by chromosome doubling. This process results in the coexistence of two distinct but homologous genomes within the same organism. The presence of duplicated genes (homeologs) increases allelic variation and allows for gene redundancy, subfunctionalization, or neofunctionalization. Moreover, differential regulation of these genes contributes to phenotypic plasticity, enabling allotetraploid plants to express multiple phenotypes and enhancing their adaptive potential under varying environmental conditions. In addition, the species' allogamy rate, although insignificant (1%), can contribute to cross-fertilization, resulting in natural genetic mixing. This great variability in colour reflects the plant's synthesis of anthocyanins, which is a drought tolerance factor for the plant (Palé *et al.*, 2004). Analysis of quantitative characteristics showed a highly significant difference at the 5% threshold for grain yield, number of branches and bolls, flowering and ripening periods, height, stem diameter and boll width and length, indicating significant agro-morphological variability within genotypes. Such diversity provides opportunities for growers to select cultivars according to production objectives and consumer preferences (Ouangraoua, 2023). In addition to the variability, several negative and positive correlations were observed between certain variables. Negative correlations between flowering and ripening times and the number of bolls indicate that late-flowering and late-ripening genotypes produce lower yields and smaller bolls. On the other hand, the positive correlations observed between the period of flower bud formation and flowering, maturity, calyx length, number of bolls and yield suggested that short-cycle genotypes are more productive. These patterns can be partly explained by rainfall distribution. Early-flowering genotypes benefited from adequate rainfall, ensuring proper boll filling, whereas late-flowering genotypes suffered from water deficit due to the early cessation of rains. Given the short rainy season in Burkina Faso (approximately three months), long-cycle genotypes are particularly vulnerable to water stress, which negatively affects growth and productivity. Positive correlations between the number of branches and plant height, stem diameter, number of bolls and yield further indicate that vigorous plants are generally more productive. This could be explained by the fact that photosynthetic activity would be important because of the high leaf production linked to height and branching. These results are similar to those of Ouangraoua *et al.* (2021) and Ognalaga *et al.* (2017), who pointed out that height could be used as a production index in *H. Sabdariffa*. Genotypes HSE4 and HSE5 are characterized by high height and good calyx yield and can therefore be considered the most productive. As *H. sabdariffa* is grown for its leaves, seeds and calyxes, these correlations can be exploited for a plant improvement programme. Cluster analysis based on morphological variability structured the genotypes into four distinct groups differing in cycle-duration, morphology and yield. The HSE6 genotype with a white calyx had the shortest cycle (maximum three months). According to Bâ (2023) white calyx genotypes have a shorter cycle than red calyx genotypes. For leaf production, this genotype could be important for selection as it has very rapid vegetative growth. In contrast, genotype HSE1 had the longest cycle (at least 4 months). Naeem and Defries (2009) reported that varieties with a cycle longer than three months are likely to disappear because the shortening of the rainy season does not favour their production and adoption by growers. The yields of such varieties can be improved by shortening their growth cycle or by adjusting the sowing dates. Analysis of variance showed that cropping treatments did not significantly affect phenological parameters, indicating that the crop cycle is mainly genotype-dependent, although it may be influenced by environmental factors such as photoperiod. *H. sabdariffa* is a short-day plant, flowering when night length exceeds day length. Thus, early sowing extends its cycle and late sowing shortens it. According to Hien (2012), *H. sabdariffa* flowering depends not only on the variety but also on environmental conditions and sowing periods. Physiological and agronomic performance varied from one treatment to another compared with the control. The agro-morphological performances obtained with the different doses of droppings were superior to those of the control, highlighting its nutrient richness. However, the combination with a legume such as voandzou without fertilizer showed very poor performance, lower than the control, likely due to competition for water and nutrients. Our results are in line with those of Ognalaga *et al.* (2017), who report that the yields of *H. sabdariffa* are reduced in intercropping systems, particularly when associated with cereals. The best yields were obtained with poultry manure at a dose of 6000kg/ha, i.e. 6t/ha. Comparable results were reported by Haruna *et al.* (2011), who recommended 5000 kg/ha of poultry manure supplemented with mineral fertilizer. Optimal performance was also achieved at a sowing density of 0.4×0.6 m. As *H. sabdariffa* is a bushy plant (it branches strongly), it needs a very airy sowing density to encourage growth in height and thickness (Sié *et al.*, 2009). The yields obtained from the different genotypes were too low for all treatments, likely due to soil fertility constraints, late sowing and water stress caused by early rainfall cessation in October. Hien (2012) reported that sowing in August considerably reduces plant size and therefore yield. These results could also be explained by the different sowing densities, which may not be very conducive to good plant growth. According to the FAO (2021), the optimum density for this crop is 50 cm x 100 cm, although this also depends on the soil and climate conditions in the area. Finally, all genotypes were subjected to significant jassid pressure, with damage affecting 26-50% of leaves. This level of attack can lead to a significant drop in grain yield and biomass. According to Sawadogo *et al.* (2023), jassids are sweaty biters that attack leaves by sucking sap and causing desiccation, stunting and complete leaf drop, with a consequent reduction in photosynthesis and yields. This highlights the need to integrate pest resistance into breeding programs and to promote. integrated pest management, including cultivation practices and the use of tolerant varieties.

The results of this study provided a better understanding of the variability of six roselle genotypes and the influence of agricultural practices on their agro-morphological performance, despite the biotic pressure from jassid attacks. Agro-morphological characterization revealed that the genotypes differed in terms of the color and shape of the leaves, calyxes, seeds, flowers and stems. They differed on the basis of phenolic (flowering and ripening periods), physiological (stem and calyx size and thickness) and agronomic (seed and calyx yields) characteristics. Depending on the length of the growing cycle, some genotypes were very early-maturing (HSE6) whereas others showed a longer growth cycle (HSE1). Genotypes HSE4 and HSE5 emerged as the most productive. This study clearly showed that cultivation practices, particularly density and fertilization, had a significant impact on the performance of the genotypes. Indeed, sowing at a density of 0.4x0.6 m and fertilising with poultry droppings at a dose of 6000 kg/ha led to the best agro-morphological performance. Intercropping without fertilization proved detrimental to good plant growth. Assessment of the damage caused by jassids on the six genotypes of *Hibiscus sabdariffa* revealed a uniform level of attack, with damage rates varying between 26 and 50%. Despite the application of fertilizers, the genotypes showed low productivity overall, making it impossible to achieve the high calyx and grain yields expected. Effective pest management, particularly targeting jassids, is therefore necessary to ensure good plant growth and yield. Further studies are recommended to evaluate the impact of jassids on *Hibiscus* performance and to broaden the range of genotypes tested in order to identify and promote resistant genotypes.

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