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Effects of Inter and Intra Row Spacing on Growth, Yield and Yield Components of Roselle (*Hibiscus Sabdariffa* L.) at Wondo Genet, Southern Ethiopia

Basazinew Degu Gebremedin[1*], Bizuayehu Tesfaye Asfaw[2]

[1]*Ethiopian Institute of Agricultural Research, Wondo Genet Agricultural Research Center, P.O. Box 198, Shashemene, Ethiopia*

[2]*Hawassa University College of Agriculture, Department of Plant and Horticultural Science, Hawassa, Ethiopia*

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ABSTRACT

Objective: A field experiment was conducted to assess the optimum inter- and intra-row spacing on growth, yield and yield component of roselle (Hibiscus sabdariffa L.) in 2014/15 cropping season at wondo Genet Agricultural Research Center experimental site (at wondo Genet station). **Methods:** Two inter-row spacings (60 and 90 cm) and three intra-row spacings (30, 60 and 90 cm) were evaluated using two varieties, WG-Hibiscus-Jamaica and WG-Hibiscus-Sudan on a plot size of 3.6 m length x 4.2 m width. The experimental design was a randomized complete block design in factorial arrangement with 12 treatments in three replications. SAS (version 9) software was used to compute the analysis of variance. **Results:** The results revealed that varieties differed markedly in most of the studied parameters. Of the two varieties tested, variety WG-Hibiscus-Jamaican showed greater plant height, number of branches per plant, number of leaves/plant, leaf area, leaf area index, days to 50 % flowering, days to 95 % maturity, number of capsules/plant, fresh calyx yield/plant, dry calyx yield/plant, seed yield/plant, total number of capsules/ha, total fresh calyx yield/ha, total dry calyx yield/ha and total seed yield/ha. In contrast, variety WG-Hibiscus-Sudan matures earlier and had heavier 1000 seed weight than variety WG-Hibiscus-Jamaican. Number of capsules/plant, fresh and dry calyx yield/plant were influenced by interaction effects of variety; inter- and intra-row spacing. Moreover, fresh and dry calyx yield/plant, total fresh and dry calyx yield/ha were influenced by interaction effects of variety, inter- and intra-row spacing.

Introduction

Roselle (*Hibiscus sabdariffa* L.) is one of the most important annual medicinal shrub that belongs to the family Malvaceae and it is locally known as "Karkade". This genus has more than 300 species among which, two species of *H. sabdariffa* and *H. altissimia* have been mentioned as an important species (Chen *et al*., 2002). It is believed to be native of India and later introduced to Malaysia where it is commonly cultivated and might have been carried at an early date to Africa (Morton, 1987). It is known in different countries by various common names, including roselle, razelle, sorrel, red sorrel, Jamaican sorrel, Indian sorrel, Guinea sorrel, sour-sour, and Queensland jelly plant (Mahadevan, 2009). In English-speaking countries it is known as roselle, Jamaican sorrel, red sorrel, Indian sorrel, rozelle hemp, natal sorrel and rosella. The Japanese name is rohzelu;

***Corresponding Author:** Basazinew Degu Gebremedin, Ethiopian Institute of Agricultural Research, Wondo Genet Agricultural Research Center, P.O. Box 198, Shashemene, Ethiopia

also sabdriqa or lalambari in Urdu (Kays, 2011); and lal-ambari, patwa or laalambaar in Hindi (Kays, 2011). Roselle is an important cash crop in Western Sudan, particularly in Northern Kordofan State, especially in Elrahad and Um-Rawaba areas (El Naim *et al*., 2012).

The calyces are widely used to prepare herbal drink, cold and warm beverages, and for making jams and jellies (Tsai *et al*., 2002). In Africa, they are frequently cooked as a side dish and eaten with pulverized peanuts for stewing as sauce, for making a fine-textured sauce or juice (zobo), syrup, jam, marmalade, relish, chutney or jelly. The seeds are somewhat bitter but have been grounded to a meal for human food in Africa and have also been roasted as a substitute for coffee (Seiyaboh *et al*., 2013). Red calyces (based on 100 g dry weight) contain 6.4 % protein, 79.3 % carbohydrates, 5.1 % fat, 2.7 % crude fiber, and 6.5 % ash (Nnam and Onyeke, 2003). Roselle is one of the most important and popular medicinal plant which has several properties. The leaves are emollient and are much used in Guinea as a diuretic, refrigerant and sedative (Anhwange *et al*., 2006) and used to sour the curry or "dal" preparation in Bangladesh as well as the young leaves are used as vegetable (Patil, 2004). The calyx, boiled in water is used as a drink in bilious attacks (Perry, 1980) and has also shown to lower blood pressure (McKay, 2010). The seeds of roselle are used as diuretic, laxative, tonic (Duke, 1985) and to treat debility (Perry, 1980).

In a study on the effect of sowing date and plant density on yield and agronomical traits of roselle in Zabol, Iran, it was reported that the increase in density from 4 to 8 plants/m^2, significantly decrease sepal weight and capsule number per plant, but capsule number per m^2, sepal to capsule weight ratio, sepal yield and biological yield per unit area increased with the increase in plant density (Mir *et al*., 2011). Gholam and Moosavi (2012) studied the effect of sowing date and plant density on yield and yield components of roselle in Birjan, Iran, it was reported that the increase in density from 8 to 13.3 plants/m^2, fruit number per plant, sepal yield per fruit and plant and single biomass decreased significantly by 29.8, 24.4, 39.1, 55.4 and 33.6 %, respectively, but fruit number/m^2 increased by 18.2%.

In Ethiopia roselle is mainly used to produce healthy juice and herbal tea with full of flavor and tart, due to its high contents of vitamin C and anthocyanins that are found in the calyces. Roselle is predominantly produced by small scale farmers in their homestead garden. Ethiopia has a suitable environment for the production of roselle. But, there are limited findings regarding the modern production technology and to increase productivity to attract the industries or enterprises which are engaged in production and processing of roselle. This is due to lack of knowledge about the crop and limited supply of the crop products. Proper production technology is necessary for productivity of roselle to supply quality product to local or international markets, pharmaceuticals and beverage industries. The crop is produced in traditional management practices by small scale-farmers, depending on rainfall and poor agronomic practices. The main gap in production of the crop is poor agronomic practice such as improper spacing. Considering the enormous benefits of the roselle crop it is necessary to promote its growth and performance in terms of marketable and edible yields by growing it at an optimum spacing. The main yield-limiting factors are information or skill gap on how to produce this crop. Therefore, the study had the following objectives:

General objective

To contribute towards improved yield of roselle produced in Ethiopia.

Specific objectives

To measure growth, yield and yield components of roselle at different inter- and intra-row spacing.

To evaluate the interaction between and within inter-, intra-row spacing and varieties in relation to yield and yield components.

Materials and methods

The experiment was conducted at Wondo Genet Agricultural Research Center experimental site in Southern Ethiopia during 2014/2015 cropping season. Wondo Genet is located between 7°19' N latitude and 38°38' E longitude; it is found at an altitude of 1780 m.a.s.l (meter above sea level) and receives mean annual rainfall of 1128 mm with minimum and maximum temperature of 11 °C and 26 °C, respectively. The soil textural class of the experimental area is sandy loam with pH of 6.4 (Abayneh *et al*, 2006).

The seeds of the two varieties; namely, WG-Hibiscus-Jamaica (V1) and WG-Hibiscus-Sudan (V2) were sown on spot directly on the experimental field at two inter-row spacings: 60 and 90 cm and three intra-row spacings 30, 60 and 90 cm after the land prepared well. The experiment was laid out as in a factorial Randomized Complete Block Design (RCBD) with three replications. The plot size was 15.12 m^2 (3.6 m length x 4.2 m width). There were a total of eighteen experimental units for each variety. The distance between each plot and

replication was 1 m and 1.5 m, respectively. Sowing was done on 18th of September, 2014. Thinning was done progressively for the seedlings from spot sowing. The first thinning was done 10 days after sowing, to obtain 2 plants per spot. The final thinning was done 17 days after sowing, to have one plant per spot. The field was weeded twice a month starting from seeding until it was established well, the first one after two weeks from sowing and the second at four weeks later. And also the remaining weeding practices, hoeing and watering were made as required.

Data on days to 50 % flowering, days to 95 % physiological maturity, plant height, number of branches/plant, number of leaves/plant, leaf area, leaf area index, number of capsules/plant, fresh calyx yield/plant, dry calyx yield/plant, seed yield/plant, 1000 seed weight, total number of capsules/ha, total fresh calyx yield/ha, total dry calyx yield/ha, total seed yield/ha and harvest index. To statically analyze the differences in characters caused by genotypic and spacing differences, five randomly selected samples were taken from each plot.

Mean values of all data for all characters measured were subjected to analysis of variance (ANOVA) using General Linear Model (GLM), statistical analysis software program (SAS inst., 2002). The Tukey's Studentized Range (HSD) Test was used to compare the mean separations at 5 % probability level.

Results and discussion

Variety

Variety had a significant effect on phonological and growth attributes (Table 1) as well as on yield attributes (Table 2). As the result revealed that, except thousand seed weight variety WG-Hibiscus-Jamaica was superior in all parameters than variety WG-Hibiscus-Sudan.

Spacing

Inter-row spacing

Inter-row spacing had a significant effect on number of leaves/plant, leaf area index (Table 1), number of capsules/ha, fresh and dry calyx yield/ha (Table 2).

Intra-row spacing

Intra-row spacing had a significant effect on days to 50% flowering, number of leaves/plant, leaf area, leaf area index (Table 1), number of capsules/ha, fresh and dry calyx yield/ha and dry seed yield/ha (Table 2).

Interactions

Days to 50% flowering

In the three way interaction the result revealed that, the highest number of days to 50 % flowering was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 60 cm and intra-row spacing of 90 cm; whereas, the lowest number of days to 50 % flowering was recorded at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 60 cm and intra-row spacing of 30 cm and also at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 90 cm and intra-row spacing of 30 cm (Table 3). This could be due to the fact that, at wider spacing plant population density was less; hence, the competition for light, nutrients and space was less thereby delay in days to 50 % flowering. Similar result was reported by Alessi *et al*. (1977) on sunflower. Contrasting results was reported by El Naim *et al*. (2012) who showed that plant population density had no significant effect on time to 50 % flowering on roselle.

Plant height

The highest plant height was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 60 cm and intra-row spacing of 30 cm; while, the least value was recorded at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 90 cm and intra-row spacing of 60 cm (Table 3). The highest plant height was obtained at planting of both varieties on closer inter- and closest intra-row spacing combination. This could be due to high competition of plants to light, nutrients, water and space. Supporting evidences were reported by Talukder *et al*. (2003) on okra, El Naim and Jabereldar (2010) on cowpea, Ramos *et al*. (2011) on roselle, Wenyonu *et al*. (2011) on okra, Zewdinesh *et al.* (2011) on *Artemisia annua* and Mushayabasa *et al*. (2014) on okra who stated that an increase in planting population markedly would increase plant height. The tallest plants produced by the most densely populated plants might be attributed to the competition for light and other growth resources among the plants that were crowded at the closer plant spacing (Maurya *et al*., 2013). Contrasting result obtained by El Naim *et al*. (2012) who showed that crop density had no significant effect on plant height of roselle.

Fresh calyx yield/plant

The highest fresh calyx yield/plant was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 90 cm and intra-row spacing of 60 cm; while, the lowest value was recorded at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 90 cm and

intra-row spacing of 60 cm (Table 3). Fresh calyx yield/plant increased by decreasing plant population density in WG-Hibiscus-Jamaica due to less competition of plants for light, nutrients and space. But in case of WG-Hibiscus-Sudan, fresh calyx yield/plant increased linearly by decreasing inter-row spacing and by increasing of intra-row spacing. This could be due to favorable growth conditions of inter- and intra-row spacing combinations for maximum fresh calyx development

Dry calyx yield/plant

The highest dry calyx yield/plant was recorded at interaction of variety WG-Hibiscus-Jamaica with inter-row spacing of 90 cm and intra-row spacing of 60 cm; whereas, the lowest dry calyx yield/plant was recorded at interaction of variety WG-Hibiscus-Sudan with inter-row spacing of 90 cm and intra-row spacing of 90 cm (Table 3). Dry calyx yield/plant increased by decreasing of plant population density due to less competition of plants for light, nutrients, water and space in WG-Hibiscus-Jamaica. But in case of WG-Hibiscus-Sudan, dry calyx yield/plant increased linearly by decreasing of inter-row spacing and by increasing of intra-row spacing. This could be due to favorable growth conditions of inter- and intra-row spacing combinations for maximum dry calyx yield production.

Thousand seed weight

The highest 1000 seed weight was recorded at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 90 cm and intra-row spacing of 90 cm; while, the lowest value was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 60 cm and intra-row spacing of 60 cm (Table 4). 1000-seed weight increased at lowest plant population density in WG-Hibiscus-Sudan due to the fact that reduced competition of plants for light, water and nutrient could able to produce highest 1000-seed weight. But in case of WG-Hibiscus-Jamaica, 1000 seed weight increased at the prescribed spacing. This could be due to favorable growth conditions of the spacing for maximum seed weight. Contrasting results were reported by Jakusko *et al*. (2013) on sesame and Yayeh *et al*. (2014) on field pea.

Table 1: Effects of variety, inter- and intra-row spacing on the phenological and growth attributes of roselle varieties planted at Wondo Genet, in 2014 cropping season

Treatments and statistics	Mean growth and phenological attributes						
	DFPF	DNFPM	PH (cm)	NBPP	NLPP	LA (m^2)	LAI
Variety							
WG-Hibiscus-Jamaica	122.3a	204.1a	123.36a	17.99a	830.65a	0.36a	2.59a
WG-Hibiscus-Sudan	70.92b	149.69b	80.37b	7.66b	154.37b	0.1b	2.22b
$CD_{0.05}$	0.64	4.37	7.58	1.29	56.01	0.04	0.19
Inter-RS (cm)							
60	96.48	176.61	103.98	12.85	528.08a	0.24	2.53a
90	96.73	177.19	99.76	12.81	456.94b	0.22	2.28b
$CD_{0.05}$	ns	ns	ns	ns	56.01	ns	0.19
Intra-RS (cm)							
30	95.50c	175.92	104.02	12.39	346.73b	0.15b	2.90a
60	96.63b	176.62	97.03	13.12	549.64a	0.25a	2.35b
90	97.69a	178.15	104.55	12.97	581.16a	0.30a	1.97c
$CD_{0.05}$	0.95	ns	ns	ns	83.09	0.06	0.28
CV (%)	0.96	3.57	10.77	14.50	16.45	23.94	11.35

Means followed by the same letter in the same column are not significantly different at 5% probability level using Tukey`s Studentized Range (HSD) Test. ns= non significant at 5 % probability level, RS= Row spacing, DEPF= Days to 50 % flowering, DNFPPM= Days to 95 % physiological maturity, PH= Plant height, NBPP= Number of branches/plant, NLPP= Number of leaves/plant, LA= Leaf area, LAI= Leaf area index and CD= Critical difference

Total fresh calyx yield/ha

The highest total fresh calyx yield/ha was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 60 cm and intra-row spacing of 30 cm; whereas, the lowest value was recorded at interaction of variety WG-Hibiscus-Sudan, inter-row spacing of 90 cm and intra-row spacing of 90 cm (Table 4). In closest spacing (60 cm x 30 cm) total fresh calyx yield/ha was

increased by 54.85 % in WG-Hibiscus-Jamaica and 86.29% in WG-Hibiscus-Sudan as compared to widest spacing (90 cm x 90 cm). Total fresh calyx yield/ha increased by increasing plant population density per unit area. This could be due to the fact that high population density per unit area attributed to the increase in total fresh calyx yield/ha.

Table 2: Effects variety, inter- and intra-row spacing on yield attributes of roselle varieties planted at Wondo Genet, in 2014 cropping season

Treatments and Statistics	NCPH	FCYPH (kg)	DCYPH (kg)	SYPH (t)
Variety				
WG-Hibiscus-Jamaica	3054187a	9258.6a	1019.76a	1.56a
WG-Hibiscus-Sudan	1496527b	4170.7b	458.80b	0.79b
Mean	2275357	6714.65	739.28	1.18
$CD_{0.05}$	493114	1141.5	149.27	0.27
Inter-RS (cm)				
60	2584845a	7817.4a	865.78a	1.30
90	1965869b	5611.8b	612.77b	1.05
Mean	2275357	6714.6	739.28	1.18
$CD_{0.05}$	493114	1141.5	149.27	Ns
Intra-RS (cm)				
30	3091832a	8983.7a	1025.42a	1.61a
60	2247463b	6241.8b	671.78b	1.18b
90	1486775c	4918.4b	520.63b	0.73c
Mean	2275357	6714.6	739.28	1.17
$CD_{0.05}$	731544	1693.4	221.45	0.4
CV (%)	31.35	24.59	29.21	33.13

Means followed by the same letter in the same column are not significantly different at 5% probability level using Tukey`s Studentized Range (HSD) Test. ns= non significant at 5 % probability level, RS= Row spacing, NCPH= Total number of capsules/ha, FCYPH= Total fresh calyx yield/ha, DCYPH= Total dry calyx yield/ha, SYPH= Seed yield/ha and CD= Critical difference

Total dry calyx yield/ha

The highest total dry calyx yield/ha was recorded at interaction of variety WG-Hibiscus-Jamaica, inter-row spacing of 60 cm and intra-row spacing of 30 cm; while, the lowest value was recorded at interaction of variety WG-*Hibiscus*-Sudan, inter-row spacing of 90 cm and intra-row spacing of 90 cm (Table 4). In closest spacing total dry calyx yield/ha was increased by 61.16 % in WG-Hibiscus-Jamaica and 87.62 % in WG-Hibiscus-Sudan as compared to widest spacing (90 cm x 90 cm). This could be due to the fact that high population density per unit area attributed to the increase in total dry calyx yield/ha.

Table 3: Interaction effects of variety, inter- and intra-row spacing on days to 50 % flowering, plant height, fresh and dry calyx yield/plant of roselle varieties planted at Wondo Genet, in 2014 cropping season

	Mean phenological, growth and yield attributes			
Treatments and statistics	**DFPF (DAS)**	**PH (cm)**	**FCYPP (g)**	**DCYPP (g)**
Variety*inter-RS*intra-RS				
V1*60 cm*30 cm	121b	140.47a	258.45bc	29.69bc
V1*60 cm*60 cm	121b	114.76abc	258.93bc	29.58bc
V1*60 cm*90 cm	124.9a	125.69ab	447.64ab	23.80cd
V1*90 cm*30 cm	121b	104.33bcd	210.43c	23.33cd
V1*90 cm*60 cm	123ab	119.78ab	563.69a	61.82a
V1*90 cm*90 cm	122.9ab	135.11ab	500.22a	49.59ab
V2*60 cm*30 cm	70c	86.07cde	155.48c	16.69cd
V2*60 cm*60 cm	71c	84.13cde	169.52c	16.97cd
V2*60 cm*90 cm	71c	72.73de	201.54c	23.8cd
V2*90 cm*30 cm	70c	85.20cde	115.63c	15.11cd
V2*90 cm*60 cm	71.5c	69.43e	108.31c	10.19cd
V2*90 cm*90 cm	72c	84.67cde	89.48c	8.6d
Mean	96.61	101.86	256.61	25.76
CD $_{0.05}$	2.76	32.58	194.44	20.32
CV (%)	0.96	10.77	25.51	24.62

Means followed by the same letter in the same column are not significantly different at 5% probability level using Tukey`s Studentized Range (HSD) Test. RS= Row spacing, DEPF= Days to 50 % flowering (days after sowing), PH= Plant height, FCYPP= Fresh calyx yield/plant, DCYPP= Dry calyx yield/plant and CD= Critical difference.

Table 4: Interaction effects of variety, inter- and intra-row spacing on 1000 seed weight, total fresh calyx yield/ha and dry calyx yield/ha of roselle varieties planted at Wondo Genet, in 2014 cropping season

	Mean yield attributes		
Treatments and statistics	TSW (g)	FCYPH (kg)	DCYPH (kg)
Variety*inter-RS*intra-RS			
V1*60 cm*30 cm	21.93b	14359a	1649.3a
V1*60 cm*60 cm	21.73b	7193bcd	819.9bcd
V1*60 cm*90 cm	22.85b	8275bcd	886.5bc
V1*90 cm*30 cm	23.27b	8350bcd	925.9bc
V1*90 cm*60 cm	23.40b	10893ab	1196.4ab
V1*90 cm*90 cm	21.98b	6483bcde	640.6bcde
V2*60 cm*30 cm	36.64a	8638bc	927.0bc
V2*60 cm*60 cm	37.08a	4709cdef	471.3cde
V2*60 cm*90 cm	36.21a	3732def	440.7cde
V2*90 cm*30 cm	37.45a	4588cdef	599.5bcde
V2*90 cm*60 cm	36.11a	2173ef	199.5de
V2*90 cm*90 cm	38.18a	1184f	114.8e
Mean	29.74	6714.75	739.28
CD $_{0.05}$	3.28	4904.3	641.33
CV (%)	3.71	24.59	29.21

Means followed by the same letter in the same column are not significantly different at 5% probability level using Tukey`s Studentized Range (HSD) Test. RS= Row spacing, TSW= 1000 seed weight, FCYPH= Total fresh calyx yield/ha, DCYPH= Total dry calyx yield/ha and CD= Critical difference

Conclusion

The present study demonstrated that, the highest total fresh and dry calyx yield/ha were recorded when WG-Hibiscus-Jamaica and WG-Hibiscus-Sudan were planted at inter-row spacing of 60 cm and intra-row spacing of 30 cm. When planting WG-Hibiscus-Jamaica at inter-row spacing of 60 cm and intra-row spacing of 30 cm (60 cm x 30 cm) total fresh and dry calyx yield/ha increased by 54.85 and 61.16 %, respectively as compared to planting at inter-row spacing of 90 cm and intra-row spacing of 90 cm (90 cm x 90 cm). When planting WG-Hibiscus-Sudan at inter-row spacing of 60 cm and intra-row spacing of 30 cm (60 cm x 30 cm) total fresh and dry calyx yield/ha increased by 86.29 and 87.62 %, respectively as compared to planting at inter-row spacing of 90 cm and intra-row spacing of 90 cm (90 cm x 90 cm). Based on

this result, 60 cm inter-row spacing with 30 cm intra-row spacing is highly recommended for the highest total fresh and dry calyx yield/ha at Wondo Genet and at a place where having similar agro-ecologies to Wondo Genet.

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