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GROWTH AND YIELD RESPONSES OF ROSELLE (*Hibiscus sabdariffa* L.) AND MAIZE (*Zea mays* L.) TO INTERCROPPING UNDER DIFFERENTIAL SPACING REGIMES

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ABSTRACT

Understanding the adaptability of roselle with maize under intercropping, can enhance roselle's integration into maize-based cropping systems. Considering the crucial influence of plant spacing on intercrop performance, this study evaluated the agronomic performance of four roselle (Hibiscus sabdariffa) accessions intercropped with maize under two roselle spacing regimes (1 × 1 m and 0.75 × 0.75 m). Sole stands of each crop were also established for comparison. The experiment was laid out in a split–split plot arrangement in a randomized complete block design with three replications. Growth parameters, including plant height, number of leaves, and stem diameter, were measured biweekly from 4 weeks after sowing (WAS) to 10 WAS for maize and 12 WAS for roselle. Data on yield and yield components were collected at harvest, and all data were subjected to Analysis of Variance (ANOVA) at α0.05. The roselle accessions varied significantly only for fresh and dry calyx yield (t/ha), ranging from 2.95 (V12R3) to 4.37 (V10R2) and 0.14 (V12R3) to 0.48 (V32R2), respectively. Closer spacing (0.75 × 0.75 m) significantly increased roselle calyx yield, whereas wider spacing (1 × 1 m) enhanced maize vegetative growth. Intercropping significantly improved roselle number of leaves, fresh calyx yield, as well as maize grain yield, although statistically longer and broader maize stem were observed under sole cropping. The results indicated that the roselle accessions are well adapted for intercropping with maize. This cropping system can improve yields, but optimal results depend on spacing and accession selection. Therefore, selection should be aligned with the production goals.

Keywords: Agronomic performance; *Hibiscus sabdariffa*; mixed cropping; planting distance; *Zea mays*

INTRODUCTION

Crop diversity is a defining characteristic of intercropping systems, arising from the simultaneous cultivation of two or more crop species with contrasting yet complementary growth habits in close spatial proximity on the same land. Component crops utilise available resources at different times, spaces, or forms, thereby promoting resource complementarity (Bello *et al.*, 2025). Studies have shown that crops in intercrop intercept more solar radiation than their sole-cropped counterparts (Gou *et al.*, 2017; Liu *et al.*, 2018; Nwokoro *et al.*, 2022), often resulting in yield advantages (Raza *et al.*, 2022; Lu *et al.*, 2023). Consequently, smallholder farmers, recognising these benefits, have strategically adopted intercropping to optimise resource-use efficiency, stabilise productivity, enhance ecological and economic sustainability, and strengthen the overall resilience of their farming systems.

Roselle (*Hibiscus sabdariffa*) is a versatile crop that has gained significant attention for intercropping because of its ecological and economic benefits. It has several desirable morphological traits, including rapid growth, numerous broad leaves forming a dense canopy, and a deep taproot system that supports weed suppression, soil and water conservation, nutrient recycling, hydraulic lift, and overall enhancement of farming system productivity. Its aboveground parts, including leaves, seeds, calyces and stems also have various industrial and nutritional uses for fibre, pulp, fuel, medicine, soups, confections, oil, and beverage production (Da-Costa-Rocha *et al.*, 2014; Hapsari *et al.*, 2021; Rana and Thakur, 2021). Roselle can be intercropped with many crops, such as cereals, oil crops, legumes, and vegetables (Roy *et al.*, 1990; Ayipio *et al.,* 2018; Banjaw *et al.*, 2020). However, the productivity of roselle-based intercropping systems mainly depends on the crop combination and plant population density (Babatunde *et al.*, 2003; Ayiopio *et al.,* 2018). Babatunde *et al.* (2003) assessed the productivity of roselle–legume systems (groundnut and cowpea) and roselle–cereal systems (millet and sorghum) in Nigeria and found higher roselle yields in the roselle–legume combinations. Ayiopo *et al.* (2018) observed a high level of complementarity between roselle and maize under intercropping, with roselle showing significantly higher yields in the mixed system compared to its sole crop, while maize yields remained unaffected.

Maize (*Zea mays*) is a staple food crop in Nigeria and globally, with growing industrial demand due to its use in animal feed and processed products. Consequently, it is a common component of many cropping systems. As a tall, erect C4 plant, maize requires high sunlight intensity. It has a fibrous root system concentrated in the topsoil (Zhu *et al.*, 2005; Lynch and Wojciechowski, 2015). In contrast, roselle is a C3 plant that thrives under moderate sunlight and cooler conditions (Ayiopo *et al.*, 2018), highlighting the ability of roselle to likely compete less with maize for solar radiation. Also, the contrasting root morphologies of the two crops enable them to utilise water and nutrients from different soil strata, thereby minimising interspecific competition for growth resources. These complementary traits underscore the compatibility of maize and roselle for intercropping. Optimising intercropping performance requires balancing competition and complementarity through appropriate spatial arrangements (Ayipio *et al.*, 2018). Wider spacing can promote roselle's vegetative growth, favouring individual plant development and calyx yield, whereas narrower spacing may increase total yield per hectare (Udoh *et al.*, 2016; Ayipio *et al.*, 2018; Inuwa *et al.*, 2023). Given the limited information available on the growth and yield performance of some roselle accessions in intercrop with maize under varying spacing configurations, this study was conducted to address that knowledge gap.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted at the research site of the Institute of Agricultural Research and Training (IAR&T), Ibadan, Nigeria (7°22'N, 3°50'E; 240 m above sea level) in 2023. The site is located within the rainforest-savannah transition agroecological zone with mean annual precipitation of approximately 1,250 mm and a mean temperature range of 24–33 °C.

Land preparation and experimental layout

The land was cleared, ploughed, harrowed, and marked into plots measuring 3 × 2 m (6 m^2) each, separated by 1 m alleys within and between blocks. Four roselle (*Hibiscus sabdariffa L.*) accessions (V6R2, V10R2, V12R3, and V32R2) were sown, one accession per plot, using two spacing arrangements: 1 × 1 m and 0.75 × 0.75 m. Maize (*Zea mays* L.) variety BR9928DMRSY-Y, was sown simultaneously with roselle in the intercrop plots at a spacing of 0.75 × 0.50 m. Both crops were also established as sole stands to provide a basis for comparison.

Experimental design and treatments

The experiment was laid out in a split–split plot arrangement using randomized complete block design (RCBD) with three replications. Spacing constituted the main plot factor, cropping system (sole and intercrop) was assigned to subplots, and roselle accessions were randomised to sub–subplots within each cropping system subplot.

Data collection

Data on growth parameters, including plant height, number of leaves, leaf area, and stem diameter, were taken at interval of two weeks from 4 to 10 WAS for maize and 4 to 12 WAS for roselle. Roselle leaf area was estimated using the non-destructive model described by Nnebue *et al.* (2015) where Leaf area = 5.20 + 0.5179 LW, and L and W are leaf length and width, respectively. Leaf area of maize was calculated with the aid of the formula: leaf area = L × W × K, where L is leaf length (cm), W is leaf width (cm), and K = 0.75, according to Elings, (2000). At harvest, yield parameters were determined as follows: 100-seed weight (kg) for both crops; fresh and dry calyx yield (t ha^{-1}) for roselle; and grain yield (t ha^{-1}) for maize.

Data analysis

All data were subjected to analysis of variance (ANOVA) using SAS software (version 9.0; SAS Institute Inc., Cary, NC, USA). Treatment means were separated using the Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT), as appropriate, at the 5% level of probability (α = 0.05).

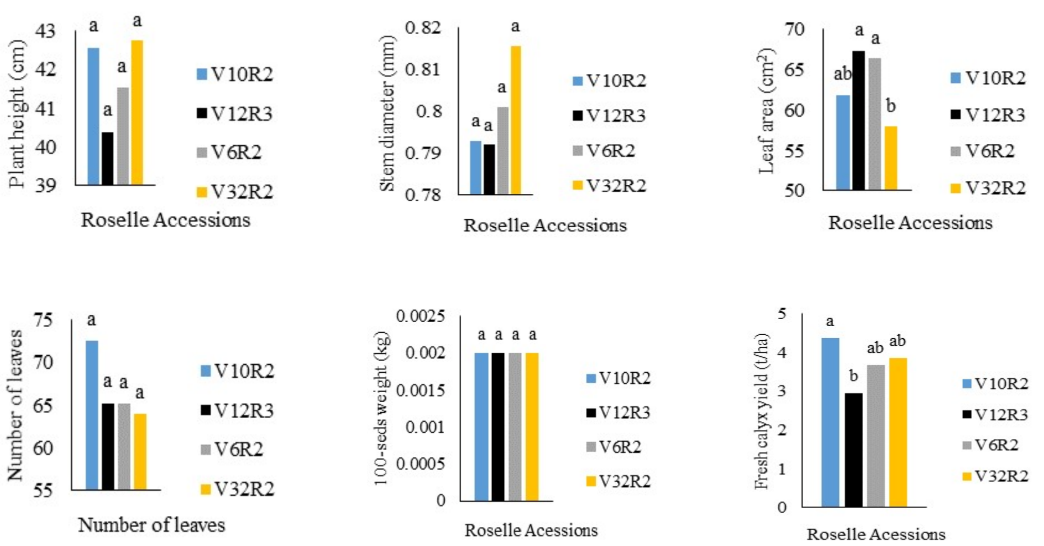
RESULTS

The effects of accession, cropping system, and spacing on roselle growth and yield parameters were generally non-significant, except for significant accession and spacing effects for leaf area, fresh and dry calyx yield (Table 1). The cropping system had a significant influence on the number of leaves and fresh calyx yield (Table 1). A significant interaction was observed between accession and cropping system for leaf area, as well as between accession and spacing for plant height and number of leaves (Table 1). The interaction between spacing and cropping system had a significant effect on plant height, stem diameter, and leaf area (Table 1). Among the accessions, V32R2 had the greatest stem dimensions (plant height and stem diameter), but the lowest leaf parameters (number and area of leaves). The observed values were comparable with the other three accessions for all the growth traits, except the leaf area of V12R3 and V6R2 (Figure 1). Accession V12R3 was characterised by the shortest plants, the thinnest stems, and the broadest leaves. The 100-seed weight of the four roselle accessions did not vary significantly. However, accessions V10R2 and V32R2 produced the highest fresh and dry calyx yields, respectively, differing significantly only from V12R3 for both roselle yield components (Figure 1). The least fresh and dry calyx yields were obtained from V12R3, which was similar with V6R2 and V32R2 for fresh calyx yield, and with V6R2 for dry calyx yield (Figure 1).

Table 1: Combined Analysis of Variance for the Effect of Accession, Cropping System and Spacing on Growth and Yield Parameters of Roselle

Sources of variation	Degree of freedom	Plant height	Stem Diameter	Number of Leaves	Leaf Area	100-seed weight	Fresh calyx yield	Dry calyx yield
		Mean square	Mean square	Mean square	Mean square	Mean square	Mean square	Mean square
Accession (A)	3	84.13	0.01	812.69	1118.15*	3.92E-39	4.16*	0.29*
Cropping system (CS)	1	97.73	0.02	16666.82 ***	809.53	3.92E-39	14.45**	0.01
Spacing (SP)	1	465.43	0.00	2475.45	9651.21***	3.92E-39	11.92*	0.63*
A×CS	3	190.75	0.01	2195.96	2179.28***	3.92E-39	3.39	0.08
A×SP	3	723.38***	0.03	4345.05*	149.74	3.92 E-39	2.04	0.09
CS×SP	1	1706.81***	0.59***	389.61	8702.43***	3.92 E-39	6.88	0.38
A × CS × SP	3	106.91	0.04	860.55	288.46	3.92 E-39	5.31	0.21

* and *** : significance at 0.05 and 0.001 levels of probability



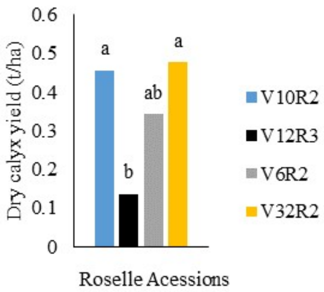


Figure 1: Variation in the growth and yield components of roselle (*Hibiscus sabdariffa* L.) accessions

Plant height, stem diameter, leaf area, and dry calyx yield of roselle grown in pure stands were comparable with those intercropped with maize (Table 2). Conversely, roselle in mixed stands produced significantly greater number of leaves and higher fresh calyx yield than those in sole stands (Table 2). Roselle plant height, number of leaves, and stem diameter were statistically similar across the two spacing dimensions. Roselle spaced 1 × 1 m apart were taller and had more and larger leaves compared with those sown using 0.75 × 0.75 m (Table 2). In contrast, roselle grown at the narrower spacing of 0.75 × 0.75 m exhibited slightly thicker stems and had significantly higher fresh and dry calyx yields (Table 2). Accession V32R2 sown at a spacing of 1 × 1 m was significantly taller but comparable only with height of accession V6R2 grown at the same spacing and V10R2 at 0.75 × 0.75 m (Figure 3). Highest number of leaves was produced by accession V10R2 spaced 1 × 1 m apart, which was higher than from V12R3 at 1 × 1 m and V32R2 at 0.75 × 0.75 m (Figure 2). Across the two cropping systems, the leaf areas of the four roselle accessions were comparable, except for V32R2 intercropped with maize, which were lower from V12R3 under intercropping and V6R2 under sole cropping (Figure 3).

Table 2: Mean Effect of Cropping System and Spacing on Growth and Yield Components of Roselle

Sources of variation	Plant height (cm)	Stem diameter (cm)	Number of leave (leaves/plant)	Leaf area (cm^2)	100-seed weight (kg)	Fresh calyx yield (t/ha)	Dry calyx yield (t/ha)
Cropping System							
Sole	41.41a	0.81a	58.34b	65.25a	0.002a	3.16b	0.37a
Intercrop	41.22a	0.79a	75.11a	61.54a	0.002a	4.26a	0.34a
Spacing							
1 × 1 m	42.51a	0.79a	68.46a	68.56a	0.002	3.21b	0.24b
0.75 × 0.75 m	41.08a	0.81a	64.90a	57.96b	0.002	4.21a	0.47a

Means with similar letters are not significantly different.

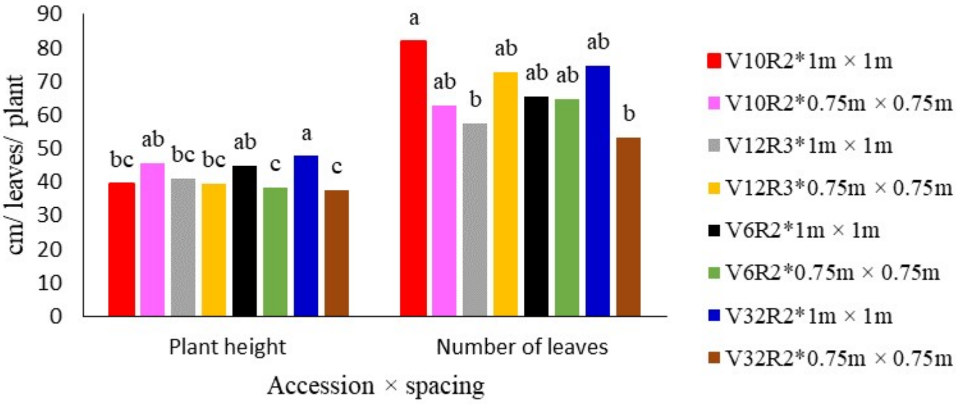


Figure 2: Variation in plant height (cm) and number of leaves (leaves/ plant) of roselle accessions as influenced by sowing spacing

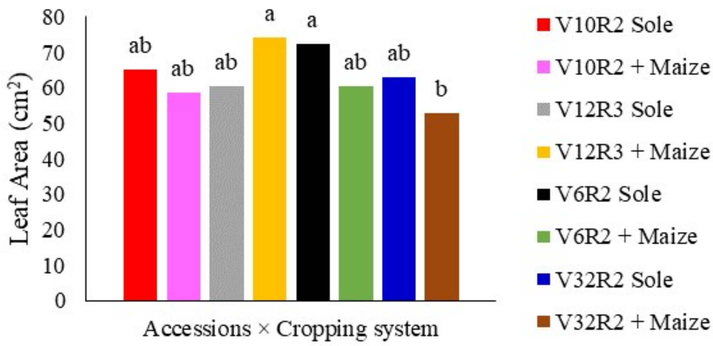


Figure 3: Leaf area (cm²) of roselle accessions under sole and intercropping systems with maize

Significant cropping system and spacing effects were observed for all maize agronomic parameters, except for the number of leaves and 100-seed weight for cropping system, and stem diameter, leaf area, 100-seed weight, and grain yield for spacing (Table 3). The interaction between cropping system and spacing had no significant effect on maize growth and yield performance (Table 3). Maize plants in sole stands were tallest, had the widest stems, produced the greatest number of leaves, and had the largest leaf area. The values for these growth traits were significantly higher than from those of maize intercropped with roselle, regardless of accession, except for maize stem diameter in V32R2 intercrop and number of leaves across all mixed plots (Figure 4). Highest 100-seed weight and maize grain yield were obtained from maize intercropped with V12R3 and V32R2, respectively. They were comparable to values from other cropping systems, except for grain yield of maize intercropped with V10R2 (Figure 4). Significantly higher maize stem length and diameter, number of leaves and leaf area, 100-seed weight were obtained from roselle spaced at 1 × 1 m compared with 0.75 × 0.75 m. Leaf area and 100-seed weight of maize in the two spacing dimensions were similar (Table 4). Grain yield did not differ significantly between spacing dimensions (Table 4).

Table 3: Combined Analysis of Variance for the Effect of Cropping Systems and Spacing on Maize Growth and Yield Parameters

Sources of variation	Degree of freedom	Plant height	Stem diameter	Number of leaves	Leaf area	100-seed weight	Grain yield
		Mean square	Mean square	Mean square	Mean square	Mean square	Mean square
Cropping System (CS)	4	3751.06***	0.39*	0.56	21083.93***	0.001	0.081*
Spacing (S)	1	2141.09**	0.77*	6.77**	8177.45	0.001	0.001
CS × S	4	17.52	0.06	1.11	1925.22	0.000	0059

*, **, and *** imply significance at 0.05, 0.01, and 0.001 levels of probability

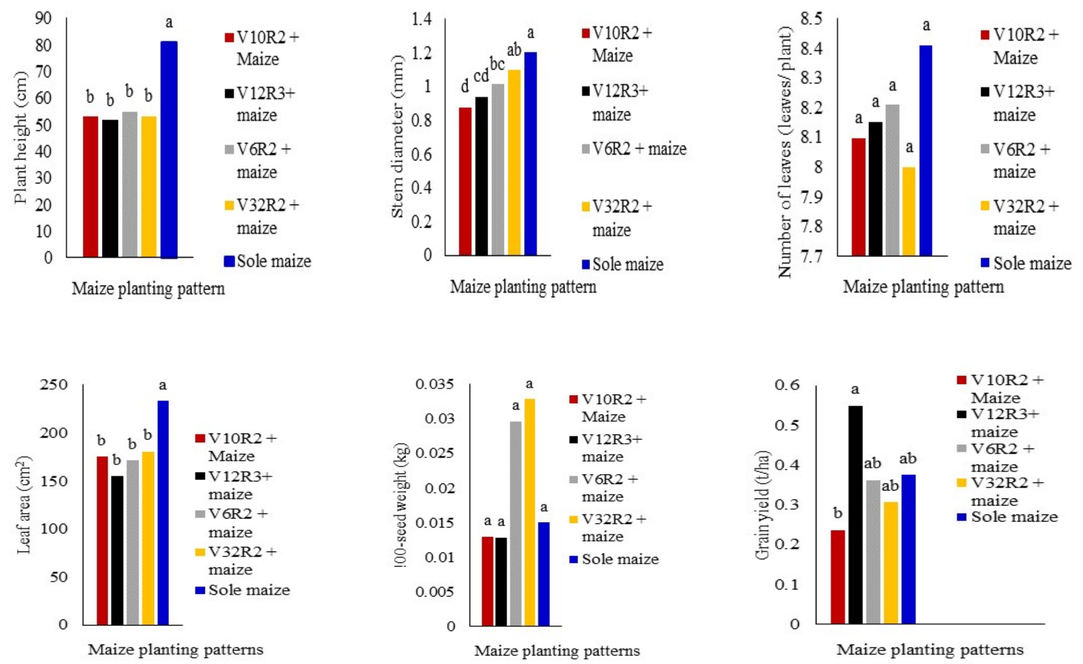


Figure 4: Effects of cropping patterns on growth traits, 100-seed weight and grain yield of maize in sole cropping and intercropping with roselle accessions

Table 4: Mean Effect of Roselle Spacing Dimension on Agronomic Performance of Maize

Spacing	Plant height (cm)	Stem diameter (cm)	Number of leaves (leaves/ plant)	Leaf area (cm^2)	100-seed weight (kg)	Grain Yield t/ha)
1 ×1 m	63.056a	1.105a	8.411a	191.100a	0.027a	0.361a
0.75 × 0.75 m	54.608b	0.945b	7.936b	174.590a	0.015a	0.369a

Means with similar letters are not significantly different.

DISCUSSION

The growth and yield performance of crops in an intercropping system can be influenced by the genetic potential of the component species, as well as by spatial arrangement and plant population density. Significant accession effects observed for leaf area of roselle and fresh and dry calyx yields indicate that the accessions differed genetically in these traits. The observed variations in leaf development and calyx formation are therefore attributable primarily to the inherent genetic potential of each accession for the traits. This finding aligns with the recent reports of Thimmaiah (2023) and Deshmukh and Wagh (2024), who also documented significant genotypic differences in roselle calyx yield in separate studies. The similar stem dimensions of plant height and stem diameter, number of leaves, and 100-seed weight among the roselle accessions suggest comparable genetic expression for these agronomic traits under the prevailing experimental conditions. Notably, observation of tallest plants, thickest stems, lowest number of leaves and leaf area; and significantly highest dry calyx yield from accession V32R2 indicate a possible physiological trade-off in which the accession allocates a greater proportion of assimilates to stem and reproductive (calyx) development at the expense of foliage growth. The higher positioning and wider spacing of leaves in the taller plants may have reduced self-shading and enhanced light interception efficiency per unit leaf area, thereby compensating for the lower number of leaves and supporting higher calyx biomass accumulation. Consequently, the superior dry calyx yield of V32R2, despite its reduced foliar development, suggests that its yield advantage was not dependent solely on total photosynthetic surface area but rather on efficient assimilate partitioning toward reproductive structures. This highlights the accession's superior resource-use efficiency and favourable reproductive allocation strategy, consistent with earlier reports by Mohammed *et al.* (2019) and Agoreyo *et al.* (2020) on genotypic variation in roselle growth and calyx yield. The relatively supra stem dimensions of V32R2 also indicate its potential to produce longer and thicker stems, which could serve as a valuable raw material for the paper and pulp industry, given the usability of roselle for this purpose. The industrial utilization of roselle stems could reduce dependence on forest wood resources, thereby alleviating deforestation pressure, enhancing carbon sequestration, mitigating climate change and promoting environmental conservation in alignment with the Sustainable Development Goals (SDGs). The short growth cycle of roselle offers the advantage of rapid stem turnover, enabling more frequent biomass production and income generation for farmers within a shorter time frame compared to the prolonged maturation period required for forest trees.

The observation of the shortest plants, thinnest stems, and significantly lowest fresh and dry calyx yields from accession V12R3 reflects its limited genetic potential for stem growth and calyx production, and possibly suboptimal adaptation to the study area. This growth pattern suggests that V12R3 may be less suited as a companion crop in intercropping systems, as its relatively weak vegetative vigour could increase its susceptibility to shading by taller component crops. Although this accession exhibited the significantly highest leaf area and the second numerically highest leaf number, its reduced stem dimensions and calyx yield likely indicate a restricted ability to partition assimilates efficiently toward productive sinks (stems and calyces), resulting in reduced economic yield potential. Consequently, its cultivation for stem or calyx production in monoculture or mixed cropping systems may not be economically viable. Nevertheless, the dwarf growth habit of V12R3, coupled with its high leaf number and large leaf area, which provide extensive ground cover, suggesting potential for use in eco-friendly weed suppression strategies within polyculture systems. The identical 100-seed weight of the accessions indicates comparable seed size and density, implying genetic similarity for seed development traits across the evaluated accessions.

Intercropping typically induces competition among component crops because they share similar ecological niches. However, the significantly comparable agronomic performance of roselle across sole and intercropped systems, except for number of leaves and fresh calyx yield, suggests that the genetic potential of the accessions for these traits was not markedly influenced by the cropping system. This indicates stability of agronomic performance across both systems and demonstrates the adaptability of the roselle accessions to intercropping, as well as their ability to withstand competitive pressure from maize. Hence, it can be inferred that the competitive effects of intercropping roselle with maize were not sufficiently intense to cause significant reductions in roselle growth and yield. The numerically higher plant height, stem diameter, leaf area, and dry calyx yield observed under monocropping may be attributed to reduced competition for growth resources such as light, nutrients, soil moisture, and space. This trend aligns with previous findings where roselle performed comparably in both systems, with sole cropping often showing slight numerical advantages due to the absence of interspecific competition (Musa *et al.,* 2010; Tadesse, 2018; Dereje, 2021). Nonetheless, intercropping provides added agronomic and economic advantages such as crop and income diversification, risk reduction, and improved land-use efficiency, in addition to the potential for comparable dry calyx yield. Interestingly, the higher fresh calyx yield observed under intercropping in this study corroborates the earlier report by Ayipio *et al.* (2018), who recorded similar outcomes in roselle–maize intercrops.

Although plant height, number of leaves, and stem diameter of roselle were similar across the two spacing regimes, the observation of taller plants and a higher leaf count at 1 × 1 m spacing suggests that reduced competition for growth resources under wider spacing promotes vertical growth and greater canopy expansion. In contrast, the slightly thicker stems observed under closer spacing of 0.75 × 0.75 m may reflect a mechanical adaptation to higher plant density, as plants grown in crowded conditions often allocate more assimilates to stem strengthening to support vertical elongation and maintain structural stability while competing for light (Alegbejo *et al.*, 2018). This submission is consistent with the findings of Udoh *et al.* (2016), who reported that increased plant density in roselle reduced plant height but enhanced stem girth, while wider spacing improved plant height and leaf development due to better access to light and soil nutrients, reflecting density-induced morphological adjustments. However, the significant effect of spacing on roselle leaf area and calyx yield indicates that plant density is a crucial factor influencing both roselle leaf expansion and reproductive performance. The higher fresh and dry calyx yields recorded at 0.75 × 0.75 m spacing are likely attributable to the greater plant population per unit area, which compensated for the lower yield per plant. Similar results were reported by Ayipio *et al.* (2018) and Inuwa *et al.* (2023), who found that denser roselle stands produced greater total calyx yield per hectare despite smaller individual calyces. Conversely, wider spacing favoured significantly larger leaf area development because reduced canopy overlap minimises shading and enhances light interception, allowing leaves to expand fully and maximise photosynthetic capacity. These findings agree with those of Musa *et al.* (2010) and Hundiwale *et al.* (2024), who observed that reduced competition in widely spaced roselle plants enhanced leaf expansion and assimilate accumulation, although the overall yield advantage tended to shift toward closer spacing due to higher plant population density.

In intercropping systems, root competition may constrain maize vegetative growth (Ren *et al.*, 2021), often accompanied by alterations in leaf morphology and functional responses (Fu *et al.*, 2023). Therefore, the superior growth performance of maize in sole stands compared with intercrops suggests that interspecific competition from roselle reduced maize vegetative growth when the two crops were grown together. This effect was likely due to below-ground competition for soil nutrients and moisture, as well as above-ground competition for light interception (Dong *et al.*, 2024). However, the differential responses among maize plants intercropped with various roselle accessions indicate that the intensity of competitive interactions was accession-dependent. The statistically comparable number of leaves and 100-seed weight of maize across both monoculture and intercropped systems, irrespective of the roselle accession, coupled with the significantly highest grain yield from the maize intercropped with V12R3, which differed statistically only from the maize in V10R2 mixture, suggests that intercropping did not significantly depress maize foliage development, seed weight, or overall grain yield. This observation corroborates the earlier findings of Ayipio *et al.* (2018). The significantly higher grain yield obtained from maize intercropped with accession V12R3 may be attributed to the compact growth habit of this roselle accession, which likely reduced shading intensity and enhanced light interception by maize, thereby promoting assimilate partitioning towards grain production. Conversely, the lowest maize grain yield recorded in the maize intercropped with V10R2 can be explained by the relatively tall and leafy architecture of accession V10R2, which could have induced shading and stronger below-ground competition. Under such competitive pressure, maize may have diverted more assimilates to stem elongation in an attempt to capture light, resulting in reduced assimilate allocation to reproductive structures and, consequently, lower grain yield.

The significantly greater plant height, stem diameter, and number of leaves of maize observed under wider roselle spacing indicate reduced interspecific competition for growth resources. Wider spacing between roselle plants likely enhanced light penetration, root proliferation, and access to soil nutrients and moisture by the maize component, thereby promoting more vigorous vegetative growth. This observation corroborates the findings of Ayipio *et al.* (2018), who reported improved growth for maize grown in association with widely spaced roselle due to reduced shading and belowground competition. Similarly, Hossain *et al.* (2019) noted that wider spacing in roselle reduced canopy overlap, thereby improving light distribution to companion crops. However, the comparable maize leaf area, 100-seed weight, and grain yield across both spacing arrangements suggest that while wider spacing enhanced vegetative growth, this advantage did not translate into a corresponding yield increase. This outcome may reflect compensatory physiological adjustments by maize, including enhanced photosynthetic efficiency per unit leaf area and more efficient assimilate partitioning to reproductive organs, thereby maintaining stable yield despite variations in vegetative growth. Such adaptive responses have been documented in maize intercropping systems (Ren *et al.*, 2021; Fu *et al.*, 2023; Dong *et al.*, 2024).

CONCLUSION

From the findings of this study, it can be concluded that the roselle accessions can be successfully integrated into maize-based cropping systems, but with varying vegetative and reproductive outcomes. Under this cropping system, a spacing configuration of 1 × 1 m promotes vegetative growth and favours biomass accumulation in both crops, whereas a closer spacing of 0.75 × 0.75 m enhances dry calyx yield of roselle and grain yield of maize, which can be optimised for commercial production. The selection of accession, spacing, and cropping system should therefore be guided by specific production objectives. Farmers may adopt either cropping system depending on their production goals, prioritising maximum dry calyx and stem yield under sole cropping, or improving land-use efficiency, output diversification, and income stability under intercropping.

Where roselle is the primary crop, cultivation of accession V32R2 is recommended for both stem and dry calyx production due to its superior yield attributes, while accession V12R3, with a compact growth habit, broad leaf area, and association with higher maize grain yield under intercropping, may be strategically utilised for eco-friendly weed suppression in maize-based systems.

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