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Growth and Yield Responses of Roselle (*Hibiscus sabdariffa* L.) Varieties to Different Common Bean (*Phaseolus vulgaris* L.) Planting Densities in Intercropping System.

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This experiment was conducted at Hawassa, southern Ethiopia, during 2017/2018 to evaluate performance of roselle yield and yield components under intercropping system with different common bean planting densities. It was arranged in a 2x4 factorial in RCBD design and consisted of three replications and 11 treatments (sole cropping of two roselle varieties (WG-Hibiscus-Sudan and WG-Hibiscus-Jamaica) and a common bean variety (Ibbado) and four common bean planting densities combinations (25%, 50%, 75%, and 100%) with each roselle varieties. Yield and yield components data were collected and subjected to analysis of variance using SAS software version 9.3. Differences between means were assessed using Duncan`s Multiple Range Test at 5% probability level. Analysis of variance showed that the main factors interactions were nonsignificant in all parameters evaluated. Significant variations were recorded between two roselle varieties in all parameters evaluated. WG-Hibiscus-Jamaica was superior in all growth and yield parameters, except for thousand seed weight. Common bean planting density significantly influenced roselle seed yield per plant and dry calyx yield per hectare. Seed yields at 25% (46.6g) and for 50% (47.05g) common bean planting densities were statistically equivalent to that of 75% (40.65g) and 100% (39.27g) common bean planting densities. Roselle dry calyx yield was higher (0.88 t ha^{-1}) for 25% and lower (0.74 t ha^{-1}) for 100% common bean planting density. Besides, the intercropping reduced roselle seed yield per plant by 16.62% and dry calyx yield per hectare by 12.1% compared to roselle sole cropping. Hence, for higher roselle calyx yield per hectare, it is logical to suggest no more than 125,000 common bean plants per hectare for intercropping with both roselle varieties.

Keywords: Calyx, common bean, planting density

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INTRODUCTION

Roselle is an annual shrub that belongs to family Malvaceae and it is known by various common names like Karkade, hibiscus, Rozelle, red sorrel, Jamaican sorrel, rosella, Indian sorrel (Mahadevan and Kamboj, 2009; El Naim *et al*., 2012).Roselle is a tap-rooted plant that grows upright, branched or unbranched, with a height range from 1 to 2.5m depending on the varieties (Babatunde *et al*., 2002). More than 300 roselle species were reported from which the most common botanical types were *Hibiscus sabdariffa var. altissima* and *Hibiscus sabdariffa var. sabdariffa* (Tejaswini *et al.,* 1995; Ibrahim *et al*., 2013). These two botanical types vary in morphology, yield and used differently for various purposes (Mahadevan and Kamboj*,* 2009). Roselle is cultivated mainly in tropical and subtropical areas of the world for its calyx yield. Besides, seeds and leaves are other important parts of the plant. According to Mohamed *et al*. (2012), roselle largely cultivated in Sudan, China, Thailand, and Mexico. Studies indicated that roselle is produced for health benefits, food, feed and for income generation purposes (Ahmed*et al.,* 2009; Mahadevanand Kamboj, 2009; Builders *et al*., 2013).

In Ethiopia, roselle is recognized as one of the medicinal plants and currently two varieties (WG-Hibiscus-Sudan and WG-Hibiscus-Jamaica) have been registered and scaled up. Studies suggested that cultivation of both of the roselle varieties was profitable in the country (Girma *et al*., 2014). However, in addition to weak research-extension linkage, lack of appropriate cropping system is one of the main production constraints of roselle in Ethiopia. Hence, in order to widen roselle production, identification and utilization of a certain cropping system like intercropping with legume crops such as common bean may be best option. Hence, the objective of this study was to assess yield and yield components performances of two roselle varieties growing in intercropping system with different planting densities of common bean at Hawassa, Southern Ethiopia

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Hawassa, Southern Ethiopia in 2017/2018 cropping season. The study site is located at 7^{0}05’ North latitude, 39^{0}29’ East longitude and at an altitude of 1652 m a.s.l. The annual precipitation of the area ranges from 1000 to 1800 mm. The minimum and maximum mean annual temperatures of the area are 13 and 27 °C, respectively. The soil textural class of the area is sandy loam with a pH of 7.2 (Dessie and Kleman, 2007).

Experimental Materials, Design, and Treatments

Two roselle varieties (WG-Hibiscus-Sudan and WG-Hibiscus-Jamaica), and a common bean variety (Ibbado) were used for the present study. Seeds of roselle and common bean for the experiment were obtained from Wondo Genet Agricultural Research Center and Hawassa Sub-Center, respectively. Seeds of both crops were subjected to germination test to check their germination performances.

Eleven treatments were used in the experiment which includes a combination of the two roselle varieties and four planting densities of a common bean (100%, 75%, 50% and 25% of its recommended Planting density) plus a sole planting of each roselle variety and a common bean. The treatments were arranged in factorial Randomized Complete Block Design (RCBD) with three replicates. The size of each plot was 8.64 m^2 (3.6 m x 2.4m), and pathways between plots and blocks were 1 and 2m, respectively. Six rows of each roselle variety and nine rows of common bean plants per plot were used throughout the experiment. For roselle planting, 60 cm distance between any two rows of roselle plants and 30 cm distance between any two roselle plants in a row, which resulted in 48 and 55,555 plants per experimental plot and per hectare have been used, respectively. For sole cropping and 100% planting density, common bean was seeded at spacing of 40 cm x 10 cm. The different common bean densities were obtained by varying a plant spacing within a row (i.e., 10, 13, 20 and 40 cm plant spacing were used to obtain 100%, 75%, 50% and 25% common bean planting densities of the recommended planting density, respectively). Both sole common bean and its 100% arrangement with roselle varieties had 250,000 common bean plants per hectare while the common bean densities of the 75%, 50%, and 25% were 187,500, 125,000 and 62,500 plants hectare, respectively.

Data Collection

Plant heights (cm), number of primary branches per plant, number of capsules per plant and seed yield per plant (g) were recorded from five central plants selected at random. Besides, fresh and dry calyx yield per hectare (ton), fresh and dry aboveground biomass weight per hectare (ton), and harvest index were recorded were recorded. 1000 seeds weight (g) was recorded by taking sample of 1000 seeds from the seeds of the whole central plants of middle rows of each plot and weighed to determine 1000 seeds weight. Calyx yield per hectare was obtained after converting yield per plot to per hectare. Fresh calyx yield per plot was recorded from plants harvested from the net area of each plot (i.e., excluding border rows and plants) by hand and dry calyx yield per plot was obtained by sun drying the fresh yield. Aboveground biomass yield was obtained after converting biomass yield per plant to per hectare. Harvest index was obtained by dividing calyx yield (kg) to biomass yield (kg).

Data Analysis

Data were subjected to analysis of variance (ANOVA) twice. First it was done for main factors roselle varieties and common bean planting densities and for interaction effects of the two factors studied, (i.e., roselle varieties and common bean planting densities) and second for roselle varieties and cropping system using SAS computer software version 9.3. Whenever the ANOVA indicated the presence of significant variations between treatments, differences between means were assessed using Duncan`s Multiple Range Test at 5%probability level to examine where the variations lay and it was indicated as critical difference at 5% probability level (CD(0.05)) to indicate the minimum difference between mean values under comparison for the variation to be significant or not. The results of the analysis were combined and presented together under the results and discussion.

RESULTS AND DISCUSION

Roselle Growth and Yield Responses

Plant height

Analysis of variance showed that the interaction between the main factors did not affect roselle plant height (P > 0.05). Plant height was significantly affected by roselle variety (P ≤ 0.05), but not by common bean planting density and cropping system (P > 0.05). The tallest plant (83.21cm) was observed for variety Hibiscus-Jamaica and the shortest (70.53 cm) was for Hibiscus-Sudan (Table 1). The findings of Girma *et al*. (2014) and Gebremedin (2015) also showed that variation in growth, yield, and yield components of the two roselle varieties indicating longer maturity period and higher yield and yield components for Jamaica type. Hence, the differences in plant obtained might be due to differences in genetic makeup of the two varieties.

The nonsignificant effect of common bean planting density and cropping system on roselle plant height might be due to lower competition for growth resources exerted from the component crop (common bean) at vegetative growth stages of roselle. It might be also due to variations in competitive ability of the crops, because of differences in their morphology, which could improve efficiency in resource use. Besides, common bean was seeded after roselle seeds were germinated and seedlings established well and this might be an opportunity in roselle to be more competent and use available resources such as nutrient and moisture before the common bean became strong enough for competition. Similarly, reports of intercropping faba bean with barley (Agegnehu *et al*., 2006), maize with common bean (Lulie *et al.,* 2016) and onion with rosemary (Nigussie *et al*., 2017) in Ethiopia showed that planting density did not affected plant height of barley, maize, and onion respectively.

Number of primary branches per plant

Analysis of variance showed that interaction of roselle varieties and common bean planting densities did not affected roselle number of primary branches per plant (P > 0.05). It was observed that the number of primary branches was affected by roselle variety (P ≤ 0.001), but not by common bean planting density and cropping system (P > 0.05). Highest mean value of primary branches per plant (20.58) was obtained from Hibiscus-Jamaica compared to the value obtained from Hibiscus-Sudan (13.45) (Table 1). It has also been reported that the two roselle varieties varied in phenological characteristics (flowering and maturity period), growth, yield and number of branches per plant (Girma *et al*., 2014; Gebremedin, 2015). The variation between the two roselle varieties might be due to their genetic difference (Satyanarayana *et al*., 2018). Lack of significant difference in number of primary branches due to common bean planting density might also be due to higher competitive ability of roselle for growth resources as roselle varieties were established well before common bean. Similarly, the nonsignificant effect of common bean intercropping on number of roselle branches may indicate less competition between the two crops or a positive effect of common bean on roselle branch growth. It seems that efficient utilization of sunlight and nutrients by intercrops that could be important for formation of axillary buds and for their differentiations leading to branching without adversely affecting number of branches per plant. This might be due to variation in below and above ground morphology of the two crops that could contribute in reducing competition for resources. On the other hand, lack of significant difference between cropping systems might be due to the mixture of the legume component crop, common bean, which might lower competition for nitrogen with roselle in the intercropping. This result was in agreement with the report of Pushpa *et al*. (2017), which showed statistically nonsignificant difference in roselle branch number for sole cropping (14.8) and intercropping (13.8) with pigeon pea.

Yield and yield components

Number of capsules per plant

The analysis result showed that interaction of main factors was nonsignificant (P > 0.05) for roselle number of capsules per plant, which was significantly affected by variety (P ≤ 0.001), whereas neither the effect of common bean planting density nor cropping system ($P > 0.05$) was significant. Accordingly, Hibiscus-Jamaica produced the highest mean capsule number per plant (46.15), while Hibiscus-Sudan had the lowest value (33.41) (Table 1). Similarly, Gebremedin (2015) has reported significantly higher number of capsules per plant for Hibiscus-Jamaica than for Hibiscus-Sudan. This difference in capsule number per plant might be due to differences in plant height and branch number between the two roselle varieties, as the shorter and less branched variety (i.e., Hibiscus-Sudan) had lower capsule number per plant. Similar to the differences in growth parameters between the two roselle varieties, significant variation in capsule number also showed a clear genetic difference between the varieties.

On the other hand, common bean planting density did not affect number of capsules per plant of roselle, which might probably be due to higher competitive ability of both roselle varieties during vegetative growth. The effect of cropping system on capsules number per plant was not significant ($P > 0.05$). Statistically similar mean value was obtained from sole (42.69) and intercropping (39.28) (Table 1). In the mixture with roselle, common bean might have contributed nitrogen, which reduced competition for this nutrient. Furthermore, variation in root system of roselle and common bean, and a higher canopy structure of roselle might have favored roselle plants to be more competent for resources such as nutrient, moisture and light.

Seed yield per plant

Although the interaction between the main factors was nonsignificant, variety ($P \leq 0.001$) as well as both planting density and cropping system significantly affected roselle seed yield per plant ($P \leq 0.05$). The highest seed yield per plant (48.38g) was obtained from Hibiscus-Jamaica, whereas the lowest value (38.41g) was from Hibiscus-Sudan (Table 1). This was in agreement with the report of Gebremedin (2015), which indicated higher seed yield from Hibiscus-Jamaica. Hibiscus-Jamaica, which is characterized by taller plants, and more number of branches and capsules. Hence, higher seed yield per plant of this variety could be due to its higher growth and yield performances compared to Hibiscus-Sudan. Roselle seed yields per plant at 25% and 50% planting density were statistically equal and significantly higher than statistically at par yields at 75 and 100% planting density (Table 1). The lower roselle seed yield per plant obtained for higher planting densities could be due to more competition for resources, such as phosphorus by common bean (Okosun *et al*, 2006). Besides, it might also be resulted from more competition, as more number of plants per unit area need more resources than does less plant population densities on the same land area for seed formation and development. Sole cropping significantly resulted in higher seed yield per plant (52.04 g), than did intercropping (43.39g) (Table 1). The possible reason for higher seed yield per plant of roselle in sole cropping might be due to lack of intercrop competition for resources (Okosun *et al*, 2006). The result of the present study was in agreement with the report of Pushpa *et al*. (2017), observed who indicated significantly higher roselle seed yield per plant for sole than for roselle-castor and roselle-pigeon intercropping.

Thousand seed weight

Analysis of variance revealed that interaction of the main effects, planting density, and cropping system did not significantly affect thousand seed weight of roselle ($P > 0.05$), which was significantly affected by roselle variety ($P \leq 0.001$). The highest mean thousand seed weight was obtained from Hibiscus-Sudan (32.57g) and the lowest from Hibiscus-Jamaica (29.62 g) (Table 1). Gebremedin (2015) has also reported higher thousand seed weight of Hibiscus-Sudan and then that of Hibiscus-Jamaica. The higher 1000 seed weight could be due to higher seed size of the variety, while Hibiscus - Jamaica has small sized seeds.

Fresh and dry calyx yield per hectare

ANOVA result showed as the interaction of the main factors did not significantly influence roselle calyx yield per hectare ($P > 0.05$). However, both fresh and dry calyx yields per hectare of roselle were significantly influenced by roselle variety ($P \leq 0.001$), common bean planting density and cropping system ($P \leq 0.05$). Hibiscus-Jamaica was found to be superior and produced 4.99 ton ha^{-1}fresh and 0.92 ton ha^{-1}dry calyx yield compared to Hibiscus-Sudan, which produced 3.98 ton ha^{-1}fresh and 0.68 ton ha^{-1}dry calyx yield (Table 2). The higher growth and yield attributes of Hibiscus-Jamaica might be the main reason for its higher calyx yield. In their studies, Ahmed *et al.* (2009) have recommended late maturing roselle varieties and those varieties having higher number of branches per plant for higher calyx yield.

Compared to other common bean planting densities, higher dry calyx yield per hectare was obtained from 25% and 50% common bean planting density (0.88 and 0.83 ton ha^{-1}, respectively) than from 75% and 100% common bean planting density (0.75 and 0.74 ton ha^{-1}, respectively) (Table 2). As planting density increased, in general, there was decreasing trend in calyx yield (Table 2). It seems that common bean at a higher planting density was more competent for nutrients that might be important for roselle calyx development. On the other hand, sole cropping resulted in higher fresh (5.40 ton ha^{-}

Table 1. Mean values of phenological and growth parameters of two roselle varieties grown with different common bean planting densities at Hawassa during 2017/2018 cropping season.

Treatments	Plant height (cm)	Branches per plant	NCPP	SYPP (g)	TSW (g)
Roselle Variety					
Hibiscus-Jamaica	83.21^{a}	20.58^{a}	46.15^{a}	48.38^{a}	29.62^{b}
Hibiscus-Sudan	70.53^{b}	13.45^{b}	33.41^{b}	38.41^{b}	32.57^{a}
CR(0.05)	11.11	3.20	5.43	3.85	1.30
Common Bean Planting Density					
100%	72.88	14.85	36.50	39.27^{b}	31.00
75%	76.13	15.03	39.48	40.65^{b}	31.19
50%	78.47	18.92	40.36	47.05^{a}	31.00
25%	80.00	19.27	40.78	46.60^{a}	31.18
CR(0.05)	NS	NS	NS	5.44	NS
CV	16.6	21.8	15.78	10.13	4.79
Cropping System					
Sole cropping	83.55	19.97	42.69	52.04^{a}	31.12
Intercropping	76.87	17.02	39.28	43.39^{b}	31.09
CR(0.05)	NS	NS	NS	4.94	NS
CV	14.86	21.8	13.85	11.63	4.94
Variety*Planting Density	NS	NS	NS	NS	NS

Note: NS = not significant; CV = Coefficient of variance; CR = Critical range; NCPP=Number of capsules per plant, SYPP=Seed yield per plant; TSW=Thousand seed weight. Means followed by the same letters with in a column for a given treatment are not significantly different at P ≤ 5% level of significance.

Table 2. Mean of fresh and dry calyces yield, fresh and dry above ground biomass yield, and harvest index of two roselle varieties grown in sole cropping and intercropping with different common bean planting densities at Hawassa during 2017/2018 cropping season.

Treatment	FCY (ton ha^{-1})	DCY (ton ha^{-1})	FAB (ton ha^{-1})	DAB (ton ha^{-1})	Harvest Index (%)
Roselle Variety					
Hibiscus-Jamaica	4.99^{a}	0.92^{a}	17.87^{a}	2.96^{a}	0.32^{a}
Hibiscus-Sudan	3.98^{b}	0.68^{b}	14.54^{b}	2.52^{b}	0.27^{b}
CR(0.05)	0.40	0.06	1.42	0.35	0.04
Common Bean Planting Density					
100%	3.88^{b}	0.74^{c}	15.52	2.65	0.29
75%	4.09^{b}	0.75^{bc}	16.37	2.72	0.27
50%	5.00^{a}	0.83^{ab}	16.44	2.74	0.30
25%	4.97^{a}	0.88^{a}	16.49	2.85	0.31
CR(0.05)	0.57	0.09	NS	NS	NS
CV	10.30	8.79	10	14.76	16.06
Cropping System					
Sole cropping	5.40^{a}	0.91^{a}	16.88	2.86	0.32
Intercropping	4.48^{b}	0.80^{b}	16.21	2.74	0.29
CR(0.05)	0.67	0.09	NS	NS	NS
CV	15.32	11.76	8.24	12.22	14.45
Variety*Planting Density	NS	NS	NS	NS	NS

Note: NS=not significant; CV=Coefficient of variance; CR = Critical range; FCY=Fresh calyx yield; DCY=Dry calyx yield; FAB=Fresh above ground biomass yield; and DAB= Dry above ground biomass yield. Means followed by the same letters with in a column for a given treatment are not significantly different at p≤5% level of significance.

^{1}) and dry (0.91 ton ha^{-1}) calyx yield of roselle compared to intercropping (Table 2). This might be due to strong competition between common bean and roselle plants for mineral nutrients that could be important for roselle calyx development. The finding of the present study was in line with the report of Fadi and Gebauer (2004), who concluded that sole cropping results in higher roselle calyx yield than intercropping yield. Besides, the findings of Babatunde *et al.* (2002) indicated that roselle calyx yield was more declined when grown in association with cereals such as millet and sorghum.

Aboveground fresh and dry biomass yield per hectare

Result of the analysis of variance showed that interaction of the main factors was nonsignificant ($p > 0.05$). It was observed that fresh and dry aboveground biomass yield were significantly ($P \leq 0.001$ and $P \leq 0.05$, respectively) affected by the main factor variety. On the other hand, planting density and cropping system didn't have significant effect ($P > 0.05$) on both fresh and dry aboveground biomass of roselle. The highest fresh and dry biomass yields (17.87 and 2.96 ton ha^{-1}, respectively) were obtained from Hibiscus-Jamaica, while Hibiscus-Sudan produced lowest amounts (14.54 and 2.52 ton ha^{-1}, respectively) (Table 2). The superior performance of hibiscus-Jamaica in aboveground biomass yield might be due to increased plant height and more number of branches per plant. Besides, genetic difference of the varieties might have greater contribution for the variation.

On the other hand, the nonsignificant effects of planting density and cropping system might be due to higher competitive ability of roselle for growth resources during its vegetative growth stage, as it was seeded first and established well before the component crop (common bean). Besides, its tap root nature that might have helped to use mineral nutrients from different soil depth, taller the plant height and more number of branches per plant might have favored roselle in light utilization while lowering the effects of common bean. In line with this, Agegnehu *et al.* (2006) have reported statistically similar barley biological yield as faba bean density increased from 12.5% to 62.5%. Besides, Lulie *et al*. (2016) have also reported that common bean planting density did not show significant variation for maize aboveground biomass yield.

Harvest index

Analysis of variance showed that harvest index of roselle was significantly affected ($p \leq 0.05$) by variety, but it was not affected ($p > 0.05$) by planting density, interaction between main factors, and cropping system. Higher harvest index (0.32) was obtained for Hibiscus-Jamaica than for Hibiscus-Sudan (0.27) (Table 2). This might be due to the differences in growth, yield, and yield components of the two roselle genotypes. Besides, similar values of harvest index for sole cropping and intercropping were consistent with the report of Lulie *et al*. (2016), who stated nonsignificant difference for maize harvest index in maize-common bean intercropping.

CONCLUSION

The result of the present study showed that there was significant variations between the two different roselle varieties in all parameters studied. The highest yield and yield component values were obtained for Hibiscus-Jamaica, except for thousand seed weight, which was higher at Hibiscus-Sudan. Dry calyx yield and dry aboveground biomass yield for Hibiscus-Jamaica were 0.92 ton ha^{-1} and 2.96 ton ha^{-1}, respectively, compared to the corresponding values 0.68 ton ha^{-1} and 2.52 ton ha^{-1}for Hibiscus-Sudan. Increase in common bean planting densities, generally reduced roselle seed yield per plant and calyx yield per hectare. The highest dry calyx yield (0.88 ton ha^{-1}) was obtained for 25% planting density followed by 50% planting density, while the lowest was obtained for 100% planting density (0.74 ton ha^{-1}). Besides, intercropping system also has significantly reduced both roselle seed yield per plant and calyx yield per hectare. Hence, it is reasonable to suggest combination of not more than 125,000 common bean planting density per hectare in intercropping for better growth and calyx yield of roselle.

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