EVALUATION OF YIELD AND ECONOMIC ADVANTAGE OF INTERCROPPING ROSELLE WITH DIFFERENT PLANTING DENSITIES OF COMMON BEAN AT HAWASSA, SOUTHERN ETHIOPIA

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EVALUATION OF YIELD AND ECONOMIC ADVANTAGE OF INTERCROPPING ROSELLE WITH DIFFERENT PLANTING DENSITIES OF COMMON BEAN AT HAWASSA, SOUTHERN ETHIOPIA

A Thesis

Submitted to the Department of Horticulture and Plant Sciences, Jimma University College of Agriculture and Veterinary Medicine, in Partial Fulfillment of the Requirement for the Degree of Master of Science in Horticulture

By

Dejene Tadesse Banjaw

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SCHOOL OF GRADUATE STUDIES

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As research advisors, we hereby certify that we have read and evaluated the thesis prepared by Dejene Tadesse Banjaw under our guidance, entitled "**Evaluation of Yield and Economic Advantage of Intercropping Roselle with Different Planting Densities of Common Bean at Hawassa, Southern Ethiopia**". We recommend that the thesis be submitted as it fulfills the requirements for the degree of Master of Science in Horticulture.

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As members of the Board of Examiners of the MSc. thesis, open defense examination of Dejene Tadesse Banjaw, we certify that we have read, evaluated the thesis, and examined the candidate. We recommend the thesis be accepted as fulfilling the requirements for the degree of Master of Science in Horticulture.

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DEDICATION

I dedicated this M.Sc. Thesis to Shewaye Tadesse and Alemayehu Umeta.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my own work and I have duly acknowledged all sources of materials that I used for writing it. I have submitted this thesis to the Department of Horticulture and Plant Sciences, Jimma University College of Agriculture and Veterinary Medicine in partial fulfillment of the requirements for the Degree of Master of Sciences in Horticulture and deposited it at the University's library to be made available to borrowers for reference under the rules and regulations of the library. I solemnly declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Dejene Tadesse Banjaw, was born on 08 November 1980 in Baco Woreda, West Shoa Zone, Oromia Region, Ethiopia. He completed elementary school from 1987 to 1995 at Guto Adulan and Sheboka Primary Schools and his secondary school from 1996 to 1999 at Baco, Metehara and Adama Hawas Secondary Schools. He joined Hawassa University in 2000 and graduated with the Degree of Bachelor of Science in Plant Production and Dry Land Farming in 2004.

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ACRONYMS AND ABBREVIATIONS

FAO	Food and Agricultural Organization of the United Nations
LER	Land Equivalent Ratio
MAFAP	Monitoring and Analyzing Food and Agricultural policies
MAI	Monetary Advantage Index
PLC	Private Limited Company
SAS	Statistically Analysis System
WGARC	Wondo Genet Agricultural Research Center
EIAR	Ethiopian Institute of Agricultural Research

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ABSTRACT

Roselle (Hibiscus sabdariffa L.*) is a medicinal plant grown for its calyx yield. But, its cultivation in Ethiopia is not as common as that of other crops due to lack of appropriate cropping system. This experiment was therefore, conducted at Hawassa, southern Ethiopia, during 2017/2018 dry season to evaluate the performance of roselle and determine best intercropping combination of roselle with common bean for better economic yield, monetary advantage, and weed suppression. The experiment was carried out in a RCBD with a a 2x4 factorial arrangement and consisted of three replications and 11 treatments (sole cropping of two roselle varieties (Hibiscus-Sudan and Hibiscus-Jamaica) and a common bean variety (Ibbado) and intercropping of the roselle varieties with four common bean planting densities combinations (25%, 50%, 75%, and 100%)). All data collected were 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. Results of the experiment showed that the interaction between the main factors were nonsignificant for all parameters. However, the difference between the two roselle varieties was significant for all parameters evaluated in this experiment. Hibiscus-Jamaica took more days to flowering and maturity (145 and 180, respectively) and it was superior all 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 of roselle intercropped with 25% (46.6g) and 50% (47.05g) were statistically similar to that of 75% (40.65g) and 100% (39.27g) common bean planting densities. Dry calyx yield of roselle was higher at 25% (0.88 t ha^{-1}) and lower at 100% planting density (0.74 t ha^{-1}). Intercropping reduced roselle seed yield per plant by 16.62% and dry calyx yield per hectare by 12.1%. Hibiscus-Jamaica significantly reduced common bean maturity period and all yield and yield components, except 1000 seed weight. While number of pods per plant and seed number per pod showed decreasing trend, seed and biomass yields per hectare increased as planting density increased from 25% to 100%. Common bean planting density and cropping system significantly affected weed infestation. The highest values for visual estimate weed ground coverage, weed density, and weed dry biomass were recorded for 25% planting density (2, 15.43 plant/m^2, and 13.34g/m^2 respectively) and for sole cropping (2.5, 17.21 plant/m^2, and 15.61g/m^2 respectively). Land equivalent ratio (LER) of Common bean was highest when intercropped with Hibiscus-Sudan (0.51) than with Hibiscus-Jamaica (0.38). Both roselle variety and common bean planting density did not influence total LER and monetary advantage index (MAI). However, higher yield and monetary advantages were obtained with variety Hibiscus-Sudan variety (35% and 17,946 ETB) and for 100% planting density (39% and 21,410 ETB) which was also effective in weed control. Therefore, intercropping Hibiscus-Sudan with a 100% planting density of common bean was recommended for growers in the same agroecology with the study area for better yield and economic advantage as well as for better weed control. Since this study was conducted during the dry season at one location, it should be repeated under rainfed condition at different locations and in different years.*

Keywords: Calyx, monetary advantage, planting density, weed control

1. INTRODUCTION

Intercropping is an agronomic practice, which involves growing two or more crops on the same land unit in a particular growing season (Sullivan, 2003). Intercropping has various advantages over sole cropping, such as, it increases yield per unit area (Ali *et al*., 2015), avoids a risk of total yield loss as when one crop fails the producer may harvest the other crop (Heydari *et al*., 2016), and improves household income of the producers (Zhang *et al*., 2015). Another important aspect of intercropping is the reduction of the negative impact of weed, insect, and disease incidences compared to sole cropping (Lithourgidis *et al*., 2011). Despite these benefits, intercropping has some limitations, such as, reduction in yields of individual crops that might be due to competition for growth resources (Mainly water, nutrients and light) and creates some difficulties in crop management when intercrops have different cultural practices like fertilizer, pesticides, irrigation, and harvesting (Lithourgidis *et al*., 2011).

Nevertheless, intercropping is more advantageous for developing countries, like Ethiopia, because it enables efficient use of limited resources like arable land. In Ethiopia, many studies reported the advantage of intercropping through combinations of different crop species, including medicinal plants. For example, maize with common bean (Hirpa, 2014; Adafre, 2016), sorghum with groundnut (Dereje *et al*., 2016), common bean with stevia (a medicinal plant) (Lulie and Bogale, 2014) and maize with basil (Girma, 2015) intercropping resulted in a higher yield and economic advantage over sole cropping. Cultivation of medicinal plants in Ethiopia is being encouraged and promoted by the government and various medicinal plants have been prioritized and being studied by Wondo Genet Agricultural Research Center (WGARC). The inclusion of medicinal plants such as garlic, basil, lepidium, stevia, geranium, coriander, and roselle in the farming system may increase income and widen farm products of the growers.

Roselle (*Hibiscus sabdariffa* L.), belonging to the family Malvaceae, is one of the important medicinal plants grown in tropical and subtropical regions mainly for its calyx (Plotto *et al.,* 2004). In addition to its health benefit, roselle has industrial and nutritional values (Mahadevan and Kamboj*,* 2009). Roselle can be cultivated either in a sole cropping or in an intercropping system with different crops. Compatibility and higher intercrop productivity of roselle with legume crops, such as cowpea (Muoneke *et al*., 2002; Heydari *et al.,* 2016; Gendy *et* *al.,* 2017), peanut (Rigi *et al.,* 2017) and groundnut (Fbabatunde, 2003), have been reported. However, the performance of roselle in intercropping system has not been well known in Ethiopia, except some inter and intra row spacing determination (Gebremedin, 2015) and cost-benefit studies during direct sowing and transplanting roselle varieties (Girma *et al*., 2014a).

In Ethiopia, two roselle varieties (WG-Hibiscus-Jamaica and WG-Hibiscus-Sudan) were released and registered and profitability of their production has been reported (Girma *et al*., 2014a). However, cultivation of roselle is restricted to few growers though it is an important medicinal plant in the country. In Wondo Genet and Hawassa areas of Southern Ethiopia, farmers often grow crops in a mixed cropping system and the released two roselle varieties are observed in few gardens. Lack of appropriate cropping system and weak research-extension linkage are among the main production constraints of roselle in Sidama zone of the Southern Nations, Nationalities, and Peoples Region (SNNPR) of Ethiopia. Hence, in order to expand the production of this crop and provide a quality product to the domestic and foreign markets, identification of a certain cropping system, like intercropping with legume crops such as common bean, can be one of the best options.

Common bean (*Phaseolus vulgaris* L.) is one of the major annual legume crops grown in different parts of Ethiopia including Hawassa. It is used as a source of food and income for a number of households. Some studies have reported the performances of common bean varieties in different areas of Ethiopia (Mulu *et al*., 2016; Gereziher *et al*., 2017). Besides, various findings also indicated that common bean improved agronomic performances of intercrops and monetary advantages from intercropping (Temesgen *et al*., 2015; Adafre, 2016). These advantages might have resulted from its fast-growing nature, ability to fix atmospheric nitrogen, and better complementary with various crops. In Ethiopia, however, the performance of roselle under intercropping with common bean has not been studied despite the release of two improved roselle varieties and availability of various common bean varieties in the country.

Therefore, identification and utilization of a suitable cropping system for different roselle varieties can play a key role to increase productivity of the crop and land use efficiency in potential growing areas. In this regard, roselle production in Southern Ethiopia, a region where common bean is widely used for intercropping and a household landholding is very small (Dessie and Kleman, 2007), can be improved by intercropping it with common bean. In addition to this, intercropping roselle with common bean may also improve incomes of the growers and provide a variety of products that have different uses (e.g., food, feed, and medicine) for households. Therefore, this study was initiated with the following objectives:

1. To assess yield and growth performances of two different roselle varieties intercropped with different planting densities of common bean,

2. To determine the best intercropping combinations of roselle varieties and common bean planting densities for higher economic yield, weed suppression, land use efficiency and monetary advantage in Hawassa area, Southern Ethiopia.

2. LITRATURE REVIEW

2.1 Roselle (*Hibiscus sabdariffa* L.)

2.1.1 Origin and Taxonomy

The origin of roselle is not clear as some authors reported to be Asia (Mahadevan and Kamboj, 2009) and others stated tropical Africa (Ismail *et al.*, 2008; Tounkara *et al.,* 2011) as its place of origin. More than 300 species reported from which the most common botanical types of roselle were *Hibiscus sabdariffa var. altissima* and *Hibiscus sabdariffa var. sabdariffa* (Purseglove, 1974; 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 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; EI Naim *et al*., 2012).

2.1.2 Botanical Description of Roselle

Roselle is an annual plant that grows upright, branched or unbranched, with a height range from 1 to 2.5m depending on the varieties (Babatunde *et al*., 2002). However, different authors reported roselle plant height differently, while Mohamed *et al*. (2012) reported a range of 0.5 to 2 meter, Mahadevan and Kamboj (2009) indicated as it was about 3.5 meter. Roselle is a deep tap-rooted plant known with dark green or red stem, alternate green leaves with reddish vein having either long or short internodes (Mahadevan and Kamboj, 2009). Flowers are borne singly in the leaf axils having yellow or rose color, which turn to pink when wither. Fruits or capsules of roselle are 1.25-2cm long and green when immature and turns brown and split open when mature and dry. It has cleistogamous flowers and known being highly self-pollinated crop (Ibrahim *et al*., 2013). However, studies in the natural outcross of Jamaica type roselle resulted as outcrossing was observed and suggested the importance of selfing to maintain the genetic purity of the genotypes (Vaidya, 2000). It was stated that *var. altissima* was taller in height, unbranched, produces inedible calyx and grown for fiber while *var. sabdariffa* was bushy, pigmented and cultivated for its fleshy calyces (Mahadevan and Kamboj, 2009). Seed capsules (pods) of roselle begin to ripen starting from bottom and continue to top. According to Schippers (2000), the main economic yield of *Hibiscus sabdariffa* is calyx, fleshy sepal surrounding the seed boll in the flower, and has green, red or dark red color. As flowers fall off, the calyces swell and mature. During harvesting bright red calyx peeled off by hand from fruit (capsule) and subjected to the sun or artificial dry to get dry calyces yield. On the other hand, seeds and leaves are other important parts of the plant even though not common in Ethiopia.

2.1.3 Ecology and Production

Roselle grows well in loamy, well-drained soil in tropical and subtropical climates (EL-Sherf and Sarwat, 2007). Medagam *et al.* (2015) quoted (Tomes, 1990) indicated that roselle can be cultivated under warm seasons being resistant to a high-temperature condition. Roselle is not shade tolerant and is susceptible to damage from frost and fog. Roselle plants can be cultivated in tropical climates with well distributed annual rainfall of 1500-2000 mm. Roselle is propagated by seeds and the possibility of its propagation from cuttings reported (Mahadevan and Kamboj, 2009). Roselle can be directly seeded on the main field or by transplanting seedlings. In direct sowing, 2-10 number of seeds per hole used and thinned later (Ahmed *et al.,* 2009; Atta *et al*., 2010) to pre-planned crop stand. Roselle can be cultivated under the sole or intercropping systems (Babatunde *et al*., 2002; Gendy *et al.,* 2017). Roselle is produced widely in the tropical and subtropical areas of the world. According to Mohamed *et al*. (2012), roselle largely cultivated in Sudan, China, Thailand, and Mexico, of which China and Thailand are the major producer and supplier countries in the world. Roselle is produced for its health benefits, food, feed and for income generation purposes (Mahadevan and Kamboj, 20009; Builders *et al*., 2013).

According to Plotto *et al*. (2004), the calyx of roselle (*Hibiscus sabdariffa)* used for health teas, medicines, syrups, and food coloring in China. The health benefit of the plant is obtained from its seeds and calyx. Findings of Pacome *et al*. (2014) also showed that calyx extract of roselle is a potential source of natural antioxidants. Furthermore, Mohd-Esa *et al*. (2010) have reported that roselle seed extracts were found to have the highest antioxidant activity and strongest radical-scavenging activity of all plants tested and suggested as roselle seeds have potential to be used as food antioxidants. Calyces of roselle are prolific in many modern commercial blends of herbal drinks, fermented, cold and hot beverages due to its pleasing taste, as well as having decorative, culinary and medicinal uses (Mahadevan and Kamboj, 2009). Besides, an anti-hypertensive effect (Ajay *et al*., 2007) of roselle calyces and its wound healing potential (Builders *et al*., 2013) have been reported. Moreover, the nutritional benefits of roselle haven been reported in different countries. In India roselle is cultivated for its green leaves under the traditional farming system (Medagam *et al*., 2015). Roselle leaves and tender shoots are eaten raw and cooked as a vegetable while seeds are eaten roasted and ground into a meal because of their important nutritional contents (Da-Costa-Rocha *et al.,* 2014). Hainida *et al*. (2008) reported the predominant macro nutrients in roselle seeds which include potassium, magnesium, and calcium. Besides, while roselle seeds are used for oil production, residues from seeds oil extraction and leaves can also be used as animal feed (Plotto *et al*., 2004). The authors also indicated as leaves and powdered seeds of roselle were used for local foodstuff in West Africa. Besides, though a type of crop cultivar, location, and environmental conditions during cultivation affect nutritional components, roselle seeds have oil and protein that can be used as a supplement material for poor food in lysine (Elneairy, 2014). In Sudan roselle being a cash crop produced for its red calyx yield for local and export purposes (Ahmed *et al.,* 2009).

Roselle is one of the medicinal plants recognized in Ethiopia cultivated for its calyx yield. The calyx is used for health tea to regulate hypertensive effects. Currently, two roselle varieties have been registered and to enhance its production in the country different research activities were being conducted. The highest fresh and dry calyx yield per hectare for both Jamaica and Sudan varieties were recorded at 60 cm x 30 cm than other spacing (Gebremedin, 2015). It was suggested as the cultivation of both roselle varieties was profitable in Ethiopia (Girma *et al*., 2014a).

2.2 Common Bean (*Phaseolus vulgaris* L.)

Common bean is an annual low land pulse crop which belongs to the family Fabaceae. It is known by names like haricot bean, kidney bean, and locally called Boleqe. Common bean is one among the most important grain legumes produced mainly in the lowlands and in the rift valley areas of Ethiopia being source of income, employment and food (FAO, 2015). It grows best in warm temperature areas. Besides, common bean is one of the widely produced legumes crops in southern and eastern parts of Ethiopia for local and export markets contributing to foreign exchange earnings.

Common bean is grown as a rotation crop with cereals and possibility and effectiveness of the crop in intercropping have been reported (Temesgen *et al*., 2015; Adafre, 2016). This might be due to fixation of atmospheric nitrogen, a wide range of growth habits, and early maturity. Furthermore, according to Hirpa (2014), intercropping of maize with common bean resulted in the highest land use efficiency value which was 54% more efficient than growing both crops in the sole stand. Besides, Lulie and Bogale (2014) reported the advantages and profitability of intercropping common bean with stevia based on the highest results of the land equivalent ratio and monetary advantage indices.

2.3 Cropping System

The cropping system is an order in which the crops are cultivated on a piece of land over a fixed period or it is the way in which different crops are grown (Rana and Rana, 2011). There are different types of cropping system among which the common ones include crop rotation, mono-cropping, mixed cropping or intercropping (Gliessman, 1985). Crop rotation is growing different crops year to year based on planned sequence with the advantages of breaking weed and other pests` life cycles and provision of complementary fertilization to crops in sequence (Sullivan, 2003). Mono-cropping is growing only one crop on a particular land year after year. It is commonly practiced preferred by developed countries because of their large-scale mechanized farming systems which are not conducive to practice multiple cropping which is growing two or more crops on the same piece of land in one calendar year. In the case of multiple cropping, crops are grown together or they are grown separately at short intervals in the same field. Unlike mono-cropping, multiple cropping systems allow practices of intercropping and enhance production per unit time and per unit space by intensification of cropping in time and space dimensions (Sullivan, 2003). Intercropping practices have been considered as best option to get a higher yield that can be used for growing world population. This might be obtained by proper crop selection and good management practices in the intercropping system. The considerations for crop selection used in the intercropping include difference in crop species, crop variation in above ground and below ground morphology, difference in maturity periods of the crops, and ability of the crops to give yield while reducing weeds and other pests in intercropping. Besides, proper plant densities, spatial arrangements, and time of planting enhance the effectiveness of the intercropping practices in crop production which can be evaluated from the yield advantage and the monetary return (Gliessman, 1985).

One of the methods intensifying crops or multiple cropping in time and space for better use of resources such as land, water, solar radiation, inputs, and labor is by doing intercropping. Intercropping, growing two or more crops either simultaneously or sequentially on the same land unit, believed to be old practices and has potential as an economical and ecological alternative fully compatible with modern agricultural (Horwith, 1985). Unlike sole cropping, two or more crops involved and share space and time in the intercropping system.

2.4 Intercropping

2.4.1 Types of intercropping

Different authors stated various systems of intercropping differently. It can be an additive series or replacement series intercropping. While one crop is main and the other becomes a component in additive series intercropping, there is no main crop as both are component in replacement series system of intercropping. In additive series intercropping, a plant population of the main crop is same as plant population recommended for a pure stand, but the plant population of component crop can vary from that of its recommendation at a pure stand. Furthermore, even though there is no information about population density, Vandermeer (1992) described four types of intercropping such as:

1. Row-intercropping: it is growing two or more crops simultaneously where one or more crops planted in regular rows, and crop or other crops be grown simultaneously in a row or randomly with the first crop,

2. Mixed-intercropping: it is growing two or more crops simultaneously with no distinct row arrangement,

3. Strip-intercropping: it is growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact ergonomically and

4. Relay- intercropping: it is growing two or more crops simultaneously during part of the life cycle of each where a second crop planted after the first crop has reached its reproductive stage but before it is ready for harvest.

2.4.2 Advantages of intercropping

Though intercropping is an old practice, it has various advantages in the current agricultural practices. It enables wise use of resources and increases the amount of harvested yield through diversifying diet by using legumes that further improve soil fertility by adding nitrogen to the soil (Tadele, 2017). Besides, crops yield increase with intercropping results from higher growth rate, reduction of weeds, pests and diseases and more effective use of resources than sole cropping (Mousavi and Eskandari, 2011; Verma *et al*., 2014). In their intercropping haricot bean with stevia research report, Lulie and Bogale (2014) have showed higher land equivalent ratio and monetary advantage index indicating the practice of intercropping was more advantageous than the conventional monoculture crop. Mousavi and Eskandari (2011) indicated more weed, insect, and disease problems in pure cropping than intercropping that might be due to the reduction of the appearance of crop plants to pests. The most common advantages of intercropping were described below.

2.4.2.1 Crop yield

A crop yield is a measurement of the amount of agricultural production harvested per unit of land area. Increment and stability of the agricultural yield, that might result from area expansion and crop productivity improvement, are very important in order to provide nutritional needs of the growing world population. Intercropping is one of the agronomic strategies that can be used in crop productivity improvement programs. Intercropping yield advantage might be the result of combined yields of component crops than producing a sole crop. Many intercropping findings showed yield advantages of intercrops than sole cropping. Heydari *et al*. (2016) reported a 65% yield improved in intercropping roselle with cowpea as compared to sole cropping.

In their studies, Raei *et al.* (2015) reported the yield advantage of intercropping potato with green bean. In addition, Bantie (2014) reported the possibility of getting higher productivity from intercropping maize with potato. A total marketable yield of root vegetable carrot and root parsley obtained from intercropping with onion was greater than that from homogeneous cultivation (Blazewicz-Wozniak and Wach, 2011). Orluchukwu and Udensi (2013) also have reported better crop yield obtained in okra, maize, and pepper intercropping. Yield advantage of intercropping goes beyond getting a higher amount of agricultural crops produces per unit area.

Apart from obtaining higher yield, intercropping can be used as crop insurance in case of a crop failure due to climate change and other biotic or abiotic factors and intercropping enables farmers get better nutrition for their family (Workayehu, 2014). Furthermore, intercropping can be practiced in forage production. According to Stoltz and Nadeau (2014), intercropping maize with faba bean resulted in higher protein content compared to monocropped maize which can increase the sustainability of forage production by reducing the need for protein feed. Various factors could be considered with respect to an advantage of practicing intercropping for better yield. Complementary effects between intercropping components, reduction in pests, and effective utilization of resources were suggested as means of yield increment in intercropping.

Yield advantages of intercropping might be resulted from greater water use efficiency (Xu *et al*., 2008) that might be because of variation in root system, that helps the uptake of moisture and nutrient from different soil depth (Li *et al*., 2003). Furthermore, it might be obtained from different branching and leaf patterns of intercrops for light interception as compared to sole crop (Mehdi *et al*., 2015) and because of quick growing nature crop that may use available moisture which slow-growing crop may not able to use (Hugar and Palled, 2008; Verma *et al*., 2014). On the other hand, yield advantage might be resulted as intercropping able to increase floral diversity which enhances abundance and diversity of beneficial insects such as pollinators and natural enemies of crop pests. According to Pereira *et al*. (2015), the richness and abundance of bees visiting pepper flowers was higher in pepper-basil intercropping than sole cropping. Hence, wider, heavier and longer fruits reported in the intercropping might be due to the attraction of pollinators in the intercropping system than sole cropping. Furthermore, intercropping productivity depends on careful variety selection, plant density, plant arrangement, growing season and crop management practices like fertilizer rate and time of application, disease, insect and weed control practices, managing time and amount of irrigation (Lithourgidis *et al*., 2011; Bantie, 2014; Kaushik and Sharma, 2017).

Desalegn and Fekadu (2012) stated the importance of crop variety selection in intercropping for better yield as potato varieties resulted in different yield in intercropping with maize. This might be either due to variation in yield potential of the varieties or their variation in response to intercrop competition. Beside, Rezaei-Chianeh *et al.* (2011) reported as biological and grain yields of maize and faba bean were significantly affected by maize and faba bean densities. Intercropping of onion with different population densities of rosemary affected fresh and dry bulb yield (Nigussie *et al*., 2017). Moreover, mixed intercropping of maize with broad bean at a density of 100% resulted in better overall yield than sole culture of each crop species (Koocheki *et al*., 2015). Similarly, the report of Raei *et al.* (2015) indicated that highest green bean and tuber potato yields were obtained by using higher population densities of both crops.

2.4.2.2 Monetary value

Another important advantage of intercropping can be seen from the amount of money gained from the current market prices of intercrops yields. Getting higher intercrops yield may not be beneficial unless produces changed to cash. On the other hand, monetary advantage can be obtained from either low-cost inputs utilization or reduction in the cost of practices like weeding and fertilizer in intercropping than sole cropping (Raei *et al*., 2015; Nchanji *et al*., 2016). Monetary advantages due to intercropping have been reported in various studies such as maize - soybean intercropping resulted in 3,408 USD ha^{-1} (Zhang *et al.,* 2015) and wheat - chickpea intercropping resulted a highest gross return of Rs.54,099 (Kaushik and Sharma, 2017). Mehdi *et al*. (2015) reported that the highest economic performance of roselle intercropping with aloe vera was at a mean yield of 3.9 t ha^{-1}. In addition, intercropping maize with French bean (Hugar and Palled, 2008) and roselle with groundnut (Fbabatunde, 2003) also showed a better economic advantage over sole cropping. For instance, studies on maize intercropping with bush bean were found agronomical viable and economically profitable than the sole crop of maize (Ali *et al*. 2015). Similarly, Sarker *et al*. (2013) reported as the higher gross return was obtained from all intercrop combinations of red amaranth, bush bean, and garden pea than sole maize and these short duration vegetables were encouraged for intercropping.

Preconditions stated for the higher intercrop yield may result in a monetary advantage in intercropping. For instance, proper crop variety, planting density, and arrangement that result in higher intercrop yield, may warranty monetary advantage as higher yield enables higher income. In the report by Fbabatunde (2003), the highest cash advantage was obtained from intercropping roselle with groundnut followed by intercropping with cowpea. Koocheki *et al.* (2015) indicated as maize-bean intercropping at 150% maize and 100% bean density resulted in higher income than other densities. Hugar and Palled (2008) indicated that gross and net income from intercropping maize with French bean under 1:2 row proportion showed higher compared to the rest of the crop combinations. Another monetary advantage of intercropping was proved from intercropping of wheat with chickpea in 2:2 row proportions (Kaushik and Sharma, 2017). According to Singh *et al*. (2016), growing intercrops in guava orchard resulted in highest gross income and net return. This enhances growers' income that might use to fulfill their household needs. In Ethiopia, various intercropping studies suggested opportunities of getting better income from intercropping practices (Agegnehu *et al*., 2006; Bantie *et al*., 2014; Tadsesse *et al*., 2015).

According to Agegnehu *et al*. (2006), mixed intercropping of faba bean in normal barley culture at a density not less than 37.5% of the sole faba bean was indicated for better overall yield and income than a sole culture of each crop species. Similarly, Waktola *et al*. (2014) reported an increase in the monetary advantage of maize intercropping with soybean resulted from the increase in planting density of soybean. The authors indicated that the highest monetary advantage was obtained from 75% soybean planting density in the intercropping system. In addition, intercropping Arabica Coffee (*Coffea Arabica* L.) with Korerima (*Aframomum Korarima*) in southwestern Ethiopia was suggested for better economic return (Tadsesse *et al*., 2015). Additionally, while Nigussie *et al.* (2017) reported the highest monetary advantage when onion intercropped with 80% rosemary planting density, Lulie *et al*. (2016) recommended 75% common bean planting density for better monetary advantage in intercropping with maize.

2.4.2.3 Control of crop pests

One of the important aspects of intercropping is its ability to reduce the negative effects of weeds, insect pest and disease. Weeds competition for light, water, nutrients, and space and affects crop production. However, intercropping is believed to reduce weed pressure (Bagheri *et al*., 2014). Intercropping studies resulted in lower weed biomass and populations in intercrops than sole crops (Orluchukwu and Udensi, 2013; Dereje *et al*., 2016). This might be due to improved use efficiency of growth resources of intercrops in the intercropping system (Yadollahi *et al*., 2014). Intercropping reduces available space for weed growth and forms higher shade that reduces germination, growth, and competitiveness of weeds than that of sole cropping (Rao, 2002). Santo *et al*. (2016) reported largely reduced weeds density and biomass in intercropping herbaceous legume lablab (*Dolichos lablab*) in a coffee plantation. According to Adeyemi *et al*. (2014), intercropping of okra with amaranths was an effective means of reducing weed pressure in okra production. Besides, intercropping sorghum with groundnut was suggested for striga control (Dereje *et al*., 2016). This confirms the report of Odhiambo and Ariga (2001) which indicated a reduction in striga incidence in maize-beans intercropping. Further, maize - Okra - pepper intercropping resulted in weed density and weed biomass reduction (Orluchukwu and Udensi, 2013). Moreover, Girma *et al*. (2005) reported as Orobanche weed was significantly reduced for tomato/maize and tomato/common bean intercropping as compared to tomato sole cropping. Reduction in weed pressure resulted from intercropping can reduce the cost of weed control that otherwise increases production cost. Apart from weed reduction, intercropping has positive effects in reducing insect and disease that negatively affect crop growth, yield, and quality.

Abdullah and Fouad (2016) reported faba bean and fenugreek intercropping reduced populations of black legume aphid of faba bean and increased seed yield. Similarly, aphid infestation was reduced in maize-pepper intercropping (Mitiku *et al*., 2013). A significant result was reported from intercropping carrot with marigold on decreasing the number of roots damaged by the carrot rust fly, *Psila rosae*, and by nematodes and decreasing the number of larvae of carrot psyllid, *Trioza viridula* (Jankowska *et al*., 2012). A tomato-basil intercropping advantage in reducing *Bemisia tabaci* infestation was reported (Mutisya *et al.,* 2016). Hence, intercropping reduces production costs and dependency on pesticides by reducing the effects of insect pest in crop production. The importance of intercropping with respect to crop protection also goes with a reduction in disease. Mitiku *et al*. (2013) reported maize intercropping with pepper was effective in protecting pepper fields infection by potyvirus. Cultivation of different crop species together delays the onset of diseases by reducing the spread of disease-carrying spores and by modifying environmental conditions so that intercrops become less favorable to the spread of certain pathogens (Lithourgidis *et al*., 2011). Disease reduction in the range of 20-40% was reported in intercropping legumes (pea, faba bean, and lupin) with barley (Hauggaard-Nielsen *et al*., 2008). Furthermore, Vieira *et al*. (2009) reported anthracnose and leaf spot reduction in common bean when intercropped with maize.

2.4.2.4 Improvement of soil fertility

Different aspects of intercropping with respect to soil fertility improvement have been reported. The most important aspect goes with the inclusion of legumes in intercropping particularly for atmospheric nitrogen fixation (Nurbakhsh *et al*., 2013; Pour *et al.,* 2016). The inclusion of legume in intercropping contributes some nitrogen for the other crops in the intercropping which indirectly increase soil fertility by increasing amount of biological nitrogen fixation (Mousavi and Eskandari, 2011). Furthermore, findings of Lulie *et al*. (2016), conducted in Ethiopia, indicated as the level of nitrogen was increased under maize-common bean intercropping system and decreased in sole cropping. The other beneficial aspect of intercropping in soil fertility improvement includes an increase in crop residues from intercrops that might use as a source of fertilizer after decomposition (Peoples *et al.,* 2009). Intercropping lemongrass and chamomile helped in ameliorating sodic soil (Patra *et al.,* 2002). The authors indicated that lemongrass was tolerant because of its N^+ exclusion and chamomile was tolerant because of its N^+ accumulator. Besides, intercropping of crop plants having different rooting patterns permit greater exploitation of a larger volume of soil and improves access to relatively immobile nutrients (Hailu, 2015). This reduces competition for nutrient among intercrops and reduces soil nutrient exhaustion. Roselle and common bean have different rooting patterns and maturity periods and these can be taken as an advantage for intercropping practice.

Generally, intercropping increases crop productivity, enhances more monetary returns, reduces pest damages, improves soil fertility, provides lodging resistance, reduces risk of crop failure, and promotes biodiversity (Agegnehu *et al*., 2006; Lithourgidis *et al.,* 2011; Khan *et al*., 2013; Kaushik and Sharma, 2017). However, for a better utilization of intercropping system in a crop production, identification of suitable crop arrangement in that enables growers to get better economic yield and monetary advantages through better resources (land, labor, water, fertilizer, pesticide) utilization is important agronomic practice for resource-poor growers. Intercropping component crop in an additive series manner with a constant population of principal crop per unit area is one of the intercropping systems in resource optimization such as arable land.

2.4.3 Disadvantages of intercropping

Despite its various advantages, intercropping has some disadvantages compared to sole cropping. Reduction of yields of individual crops in intercropping, complexity of management activities, increase in labor demands and difficulty for mechanization are some of the disadvantages of intercropping (Gliessman, 1985; Ali *et al*., 2015; Heydari *et al*., 2016). This yield reduction could be resulted from competition for light, water, and nutrients and/ or due to allelopathic effects between intercrops. Furthermore, the complexity of crops management occurs when the different intercrops have different requirements for fertilizer and pesticides (Lithourgidis *et al*., 2011). Besides, there might be a lodging problem in intercropping that makes harvesting difficult in addition to a risk of mixing up of products, an increase in cost separation of mixed yield, product loss and lack of market for the mixed products.

2.5 Effect of Intercropping on Growth, Yield and Yield Components of Roselle

Different studies indicated that intercropping influenced crops growth parameters as well as yield and yield components. The differences in growth and yield performances of crops in intercropping and sole cropping systems resulted from variation in crops densities (Mehdi *et al*., 2015), spatial arrangements (Zhang *et al*., 2015), and crop selection (Pushpa *et al.,* 2017), which might result increase in competition for resources or improve complementarities among crops particularly when legumes involved in the cropping system. Besides, complementary resource use might occur when crops vary in resource use, when crops have different rooting patterns and vary in growth duration (Lithourgidis *et al.,* 2011). Variation in performances of roselle has been reported among intercropping and sole cropping systems (Fadi and Gebauer, 2004; Mehdi *et al*., 2015; Rigi *et al*., 2017).

According to Mehdi *et al*. (2015), roselle intercropping with aloe vera resulted in significant variation in plant dry weight, stem diameter, number of capsule per plant, 100 seed weight, economic yield but did not affect plant height. According to the report, a combination of 25% roselle with 75% aloe vera resulted in an increase in stem diameter (23.3mm), a number of capsules per plant (364.5), and economic yield (3.9 ton/hectare) as compared to roselle sole cropping. But, a pure stand of roselle was high in stem diameter (15.6), capsule dry weight (26.5 ton/hectare), and harvest index (0.06%). Furthermore, Rigi *et al*. (2017) have reported significant variation in roselle yield from which maximum boll wet weight was obtained from 60% roselle + 20% peanut + 20% aloe vera crop combinations next to sole roselle cropping. According to Fadi and Gebauer (2004), roselle plant height (63.7cm), the number of leaves per plant (40.7), the number of capsule per plant (26.3), and yield were reduced significantly as compared to its sole cropping. However, roselle-cowpea intercropping resulted in significant increase in the number of roselle fruits per plant and dry sepals yield per plant compared with sole roselle planting system (Gendy *et al*., 2017). Besides, Pushpa *et al.* (2017) did concluded that intercropping influenced growth and yield of roselle as significantly shorter plant height was obtained from sole cropping (135.7cm) than both roselle-pigeon pea (144.9cm) and roselle-castor (147.6cm) intercropping. However, the authors have also indicated that, number of branches, plant spread, leaf dry weight, seed yield, and fresh and dry calyx yield of roselle were significantly reduced in intercropping. Egbutah *et al.* (2015) summarized that variations in growth and yield of roselle were observed in intercropping with cowpea and with groundnut. According to the report, higher significant results of 100 seed weight (3.51g and 3.86g), number of pods per plant (23.19 and 22.97) and dry calyx yield per hectare (84.32kg and 92.04kg) were obtained from roselle-cowpea and roselle groundnut intercropping systems, respectively. However, seed yield per plant (9.64g), number of seeds per pod (15.72) and harvest index (4.93%) recorded from sole roselle cropping were not significantly varied from roselle-cowpea intercropping but varied from those obtained from roselle-groundnut intercropping except harvest index.

2.6 Intercropping Performance of Roselle Based on Competition Indices

Various competition indices were used in evaluating the advantage of intercropping over sole cropping. According to Mead and Willey (1980) cited in Bantie *et al.* (2014), land equivalent ratio (LER) which indicates the efficiency of intercropping in using the resources of the environment compared, was one of the indices developed to evaluate intercropping performances and it was stated as intercropping is advantageous when values of LER is greater than one. Some studies also reported that intercropping roselle is advantageous than sole cropping. Gendy *et al*., (2017) reported 1.252, 1.204, and 1.143 values of LER for intercropping roselle with cowpea. Furthermore, Pushpa *et al*. (2017) have reported 1.41 and 1.29 LER values for intercropping roselle with pigeon pea and castor, respectively.

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted in 2017/2018 cropping season (from September 2017 to March 2018) at Hawassa Green Mark Herb Research Station, in Southern Ethiopia. This 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. It receives a bimodal rainfall with short and long rainy seasons from March to April and June to August, respectively and the average annual precipitation ranges from 1000 to 1800 mm. The minimum, mean and maximum temperatures of the area are 13, 20 and 27 °C, respectively. The soil textural class of the area is sandy loam with a pH of 7.2 (Dessie and Kleman, 2007). The agro-climatic condition of the area is warm sub-humid in which both food and cash crops are grown. Some of the common crops in the area include enset, maize, coffee, khat, banana, sugarcane and common bean. Maize and enset production for food as well as enset-coffee agroforestry farming system are largely practiced in the area. Common bean is commonly intercropped with other crops in the area.

3.2 Experimental Materials

Two roselle varieties (WG-Hibiscus-Sudan and WG-Hibiscus-Jamaica) and a common bean variety (Ibbado) were used for the study. Both roselle varieties were released recently by Wondo Genet Agricultural Research Center (WGARC) of the Ethiopian Institute of Agricultural Research (EIAR) and currently, they are being scaled up. Both roselle varieties are annual, erect and branching herbaceous sub-shrub type (Appendix Figures 1 & 2). They have alternate and green leaves with reddish veins, and deep tap roots, and grow well in a well-drained loamy soil. Common bean variety, Ibbado, is an improved type released in 2003 by Southern Agricultural Research Institute for warm sub-humid agroecology. It is a determinate bush type in growth habit, having 90-95 days of growth duration. It is grown in Hawassa and other areas with similar agroecologies in the southern region of Ethiopia.

3.3 Experimental Design and Treatment Arrangement

The treatments were arranged in factorial Randomized Complete Block Design (RCBD) with three replicates (Table 1). the experiment consisted of a total pf 11 treatments arrangement consist of a total of 11 treatments (2 roselle varieties × 4 planting densities of common bean plus 3 sole plots). 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 2 m, respectively. The total experimental area was 538.72 m^2 (14.8m x 36.4m). Six rows of roselle were maintained in each plot, with a spacing of 60 cm between rows and 30 cm between plants in a row, which resulted in 48 and 55,555 plants per experimental plot and per hectare have been used, respectively. Nine rows of common bean were maintained per plot and for sole and 100% common bean planting density, 40 cm spacing between rows and 10 cm between plants within a row were used. The different common bean densities (100%, 75%, 50% and 25%) were obtained by varying spacing between plants with in a row (i.e., 10, 13, 20 and 40 cm for 100%, 75%, 50% and 25% common bean planting densities, respectively). Both sole common bean and its 100% arrangement with roselle had 250,000 common bean plants per hectare while densities of 75%, 50%, and 25% had 187,500, 125,000 and 62,500 plants per hectare, respectively (Table 1).

Table 1. Treatments and corresponding roselle and common bean planting densities (number of plants per hectare and plot; figures in the bracket indicate number of plants per plot).

Treatments	WG-Hibiscus-Sudan (Var 1)	WG-Hibiscus-Jamaica (Var 2)	Common bean CB)
1.Var 1 sole	55,555 (48)	-	-
2.Var2 sole	-	55,555 (48)	-
3. CB sole	-	-	250,000 (216)
4. Var 1 + 100% CB	55,555 (48)	-	250,000 (216)
5. Var 1 + 75% CB	55,555 (48)	-	187,500 (162)
6. Var 1 + 50% CB	55,555 (48)	-	125,000 (108)
7. Var 1 + 25% CB	55,555 (48)	-	62,500 (54)
8. Var 2 + 100% CB	-	55,555 (48)	250,000 (216)
9. Var 2 + 75% CB	-	55,555 (48)	187,500(162)
10. Var 2 + 50% CB	-	55,555 (48)	125,000 (108)
11. Var2 +25% CB	-	55,555 (48)	62,500 (54)

3.4 Experimental Procedures and Methods of Data Collection

3.4.1 Management practices

The experimental land was prepared and uniformly labeled in September 2017. Seeds of roselle and common bean for the experiment were obtained from Wondo Genet Agricultural Research Center and Hawassa Maize Research Sub-Center, respectively. Seeds of both crops were subjected to germination test to check their viability prior to sowing. After verifying germination capacity seeds of each crop were sown in separate rows (Appendix Figure 3). For roselle, four seeds were sown per planting hole in September 2017, followed by thinning to one plant per hole two weeks after emergence. Two seeds per hole of common bean were sown in October 2017, 30 days after roselle and thinned to one plant per hole just two weeks after emergence. Irrigation was applied carefully at 2-3 days interval and during the experimental period, hand weeding was done uniformly at the same time for all experimental plots after collecting the necessary. No fertilizer and no other chemical inputs were applied throughout the experimental period.

3.4.2 Data collection

3.4.2.1 Roselle

Phenology:

Days to 50% flowering: It was recorded by counting the number of days from sowing to 50% of the plants in plot started flowering.

Days to maturity: It was recorded by counting the number of days from sowing till 95% of the plants in the plot became yellow and the lowest capsules on the stem were about to split open.

Yield and yield components:

Plant height (cm): It was recorded by measuring from the base (root collar) to the top of five randomly selected central plants of the central rows of each plot at harvesting stage using measuring tape (model XB-089) and the average value was used for analysis.

Number of primary branches per plant: It was recorded by counting all primary branches on five randomly selected central plants of the central rows.

Number of capsules per plant: It was recorded by counting all capsules available on the five selected sample plants.

Seed yield per plant (g): It was measured using sensitive balance after harvesting seeds from the five sampled plants. The harvested seeds were sun dried until a constant weight was achieved.

Fresh calyx yield per plot (g): It was recorded from plants harvested from the net area of each plot (i.e., excluding border rows and plants) and weighing calyx using digital balance (model YP20002). Harvesting was done by detaching capsules by hand (Appendix Figure 4) when the majority of the lower capsules started to crack at their tips.

Dry calyx yield per plot (g): It was recorded for sun dried fresh calyx yield per plot (which was harvest from net plot area by excluding border rows and plants) using digital balance (model YP20002) until a constant weight was achieved (Appendix Figure 5).

Calyx yield per hectare (ton): It was recorded by converting the values of calyx yield per plot to per hectare and both fresh and dry calyx yields per plot were converted to hectare for analysis.

1000 seed weight (g): A sample of 1000 seeds was taken from the seeds harvested from the whole central plants in the middle rows of each plot and weighed to determine 1000 seeds weight.

Fresh and dry aboveground biomass weight per plant (g): Fresh aboveground biomass per plant was recorded at harvesting for randomly selected five central plants of each plot by cutting from the base of the plant, chopping into manageable size and finally weighing the samples by using digital balance (model YP20002). Dry aboveground biomass weight per plant was measured after oven drying of the fresh samples at 70 ^oC using digital balance until a constant weight was achieved.

Fresh and dry aboveground biomass weight per hectare (ton): Both fresh and dry aboveground biomass weight per plant were converted into fresh and dry aboveground biomass yield per hectare for analysis, respectively.

Harvest index: Harvest index was calculated by dividing dry calyx yield to dry aboveground biomass as described by Atta *et al*. (2010).

3.4.2.2 Common bean

Phenological data:

Days to flowering: It was recorded by counting the number of days from sowing to 50% of the plants in a plot started flowering.

Days to Maturity: It was recorded by counting number of days taken from sowing to 50% of the plants in the plot started changing their leaves and pods to yellow color.

Yield and yield components:

Plant height (cm): It was recorded by measuring height from base (root collar) to top of the five randomly selected central plants at harvesting stage using measuring tape (model XB-089) and the average value was used for analysis .

Number of pod per plant: It was recorded by counting the number of pods produced by the five central plants of the middle rows selected at random from each plot and the average value was used for analysis.

Seed number per pod: It was recorded by counting number of pods in each pod of ten randomly selected pods from the five central plants selected at random from each plot.

Seeds yield per plot (g): It was recorded after weighing seeds of the whole central plants (by excluding the border rows and plants) using digital balance (model YP 20002) and after the seeds were adjusted to 10% moisture content using a digital moisture tester (model M-3G) according to the following formula (Hellevang, 1995). Then, seed yield per plot was converted into seed yield per hectare which was used for analysis.

Adjusted yield = [(100-AM)/(100-SM)] X Obtained yield

Where, A M = actual moisture and SM =standard moisture

1000 seed weight (g): It was recorded by weighing a sample of 1000 seeds randomly taken from the whole central plants of each plot.

Aboveground biomass per plant (g): Fresh aboveground biomass per plant was recorded for the five sample plants of each plot by cutting from the base of plants, chopping into manageable size for weighing and finally weighing the samples by using digital balance (model YP20002). Dry aboveground biomass per plant was recorded after a freshly weighed sample was subjected to over drying at 70 ^{o}C to constant weight.

Aboveground biomass per hectare (ton): Both fresh and dry aboveground biomass weight per plant were converted into fresh and dry aboveground biomass weight per hectare for analysis respectively.

3.4.2.3 Weed data:

Visual rating of weed ground coverage, weed density, and weed aboveground biomass were recorded and analyzed to evaluate the effect of roselle intercropping with different common bean planting densities on weed growth. Estimation of visual rating of weed infestation was done for each plot using 1-6 scale, where 1 = 0-5% weed cover, 2 = 6-25% weed cover, 3 = 26-50% weed cover, 4 = 51-75% weed cover, 5 = 76-95% weed cover and 6 = 96-100% weed cover following the method developed by Subramanian *et al.* (1991) as cited by Orluchukwu and Udensi (2013). This was done twice during the experimental period (first weeding was done at 30 days after common bean planting and second weeding was done 30 days after the first weeding) and the average values per plot were used for analysis.

Weed density (plant/m^2) was also estimated twice during the experimental period at a similar time with that of visual rating of weed infestation by counting plants of each weed species observed in the net area of each plot and by converting the observed total number of weeds per net area of each plot to m^2. The average values of the two measurements per plot were calculated and converted into weed density per m^2.

Fresh aboveground weed biomass weight (g) in the net area of each plot was measured by weighing it using digital balance (model YP20002) and then oven drying at 70 °C until constant weight achieved to record the dry biomass weight (Prasad *et al*., 2015). Finally, the dry weed biomass values were converted to m^2 for analysis.

3.4.2.4 Indices of intercropping competition

Land equivalent ratio (LER): The yield advantage of roselle and common bean intercropping was determined by calculating LER, which is the amount of land required under sole cropping to obtain the same yield as produced in the intercrop (Mead and Willey, 1980) as cited by Bantie *et al*. (2014). When LER measures 1.0 or greater than 1.0, it means that an intercropping is more advantageous than sole cropping in utilizing resources. Hence, the effectiveness of roselle and common bean intercropping for using available resources was evaluated using the following formula.

LER = (YRI/YRP) + (YCBI/YCBP), Where, YRI = Calyx yield of roselle under intercropping, YCBI = Seed yield of common bean under intercropping, YRP = Calyx yield of roselle in sole cropping, and YCBP = Seed yield of common bean in sole cropping.

Monetary advantage index (MAI): The yields of both roselle and common bean crops in intercropping and sole cropping systems and their economic returns in terms of monetary value were evaluated by calculating MAI to check whether intercropping or sole cropping of roselle and common bean is profitable or not.

MAI= [(PR*YRI) + (PCB*YCBI)]*((LER-1)/LER), where, PR = Price of roselle calyx yield and PCB = Price of common bean seed yield.

Local market prices of a kg of dry calyx of roselle and a kg of common bean seed were used for monetary advantage determination. The average prices for a kg of a dry calyx of roselle (70 ETB) and common bean (11 ETB) were taken from local markets in Hawassa and Shashamane towns.

3.5 Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using SAS software version 9.3. Whenever the ANOVA indicated the presence of significant variations between treatments, mean separation was done using Duncan`s Multiple Range Test at 5% probability level [CR (0.05)] to indicate the minimum difference between mean values under comparison for the variation to be significant or not.

4. RESULTS AND DISCUSION

4.1 Responses Roselle (*Hibiscus sabdariffa* L.) to Intercropping

4.1.1 Phenological and growth responses

4.1.1.1 Days to 50% flowering and days to maturity

Analysis of variance showed that the interaction of roselle varieties and common bean planting densities on for phenological responses of roselle was nonsignificant ($P > 0.05$) (Appendix Table 1). However, both days to 50% flowering and maturity were significantly ($P \leq 0.001$) affected by roselle variety (Appendix Table 1) where Jamaica type more mean days to flower (145 days) and mature (180 days) as compared to Sudan type that took 123 days to flower and 151 days to mature (Table 2). It was reported that the Jamaica type roselle variety showed an indeterminate type of maturity and a higher cost of production in Ethiopia as compared to the Sudan type (Girma *et al*., 2014a). These results are similar with that of Satyanarayana *et al*. (2018), indicating variation among roselle genotypes evaluated in India for days to flowering, which was found to vary. Significant variation in phenology might be resulted due to the genetic difference between the roselle varieties.

However, the effect of planting density of common bean on days to 50% flowering and maturity of roselle was not significant was not significant ($P > 0.05$) (Appendix Table 1). This could be due to the higher competitive ability of roselle during its vegetative growth stage. The time interval between sowing roselle and common bean has also not significantly contributed to this. Lulie *et al.* (2016) reported similar findings for maize intercropped with common bean.

On the other hand, cropping system significantly affected days to maturity ($P \leq 0.05$), where intercropping resulted in more days to maturity, but it did not affect days to flowering ($P > 0.05$) (Appendix Table 1). The longer maturity period of roselle at with intercropping might be due to the contribution of common bean to fix nitrogen into the soil which could extend vegetative growth period of the plants.

Table 2. Mean performance of phenological and growth parameters of two roselle varieties grown with sole cropping and intercropping systems with different common bean planting densities at Hawassa during 2017/2018 cropping season.

Treatments	Days to 50% flowering	Days to maturity	Plant height (cm)	Branches number per plant
Roselle Variety				
Hibiscus-Jamaica	145.00[a]	180.00[a]	83.21[a]	20.58[a]
Hibiscus-Sudan	123.33[b]	151.33[b]	70.53[b]	13.45[b]
CR(0.05)	0.89	0.54	11.11	3.20
Common Bean Planting Density				
100%	134.33	165.67	72.88	14.85
75%	134.33	165.67	76.13	15.03
50%	134.00	165.67	78.47	18.92
25%	134.00	165.67	80.00	19.27
CR(0.05)	NS	NS	NS	NS
CV	0.76	0.37	16.6	21.8
Cropping System				
Sole cropping	133.33	165.00[b]	83.55	19.97
Intercropping	134.17	165.67[a]	76.87	17.02
CR(0.05)	NS	0.53	NS	NS
CV	0.79	0.34	14.86	21.8
Variety*Planting Density	NS	NS	NS	NS

NS = not significant; CV = Coefficient of variance; CR = Critical range; Means followed by the same letters with in a column for a given treatment are not significantly different at p≤ 5% level of significance

4.1.1.2 Plant height

Analysis of variance showed that the interaction between the main factors did not affect roselle plant height (P > 0.05) (Appendix Table 1). 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 (83.21 cm) was observed for variety Hibiscus-Jamaica and the shortest (70.53

cm) was for Hibiscus-Sudan (Table 2). The findings of Girma *et al*. (2014a) and Gebremedin (2015) also showed 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 at vegetative growth stages. 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 affect plant height of barley, maize, and onion respectively. However, at 100% mixture of component crop, height of the principal crop was reduced, which was in agreement with the report of Lulie *et al.* (2016), but quite contrary to the reports of Agegnehu *et al*. (2006) and Nigussie *et al*. (2017). On the other hand, the non significant difference between sole cropping and intercropping for plant height was similar with the results obtained from onion intercropped with rosemary (Nigussie *et al*., 2017) and maize intercropped with red amaranths, bush bean, and garden pea (Sarker *et al*., 2013). On the contrary, Fadi and Gebauer (2004) reported significantly higher roselle plant height (67.1cm) in sole cropping than in intercropping (63.7cm) with *Acacia senegal* probably because of strong competition exerted by *Acacia senegal.*

4.1.1.3 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) (Appendix Table 1). 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 2). It has been reported that the two roselle varieties varied in phenological characteristics (flowering and maturity period), growth, and yield (Girma *et al*., 2014a; Gebremedin, 2015) and branches number. 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 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 axillury 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.

4.1.2 Yield and yield components

4.1.2.1 Number of capsules per plant

ANOVA showed as 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 (Appendix Table 1). Accordingly, Hibiscus-Jamaica produced the highest mean capsule number per plant (46.15), while Hibiscus-Sudan had the lowest value (33.41) (Table 3). 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 ($P > 0.05$) (Appendix Table 1). Statistically similar mean value was obtained from sole (42.69) and intercropping (39.28) (Table 3). 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.

4.1.2.2 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 ($P \leq 0.05$) (Appendix Table 1). The highest seed yield per plant (48.38g) was obtained from Hibiscus-Jamaica, whereas the lowest value (38.41g) was from Hibiscus-Sudan (Table 3). 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 3). The lower roselle seed yield per plant obtained for higher planting densities could be due to competition for resources, such as phosphorus which is also important for common bean seed formation and development during intercropping (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 (52.04g), than did intercropping (43.39g) (Table 3). 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.

4.1.2.3 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 ($P \leq 0.001$) (Appendix Table 1). The highest mean thousand seed weight was obtained from Hibiscus-Sudan (32.57g) and the lowest from Hibiscus-Jamaica (29.62 g) (Table 3). Gebremedin (2015) has also reported higher thousand seed weight of Hibiscus-Sudan and than 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.

Table 3. Mean capsules number per plant, seed yield per plant, and thousand seed weight of two roselle varieties grown in sole cropping and intercropping with different common bean planting densities at Hawassa during 2017/2018 cropping season.

Treatment	NCPP	SYPP (g)	TSW (g)
Roselle Variety			
Hibiscus-Jamaica	46.15[a]	48.38[a]	29.62[b]
Hibiscus-Sudan	33.41[b]	38.41[b]	32.57[a]
CR(0.05)	5.43	3.85	1.30
Common Bean Planting Density			
100%	36.50	39.27[b]	31.00
75%	39.48	40.65[b]	31.19
50%	40.36	47.05[a]	31.00
25%	40.78	46.60[a]	31.18
CR(0.05)	NS	5.44	NS
CV	15.78	10.13	4.79
Cropping System			
Sole cropping	42.69	52.04[a]	31.12
Intercropping	39.28	43.39[b]	31.09
CR(0.05)	NS	4.94	NS
CV	13.85	11.63	4.94
Variety*Planting Density	NS	NS	NS

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.

4.1.2.4 Fresh and dry calyx yield per hectare

ANOVA result showed as interaction of the main factors did not significantly influence roselle calyx yield per hectare ($P > 0.05$) (Appendix Table 2). 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 4). 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) recommended late maturing roselle varieties and those varieties having higher number of branches per plant for higher calyx yield. Besides, the present finding was also similar with the report of Gebremedin (2015), which showed significantly higher fresh and dry calyx yields per hectare for Hibiscus-Jamaica and lower calyx yield for Hibiscus-Sudan variety.

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 4). As planting density increased, in general, there was decreasing trend in calyx yield (Table 4). It seems that common bean at a higher planting density was more competent for nutrients that might be important for roselle calyx development.

As compared to intercropping, sole cropping resulted in higher fresh (5.40 ton ha^{-1}) and dry (0.91 ton ha^{-1}) calyx yield of roselle (Table 4). 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.

4.1.2.5 Aboveground fresh and dry biomass yield per hectare

Result of the analysis of variance showed that interaction of the main factors was nonsignificant ($p > 0.05$) (Appendix Table 2). 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 4). 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 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.

4.1.2.6 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 (Appendix Table 2). Higher harvest index (0.32) was obtained for Hibiscus-Jamaica than for Hibiscus-Sudan (0.27) (Table 4). 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. This might be due to the nonsignificant effect of cropping system on the aboveground biomass weight of roselle.

Table 4. 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

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 $p \leq 5\%$ level of significance.

4.2 Common Bean Responses to Intercropping

4.2.1 Phenological and growth responses

4.2.1.1 Days to 50% flowering and days to maturity

Analysis of variance showed as interaction of the main factors was nonsignificant ($P > 0.05$) for days to 50% flowering and days to maturity of common bean (Appendix Table 3). Besides, the effect of roselle varieties on days to 50% flowering was also not significant ($p > 0.05$). However, both common bean planting density and cropping system significantly affected ($P \leq 0.05$) days to 50% flowering of common bean plants. More days to flowering (63.33 days) was observed for 100% common bean density (Table 5). This was probably due to higher competition for light that forces the crop to maintain vertical growth while prolonging its flowering time. In consistent with the present result, Lulie *et al*. (2016) have indicated significant longer flowering periods of common bean at 100% planting density in maize-common bean intercropping.

Flowering took longer time (63.67 days) in sole common bean plots than in the plots intercropped with roselle ((Table 5). This might be due to lack of intercrop competition for resources. Space, nutrient, and light limitations might have cause early flowering in intercropped plots instead of allowing more time for vegetative growth, as the case with sole cropping. Similarly, Alemayehu *et al.* (2018) reported that number of days to 50% flowering was significantly reduced with intercropping common bean variety (Ibbado) with maize compared to Ibbado sole cropping. Reduction in days to 50% flowering might be due to delay in plating time of common bean, as plants emerged earlier might have resulted in strong competition for growth resources, mainly soil moisture and light.

It was observed that days to maturity of common bean was significantly ($P \leq 0.001$) affected by roselle varieties, but the effects of common bean planting density and cropping system were not significant ($P > 0.05$) (Appendix Table 3). Intercropping common bean with roselle variety Hibiscus-Jamaica shortened its maturity period (96.75 days) compared to maturity period at intercropping with roselle variety Hibiscus-Sudan (100 days). The shorter maturity period might be due to higher rate of vegetative growth of the Jamaica type roselle variety that makes roselle more competitor for growth resources.

4.2.1.2 Plant height

Results of the analysis of variance showed that common bean plant height was not significantly affected by interaction of the main factors or by common bean planting density ($P > 0.05$), but, it was affected by roselle variety ($P \leq 0.01$) and cropping system ($P \leq 0.001$) (Appendix Table 3). The highest mean plant height (51.33cm) of common bean was obtained for intercropping with Hibiscus-Sudan and the lowest value (40.19cm) for intercropping with Hibiscus-Jamaica (Table 5). This could be due to the difference between roselle varieties in competing for resources like light, water, and nutrients. Due to its higher rate vegetative growth and more days of maturity, Hibiscus-Jamaica might have influenced the growth of common bean compared to the effect of Hibiscus-Sudan. The higher numerical plant height value (50.33 cm) was recorded for 25% and lower values (41.93 cm) for 100% planting density of common bean. The higher numerical value for 25% planting density might be due to low resources competition. Sole common bean cropping resulted in 69.27cm plant height, while intercropping with roselle resulted in shorter plants (45.76cm) (Table 5). Lack of intercrop competition at common bean sole cropping could be the possible reason for the crop to growth more in height. Similarly, Jerai *et al.* (2010) also have reported higher chick pea height with sole cropping and shorter plants under intercropping with mustard. However, report of Pushpa *et al.* (2017) indicated that cropping system resulted in no significant difference for pigeon pea height in intercropping with roselle. They have further elaborated that lack of difference could be due to fertilizer applied in pigeon pea-roselle intercropping that might have lowered intercrop competition, unlike the result of the present study, where fertilizer was not applied.

Table 5. Mean values of phenological and growth parameters of common bean grown in sole cropping and intercropping systems with two roselle varieties at Hawassa during 2017/2018 cropping season

Treatment	Days to 50% flowering	Days to maturity	Plant height (cm)
Roselle Variety			
Hibiscus-Jamaica	62.17	96.75[b]	40.19[b]
Hibiscus-Sudan	62.50	100.00[a]	51.33[a]
CR(0.05)	NS	1.19	7.93
Common Bean Planting Density			
100%	63.33[a]	97.50	41.93
75%	62.67[ab]	98.33	41.87
50%	61.67[b]	98.33	45.90
25%	61.67[b]	98.33	50.33
CR(0.05)	1.34	NS	NS
CV	1.73	1.39	19.78
Cropping System			
Sole cropping	63.67[a]	99.33	69.27[a]
Intercropping	61.33[b]	98.37	45.76[b]
CR(0.05)	1.16	NS	10.52
CV	1.96	1.46	22.14
Variety*Planting Density	NS	NS	NS

NS=not significant; CV=Coefficient of variance; CR= Critical range; Means in a column followed by the same letters are not significantly different at P≤5% level of significance.

4.2.2 Yield components and seed yield

4.2.2.1 Number of pods per plant

ANOVA showed that number of pods per plant was not significantly affected by interaction of the main factors ($P > 0.05$), but it was significantly influenced by roselle varieties ($P < 0.01$), planting densities ($P \leq 0.05$), and the cropping system ($P \leq 0.01$) (Appendix Table 4). The higher significant value (28.17) was obtained for intercropping common bean with Hibiscus-Sudan and the lower pods number per plant (17.36) at intercropping with Hibiscus-Jamaica (Table 6). Different varieties of a crop may respond differently to various growth resources. Probably, the variation in common bean number of pods per plant when intercropped with the two roselle varieties could be due to higher level competition exerted by the Hibiscus-Jamaica variety because of its higher rate of vegetative growth. It was similar with the report of Dahmardeh (2013) who indicated variation in peanut intercropped with different maize varieties. Furthermore, as common bean planting density increased from 25% to 100%, number of pods per plant declined from 28.92 to 16.03 (Table 6). The decline in pods number per plant at higher planting densities of common bean might be due to increased competition for growth resources as more plants per unit area need more resource. Besides, at higher common bean density there might also be higher competition between intercrops and between different parts of individual plants, leading to lower number of pods per plant. The decrease in pods number per plant at higher planting density was quite in agreement with the report of Alemayehu and Boki (2015) for their studies on common bean planting density.

The highest mean number of pods per plant (38) was obtained at sole cropping and the lowest value at intercropping common bean with roselle (22.76) (Table 6). When common bean and roselle were grown in association (intercropping), the intercrop competition might have adversely influenced the growth of common bean, which further affected pod formation and development. Besides, the time interval between planting of the two crops might have enhanced competition for growth resources. This result was in agreement with the report of Lulie *et al*. (2016), who reported significantly higher number of common bean pods per plant in sole cropped plots than in plots intercropped with maize. In addition, Jerai *et al.* (2010) have also reported higher number of chickpea pods per plant for sole cropping and lower value for intercropping with mustard.

4.2.2.2 Seed number per pod

Analysis of variance showed that common bean seed number per pod was significantly affected by both main factors (roselle variety and common bean planting density) ($P \leq 0.05$), but their interaction as well as cropping system did not have significant effect ($P > 0.05$) (Appendix Table

4). Common bean seed number per pod was higher when intercropped with variety Hibiscus-Sudan (4.10) but lower with Hibiscus-Jamaica (3.58) (Table 6). This could be due to variations in morphological structure of roselle varieties which might have affected seed formation through enhanced competition and shading effects. Moreover, mean seed number per pod was significantly reduced from 4.27 to 3.47 as planting density of common bean increased from 25% to 100% (Table 6). This probably might be due to the fact that at higher planting density there might be higher level of competition for growth resources that might have reduced vegetative growth of plants. Hence, such reduced rate of vegetative growth as a result of lower amount of photosynthetic assimilate used for seed development might have reduced the amount seed number per pod of common bean.

4.2.2.3 Thousand seed weight

Analysis of variance showed that the main factors (roselle variety and common bean planting density), their interaction, and cropping system did not significantly affected common bean thousand seed weight ($P>0.05$) (Appendix Table 4). This might be due to efficient conversion of biological yield to economic yield which might have resulted from the ability of common bean in to partition or allocate more amount of the available photosynthetic assimilates by enhancing the linkage between source and sink during its grain filling stage. Similarly, Alemayehu and Boki (2015) have reported the non significant variation in seed weight of common bean due to planting densities.

4.2.2.4 Seed yield per hectare

Analysis of variance showed that unlike the nonsignificant result of interaction of main factors ($P > 0.05$), common bean seed yield per hectare was significant affected by the main effects of roselle variety and common bean planting density ($P \leq 0.01$) and by cropping system ($P \leq 0.001$) (Appendix Table 4). While the highest mean seed yield (2.17 ton ha $^{-1}$) was obtained at intercropping with Hibiscus-Sudan, the lower mean seed yield (1.40 ton ha $^{-1}$) was recorded at intercropping with Hibiscus-Jamaica (Table 6). The lower yield and yield attributes obtained at intercropping with Hibiscus-Jamaica, in the present study, clearly indicated the inappropriateness of the variety in cultivation practice in intercropping with common bean as compared to the

Hibiscus-Sudan. It could be due to difference in genetic character of the variety being more competent for resources because of its higher growth characteristics. Increase in common bean planting density enhanced its seed yield per hectare. The highest common bean seed yield (2.38 ton ha $^{-1}$) was obtained at 100% common bean planting density while the lowest yield (1.26 ton ha^{-1}) at 25% common bean planting density intercropped with roselle (Table 6). Possible reason why seed yield increased at higher density could be due to presence of higher number of common bean plants per hectare. The present finding was similar with the findings of Adafre (2016) and Lulie *et al.* (2016) who reported highest common bean seed yield at its 100% planting density when intercropped with maize and Raei *et al.* (2015) who stated higher green bean yield at higher its density intercropped with potato. Alemayehu and Boki (2015) obtained higher common bean seed yield per hectare at higher planting density compared to yield obtained from lower planting densities.

Furthermore, common bean sole cropping resulted in a higher seed yield (4.02 ton ha^{-1}) as compared to the lower yield (1.74 ton ha^{-1}) obtained at intercropping with roselle (Table 6). The intercrop competition for resources such as phosphorus (Girma *et al*., 2014b) at intercropping could be the main reason for the yield difference recorded. Similarly, reports showed higher significant faba bean (Agegnehu *et al.*, 2006), common bean (Adafre, 2016; Lulie *et al*., 2016), and soybean (Waktola *et al*., 2014; Zhang *et al*., 2015) seed yields per hectare at sole cropping than intercropping faba bean with barley, common bean with maize, and soybean with maize.

Table 6. Mean values of yield and yield components of common bean as affected by sole cropping and intercropping with two roselle varieties at Hawassa during 2017/2018 cropping season.

Treatment	Pod number per plant	Seed number per pod	Seed yield (ton ha^{-1})	TSW (g)
Roselle Variety				
Hibiscus-Jamaica	17.36^{b}	3.58^{b}	1.40^{b}	288.92
Hibiscus-Sudan	28.17^{a}	4.10^{a}	2.17^{a}	288.24
CR(0.05)	7.40	0.40	0.44	NS
Common Bean Planting Density				
100%	16.03^{c}	3.47^{b}	2.38^{a}	288.02
75%	17.83^{bc}	3.67^{b}	2.04^{ab}	287.75
50%	28.27^{ab}	3.97^{ab}	1.46^{bc}	290.21
25%	28.92^{a}	4.27^{a}	1.26^{c}	288.24
CR(0.05)	10.47	0.56	0.62	NS
CV	37.15	11.84	28.19	15.97
Cropping System				
Sole cropping	38.00^{a}	4.00	4.02^{a}	290.15
Intercropping	22.76^{b}	3.84	1.74^{b}	288.85
CR(0.05)	8.46	NS	0.62	NS
CV	34.81	19.81	29.94	14.22
Variety*Planting Density	NS	NS	NS	NS

NS=not significant; CV=Coefficient of variance; CR= Critical range; TSW=Thousand seed weight. Means in a column followed by the same letters are not significantly different at P≤5% level of significance.

4.2.2.5 Aboveground fresh and dry biomass yield per hectare

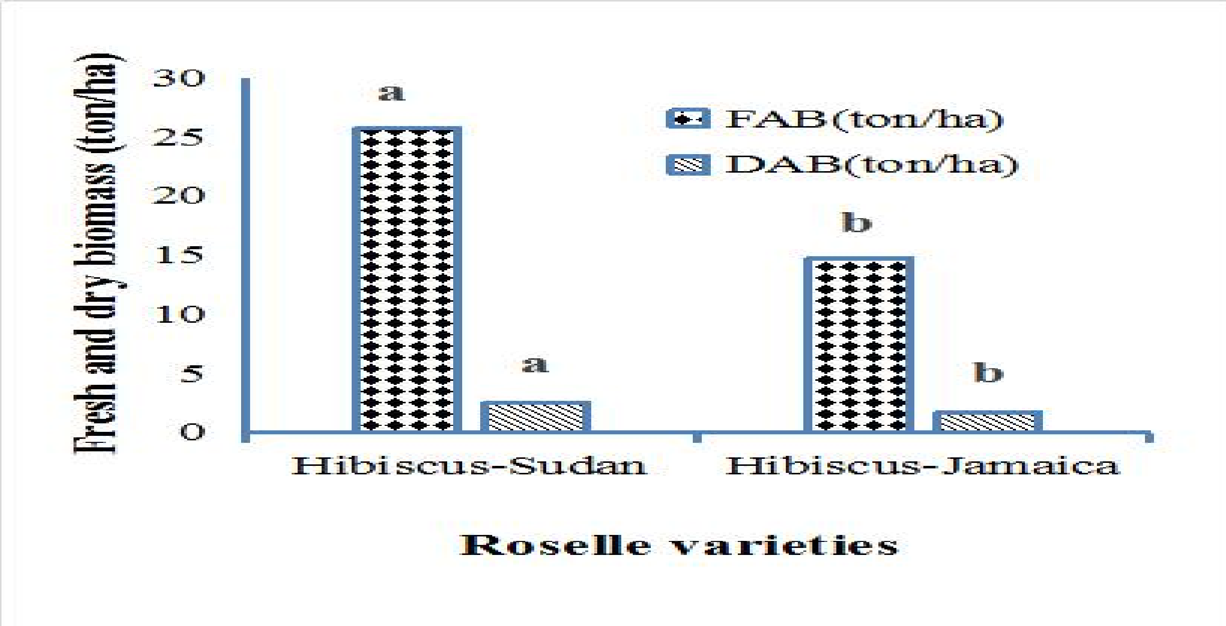

Figure 1. Mean values of fresh above ground biomass (FAB) and dry aboveground biomass (DAB) weights (ton/ha) of common bean as affected by roselle varieties at Hawassa during 2017/2018 cropping season.

Results of the analysis of variance showed nonsignificant effect of the interaction of main factors ($P > 0.05$) on common bean fresh and dry aboveground biomass yield, but both parameters were significantly affected by roselle variety ($p < 0.01$), by common bean planting density ($P < 0.01$), and by cropping system ($p < 0.001$) (Appendix Table 5). The higher values of aboveground fresh biomass (25.75 ton ha^{-1}) and dry biomass (2.52 ton $ha^{-}1$) of common bean were obtained for intercropping with variety Hibiscus-Sudan compared to the corresponding value for Hibiscus-Jamaica (14.79 ton ha^{-1}, and 1.71 ton ha^{-1}) (Figure 1). This might be due to difference between roselle genotypes in computing for growth resources because of their variation in growth characteristics. Hibiscus-Jamaica variety had more branches per plant which might have enhanced competition and shading effect on common bean in the intercropping. The shade effect might caused common bean grow with less vegetative parts such as branch, leaf, flower, and pod that could lower the aboveground biomass weight of the crop.

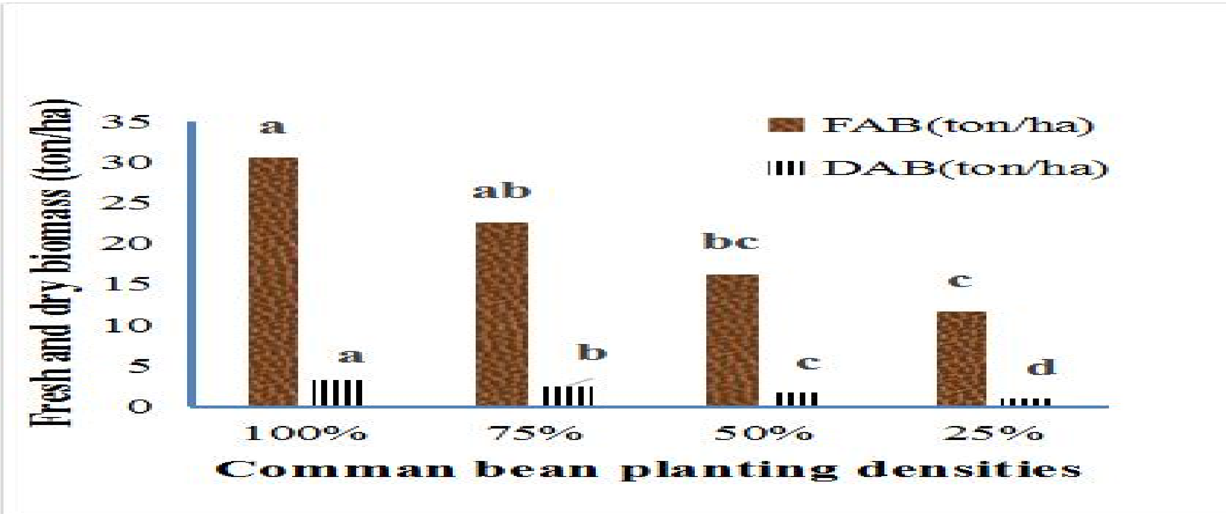

Figure 2. Mean values of fresh aboveground biomass (FAB) and dry aboveground biomass (DAB) weights (ton/ha) of common bean as affected by its planting densities at Hawassa during 2017/2018 cropping season.

Fresh and dry aboveground biomass weight per hectare increased from 11.62 ton to 30.58 ton and from 1.05 ton to 3.26 ton, respectively, as planting density of common bean increased from 25% to 100% (Figure 2). This might be due to higher number of plants per unit area. In line with this, Lulie *et al*. (2016) have reported increases in biomass weight of common bean as planting density increased in common bean-maize intercropping system. In addition, Alemayehu and Boki (2015) have reported higher common bean biomass yield for than for higher planting densities. Moreover, intercropping common bean with roselle declined fresh and dry above ground biomass of common bean by more than threefold compared to sole cropping (Figure 3). This indicated higher competitiveness of the roselle varieties grown in association with common bean, specially for light, water, and nutrients.

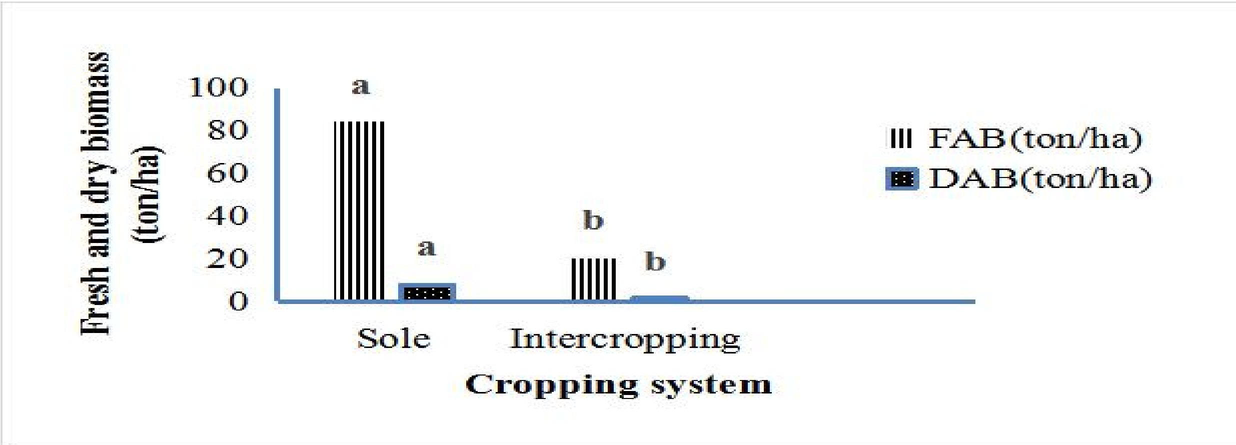

Figure 3. Mean values of fresh aboveground biomass (FAB) and dry aboveground biomass (DAB) weights (ton/ha) of common bean as affected by sole cropping and intercropping systems at Hawassa during 2017/2018 cropping season.

4.3 Effect of Roselle and Common Bean Intercropping on Weed Infestation

The effect of intercropping roselle varieties with different planting densities of common bean on weed infestation was evaluated by visual rating of weed ground cover at a scale of 1- 6, weed density, and aboveground weed biomass weight and the results are presented as follows.

4.3.1 Visual weed infestation rating (scale 1-6)

Weed ground cover, as visually rated on 1-6 scale, was significantly affected by common bean planting density ($P \leq 0.01$) and cropping system ($P \leq 0.001$), but the effect of roselle variety and interaction of main factors was not significant ($P > 0.05$) (Appendix Table 6). A mixture of common bean with 25% planting density resulted in significantly higher scale value for weed infestation (2.0) compared to other planting densities (Table 7). The higher visual scale value for weed infestation at lower common bean planting density might be due to availability of free spaces and resources, which favored the growth of weeds. Similarly, significantly higher values of visual weed infestation rating was recorded for sole cropping (2.5) than for intercropping (1.56) (Table 7). Higher free spaces and availability of more light in the sole cropping system due to lower canopy closure might have favored weed growth compared to the case in the intercropping system. It is also clear that, higher density of different crops in the intercropping system competes for resources and, thereby, reduces weed germination and growth more than in sole cropping. Hence, weed germination and growth might be reduced when roselle grown in combination with common bean as compared to roselle sole cropping.

4.3.2 Weed density

Weed species density was recorded by counting number of weeds per net plot area of each plot and converted to m^2 for statistical analysis. Fifteen weed species were identified, among which broad leaved weeds were dominant (73%), followed by grassy weeds (20%) and sedges (7%) (Appendix Table 8). It was observed that both interaction of the main factors and roselle variety did not have significant effect on weed density ($P > 0.05$), however, it was significantly ($p \leq 0.01$) influenced by common bean planting density and cropping system (Appendix Table 6). Significantly ($p \leq 0.01$) the lowest weed density (7.19 count per m^2) was observed for intercropping roselle with 100% common bean planting density, while the highest value (15.43 count per m^2) was recorded for intercropping roselle with 25% common bean planting density (Table 7). This could be because of the fact that, in less populated crop stands, there is more free space that favors weed germination and growth than the closely populated crops. Besides, weeds might got more light at distantly populated crops due to lower canopy closure and became competitor in field. Hence, reduction in weed density at higher common bean planting density in the present study could be due to limitation of resources like space and light.

Besides, weed density was significantly ($p \leq 0.01$) the highest for sole cropping (17.21 count per m^2), while the lowest for intercropping (9.52 count per m^2) (Table 7). The lower weed density in intercropping as compared to sole cropping might be due to inclusion of component crop (common bean) which enhances competition for growth resources. This was similar with the report of Odhiambo and Ariga (2001), which indicated that high populations of bean intercropped with maize reduced striga weed. The present finding was also similar with the report of Dejere *et al*. (2016) who concluded that intercropping sorghum with groundnut and soya bean reduced population density of striga weed. Besides, Prasad *et al.* (2015) have reported significant reduction in weed population for intercropping maize with cowpea than for sole maize. Furthermore, different reports showed the positive contributions of cultivating crops in association in reducing weed density, like the case of wheat-pea intercropping (Khan *et al*., 2013), maize-bean intercropping (Chipomho *et al*., 2015), and maize-faba bean intercropping (Stoltz and Nadeau, 2014).

Table 7. Mean values of visual weed infestation rating, weed density, and aboveground dry weed biomass as affected by in intercropping two roselle varieties with different planting density of common bean

Treatment	Visual weed infestation rating (scale1-6)	Weed density (count / m^2)	Aboveground dry weed biomass (g/m^2)
Roselle Variety			
Hibiscus-Jamaica	1.67	8.67	8.91
Hibiscus-Sudan	1.46	10.37	11.27
CR(0.05)	NS	NS	NS
Common Bean Planting Density			
100%	1.17^{c}	7.19^{b}	7.47^{b}
75%	1.50^{bc}	7.89^{b}	8.37^{b}
50%	1.58^{b}	7.56^{b}	11.19^{ab}
25%	2.00^{a}	15.43^{a}	13.34^{a}
CR(0.05)	0.36	4.27	4.35
CV	18.64	36.19	34.82
Cropping System			
Sole cropping	2.5^{a}	17.21^{a}	15.61^{a}
Intercropping	1.56^{b}	9.52^{b}	9.92^{b}
CR(0.05)	0.40	4.84	3.76
CV	24.27	46.47	36.10
Variety*Planting Density	NS	NS	NS

NS=not significant; CV=Coefficient of variance; CR= Critical range; Means in a column followed by the same letters are not significantly different at P≤5%.

4.3.3 Aboveground weed biomass weight

Similar to the values for weed infestation and weed density, interaction of main factors as well as roselle variety did not affect aboveground weed biomass ($P > 0.05$), but it was significantly affected by common bean planting density ($P \leq 0.05$) and cropping system ($p \leq 0.01$) (Appendix Table 6). The higher dry weed biomass (13.34 g/m^2) was resulted from intercropping roselle with common bean at 25% planting density and the lowest value (7.47 g/m^2) was obtained from intercropping common bean at 100% planting density (Table 7). This could be due to increases in competition for space and growth resources suppressing weed germination and growth as the planting density increased. The role of common bean in weed suppression when intercropped with roselle was clearly reflected by the significantly higher weed biomass yield obtained from sole cropped plots (15.61 g/m^2) compared to the lowest value for intercropping (9.92 g/m^2) (Table 7). This might be due to effectiveness of intercrops in resource utilization, leaving smaller amounts for weeds growth compared to sole cropping, and it could also be through allelopathic effects of the intercrops on weeds (Yadollahi *et al.,* 2014). Similarly, Orluchukwu and Udensi (2013) reported significantly higher weed biomass for sole cropping of okra than when intercropped with maize and pepper. In contrary, lower weed dry weight was reported for sole maize than for the plots intercropped with cowpea (Prasad *et al.,* 2015) and beans (Chipomho *et al.,* 2015).

4.4 Productivity of Roselle-Common Bean Intercropping

4.4.1 Partial and total land equivalent ratio

4.4.1.1 Roselle and common bean partial land equivalent ratio

ANOVA revealed that the interaction of main factors was non significant for both roselle and common bean partial land equivalent ratio ($P > 0.05$) (Appendix Table 7). However, partial land equivalent ratio of the two roselle varieties were significantly ($P \leq 0.05$) affected by common bean planting density. The higher partial land equivalent ratio of roselle (0.97) was obtained from intercropping with common bean at 25% planting density and the lowest (0.82) from intercropping with common bean at 100% planting density (Table 8). This might be due to the reduction in yield contribution of roselle as common bean planting density increased which favored yield of the common bean. This might have resulted from efficient utilization of resource as a result of increased competition of common bean at higher planting density. Furthermore, partial land equivalent ratio of common bean was significantly affected by roselle variety and common bean planting density ($p \leq 0.01$) (Appendix Table 7). The higher common bean partial land equivalent ratio (0.51) was obtained when intercropped with Hibiscus-Sudan and the lower (0.38) when intercropped with Hibiscus-Jamaica (Table 8). The lower partial land equivalent ratio, which was less than 0.5, showed the disadvantageous of intercropping, and thus, according to the present finding, common bean intercropping with variety Hibiscus-Jamaica was found to be inappropriate. This could be due to the competitive ability of the roselle variety for light, water and nutrients. On the other hand, the higher partial land equivalent ratio (0.51) of common bean from intercropping with Hibiscus-Sudan variety indicated as yield of common bean was more favored than the case of intercropping with Hibiscus-Jamaica. Furthermore, as common bean planting density increased from 25% to 100%, partial land equivalent ratio of common bean increased from 0.32 to 0.56, which, might be due to better resource utilization (Table 8). A similar increase in partial LER of common bean with increases in planting density has been reported for intercropping common bean with maize (Lulie *et al*., 2016).

4.4.1.2 Total land equivalent ratio

The combined (total) land equivalent ratio of roselle and common bean intercropping was not significantly influenced ($P > 0.05$) by the interaction between main factors, by roselle variety and common bean planting density (Appendix Table 7). However, numerically, total LER was higher for intercropping common bean with variety Hibiscus-Sudan (1.35) compared to the result obtained for intercropping common bean with variety Hibiscus-Jamaica (1.30) (Table 8). This showed that intercropping Hibiscus-Sudan with common bean was more advantageous compared to Hibiscus-Jamaica. Furthermore, as common bean planting density increased from 25% to 100%, there was an increasing trend in total LER from 1.29 to 1.39 (Table 8). This was in agreement with the reports of Lulie *et al*. (2016) and Adafre (2016) who observed increment in total LER as common bean planting density increased from 25% to 100%. Based on the values of total LER, advantage of intercropping roselle with pigeon pea (Pushpa *et al*., 2017), maize with faba bean (Rezaei-Chianeh *et al.***,** 2011) and cotton with cow pea **(**Aesim *et al*., 2008) has been reported.

4.4.2 Monetary advantage index (MAI)

Monetary advantage index of roselle-common bean intercropping was not affected by variety, planting density and their interaction ($p > 0.05$) (Appendix 7). However, numerically the highest monetary advantage (17, 946 ETB) was obtained from Hibiscus-Sudan than from Hibiscus-Jamaica (17, 283 ETB) (Table 8). Besides, as planting density increased from 25% to 100%, MAI increased from15, 525 ETB to 21, 410 ETB (Table 8). This could be due to difference in the amount of yield of common bean.

Table 8. Productivity of two roselle varieties and a common bean under an intercropping system of roselle with different common bean planting densities at Hawassa during 2017/2018 cropping season.

Treatment	LER			MAI
	Roselle	Common bean	Total	
Roselle Variety				
Hibiscus-Sudan	0.84	0.51^{a}	1.35	17946
Hibiscus-Jamaica	0.93	0.38^{b}	1.30	17283
CR(0.05)	NS	0.08	NS	NS
Common Bean Planting Density				
100%	0.82^{b}	0.56^{a}	1.39	21410
75%	0.83^{b}	0.51^{a}	1.33	17548
50%	0.9^{ab}	0.38^{b}	1.29	15976
25%	0.97^{a}	0.32^{b}	1.29	15525
CR(0.05)	0.13	0.12	NS	NS
CV	11.93	21.99	12.32	50.17

NS=not significant; CV=Coefficient of variance; CD = Critical difference; LER= Land equivalent ratio; MAI=Monetary advantage index. Means in a column followed by the same letters are not significantly different at P≤5%.

5. SUMMARY AND CONCLUSIONS

Significant variations were observed between the two roselle varieties for all parameters. The highest values for yield and yield component were recorded for variety Hibiscus-Jamaica, except for thousand seed weight, which was higher for variety Hibiscus-Sudan. Dry calyx yield and dry aboveground biomass yield of Hibiscus-Jamaica were 0.92 ton ha^{-1} and 2.96 ton ha^{-1}, respectively, compared to the corresponding values of 0.68 ton ha^{-1} and 2.52 ton ha^{-1} for Hibiscus-Sudan. Increases in planting densities of common bean reduced roselle seed yield per plant and calyx yield per hectare. The highest dry calyx yield (0.88 ton ha^{-1}) was obtained at 25% planting density, while the lowest was at 100% planting density (0.74 ton ha^{-1}). Besides, intercropping significantly reduced both seed yield per plant and calyx yield per hectare. All the evaluated parameters of common bean were significantly influenced by roselle varieties, except days to 50% flowering and thousand seed weight. In addition, the highest number of pods per plant, seeds per pod, and seed yield per hectare were obtained from plots intercropped with Hibiscus-Sudan compared to their respective values with Hibiscus-Jamaica. Moreover, an increase in planting density prolonged days to 50% flowering and reduced both number of pods per plant and seeds per pod, but increased both seed yield and aboveground biomass yield per hectare. Furthermore, intercropping significantly reduced days to 50% flowering, plant height, pods $plant^{-1}$, seed yield $hectare^{-1}$, and aboveground biomass yield. Higher aboveground dry biomass weight was obtained from plots intercropped with Hibiscus-Sudan (2.52 ton ha^{-1}), at 100% common bean planting density (3.26 ton ha^{-1}), and at sole cropping (7.96 ton ha^{-1}). Visual rating of weed infestation parameters such as visual weed infestation rating, weed density, and weed aboveground biomass weight showed that there was better weed control at higher common bean planting densities and in intercropped plots. The highest dry weed biomass (13.34 g) was recorded for 25% common bean planting density and the lowest (7.47 g) was for 100% planting density. Intercropping roselle with common bean reduced weed density by 44.68% and weed dry biomass by 36.45% compared to sole cropping. There was no variation between roselle varieties for weed control based on the parameters used for evaluation.

The productivity of the intercropping roselle with common bean was also evaluated based on land equivalent ratio (LER) and monetary advantage index (MAI). Partial LER of common bean was significantly influenced due to roselle variety, where, Hibiscus-Jamaica resulted in lower value (0.38). However, as planting density increased from 25% to 100%, partial LER of roselle decreased from 0.97 to 0.82, while that of common bean increased from 0.32 to 0.56. Both total LER and MAI were not significantly affected by roselle varieties and common bean planting densities. But, both parameters were numerically higher for Hibiscus-Sudan and showed an increasing trend as planting density increased. Intercropping Hibiscus-Sudan with common bean resulted in 35% yield advantage and 17,946 ETB monetary advantage while Hibiscus-Jamaica intercropped with common bean resulted in 30% yield advantage and 17,283 ETB monetary value. In addition, common bean at 100% planting density intercropped with roselle resulted in 39% yield advantage as well as 21,410 ETB monetary value. Therefore, it was suggested that a combination of Hibiscus-Sudan and common bean at 100% planting density would be advantageous for growers in Hawassa area and in similar agroecologies for better yield, economic benefit and weed control. However, further studies should be carried out under rainfed condition, at different locations and in different years to come up with more comprehensive result.

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7. APPENDICES

7.1 Appendix Tables

Appendix Table 1 Analysis of variance for phenology, yield and yield components of roselle as affected by roselle variety, planting density of common bean, and cropping system at Hawassa during 2017/2018

				Mean squares				
Source	DF	DFL	DM	PH (cm)	NBPP	NCPP	TSW(g)	SYPP(g)
Rep	2	8.67**	2.67**	1152.78**	18.85 NS	434.28**	0.70NS	65.84 NS
Var	1	2816.67***	4930.67***	963.93*	305.45***	1132.72***	52.24***	596.40***
PD	3	0.22NS	0.00NS	57.56NS	34.69 NS	22.30NS	0.07NS	96.26*
Var*PD	3	2.00NS	0.00NS	11.00NS	12.68NS	14.66NS	0.26NS	5.01NS
Error	14	1.05	5.33	160.99	13.34	38.42	2.22	19.33
CV		0.76	0.37	16.5	21.46	15.78	4.79	10.13
				Cropping system				
Rep	2	11.20***	4.13***	1177.26**	23.24NS	426.95**	0.111NS	112.49**
CS	1	3.33NS	2.13*	214.13 NS	41.94NS	55.81NS	0.003NS	359.29*
Error	2	1.12	0.32	135.08	14.74	30.64	2.36	27.53
CV		0.79	0.34	14.86	21.8	13.85	4.94	11.63

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; DF = degree of freedom; Var = Variety; PD = Planting density; CS = Cropping system; DFL = Days to 50% flowering; DM = Days to maturity; PH = Plant height; NBPP = Number of primary branch per plant; NCPP = Number of capsule per plant; TSW=Thousand seed weight; SYPP=Seed yield per plant.

Appendix Table 2 Analysis of variance (ANOVA) for fresh and dry calyx yield per hectare, fresh and dry above ground biomass yield per hectare, and harvest index of roselle as affected by roselle variety, common bean planting density, and cropping system at Hawassa during 2017/2018

Mean Squares						
Source	DF	FCY (ton ha^{-1})	DCY (ton ha^{-1})	FAB (ton)	DAB (ton)	HI (%)
Rep	2	3.03***	0.015^{NS}	8.58^{NS}	0.45^{NS}	0.001^{NS}
Var	1	6.06***	0.36***	66.31***	1.18*	0.015*
PD	3	2.04**	0.025*	1.28^{NS}	0.04^{NS}	0.001^{NS}
Var*PD	3	0.34^{NS}	0.006^{NS}	0.08^{NS}	0.03^{NS}	0.001^{NS}
Error	14	0.21	0.005	2.61	0.16	0.002
CV		10.30	8.79	10	14.76	16.06
Cropping System						
Rep	2	2.75*	0.03^{NS}	8.16*	0.38^{NS}	0.001^{NS}
CS	1	4.01**	0.06*	2.22^{NS}	0.07^{NS}	0.003^{NS}
Error	2	0.51	0.01	1.81	0.114	0.002
CV		15.32	11.76	8.24	12.22	14.45

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; DF = degree of freedom; Var = Variety; PD = Planting density; CS = Cropping system; FCY=Fresh calyx yield per hectare; DCY= Dry calyx yield per hectare; FABPH=Fresh above ground biomass per hectare; DABPH=Dry above ground biomass per hectare; HI=Harvest index.

Appendix Table 3 Analysis of variance for phenological and growth parameters of common bean as affected by roselle variety, common bean planting density, and cropping system at Hawassa during 2017/2018

Source of variation	DF	Days to		Plant Height (cm)
		50% Flowering	Maturity	
Rep	2	1.67^{NS}	7.12*	133.98^{NS}
Var	1	0.67^{NS}	63.37***	745.49**
PD	3	4.00*	2.37^{NS}	174.25^{NS}
Var*PD	3	2.00^{NS}	1.04^{NS}	56.76^{NS}
Error	14	1.17	1.84	81.97
CV		1.73	1.39	19.78
		Cropping system		
Rep	2	1.6^{NS}	17.03**	395.81^{NS}
CS	1	8.53*	4.41^{NS}	2652.30***
Error	2	1.50	2.06	124.80
CV		1.96	1.46	22.14

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; Rep= Replication; DF = degree of freedom; Var =Variety; PD = Planting density; CS = Cropping system; CV= coefficient of variance.

Appendix Table 4 Analysis of variance for yield and yield components of common bean as affected by roselle variety, common bean planting density, and cropping system at Hawassa during 2017/2018

			Mean squares		
Source	DF	Pod number per plant	Seed number per pod	Seed yield (ton ha^{-1})	TSW (g)
Rep	2	283.17*	1.47**	0.86NS	1056.28 NS
Var	1	700.92**	1.60*	3.56**	2.78 NS
PD	3	275.49*	0.74*	1.59**	7.23 NS
Var*PD	3	0.59NS	0.52NS	0.08NS	0.62 NS
Error	14	71.49	0.21	0.25	2124.79
CV		37.15	11.84	28.19	15.97
			Cropping system		
Rep	2	285.02*	0.21NS	3.63**	1.87 NS
CS	1	1114.47**	0.12NS	24.94***	11.79 NS
Error	2	80.73	0.59	0.43	1688.24
CV		34.81	19.81	29.94	14.22

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and pP≤0.001 probability levels respectively; Rep= Replication; DF = degree of freedom; Var =Variety; PD = Planting density; CV= coefficient of variance; CS = Cropping system; TSW=Thousand seed weight.

Appendix Table 5 Analysis of variance for fresh and dry aboveground biomass yield of common bean as affected by roselle variety, common bean planting density, and cropping system at Hawassa during 2017/2018

		Mean squares	
Source	DF	Aboveground fresh biomass(ton ha^{-1})	Aboveground dry biomass (ton ha^{-1})
Rep	2	49.09^{NS}	1.06 ^{NS}
Var	1	720.11**	3.94**
PD	3	405.15**	4.31***
Var*PD	3	5.68^{NS}	0.60^{NS}
Error	14	56.99	0.43
CV		37.24	25.99
		Cropping system	
Rep	2	16.84^{NS}	1.00 ^{NS}
CS	1	19647.98***	142.30***
Error	2	132.10	0.96
CV		34.76	27.20

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; Rep= Replication; DF =Degree of freedom; Var =Variety; PD = Planting density; CV= coefficient of variance; CS = Cropping system; HI=Harvest index

Appendix Table 6 Analysis of variance for visual rating of weed infestation, weed density, and aboveground biomass as affected by roselle variety, common bean planting density, and cropping system at Hawassa during 2017/2018

Mean squares				
Source	DF	Visual weed infestation rating (scale1-6)	Weed density (plant/m^2)	Aboveground dry weed biomass (g/m^2)
Rep	2	0.66**	77.73 **	59.17 *
Var	1	0.26 NS	17.29 NS	33.56 NS
PD	3	0.70 **	93.70 **	42.20*
Var*PD	3	0.09NS	19.9 NS	1.45NS
Error	14	0.08	11.87	12.35
CV		18.64	36.19	34.82
		Cropping system		
Rep	2	0.70 *	127.33*	55.15*
CS	1	4.22***	283.64**	155.21**
Error	2	0.18	26.40	15.95
CV		24.27	46.47	36.10

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; Rep= Replication; DF =Degree of freedom; Var =Variety; PD = Planting density; CV= coefficient of variance; CS = Cropping system;

Appendix Table 7 Analysis of variance for productivity of roselle as affected by roselle variety and common bean planting density in roselle-common bean intercropping at Hawassa during 2017/2018.

		Mean squares			
Source	DF	LER			MAI
		Roselle	Common bean	Total	
Rep	2	0.084**	0.022^{NS}	0.141*	177953659.4^{NS}
Var	1	0.047^{NS}	0.010**	0.012^{NS}	2632934.8^{NS}
PD	3	0.029*	0.077**	0.015^{NS}	42919364.2^{NS}
Var*PD	3	0.007^{NS}	0.010^{NS}	0.011^{NS}	27327736.2^{NS}
Error	14	0.011	0.009	0.027	78096750
CV		11.93	21.99	12.32	50.17

NS=not significant; *, **, and *** significant at P≤0.05, P≤0.01 and P≤0.001 probability levels respectively; Rep= Replication; DF = degree of freedom; LER=Land equivalent ratio; MAI=Monetary advantage index.

Appendix Table 8 Weeds species and their relative density in roselle-common bean intercropping at Hawassa during 2017/2018 cropping season

Number	Weed species	Weed density (count/m^2)	Relative density (%)
1	*Portulaca oleracea*	4.76	24.84
2	*Cyprus spp*	3.86	20.13
3	*Conyza canadensis*	2.06	10.74
4	*Datura stramonium*	1.49	7.77
5	*Digitaria abyssinica*	1.27	6.61
6	*Guizocia spp*	0.92	4.82
7	*Cynodon dactylon*	0.87	4.53
8	*Bidens pilosa*	0.71	3.71
9	*Galinsoga parviflora*	0.69	3.60
10	*Sonchus spp*	0.65	3.38
11	*Tagetus minuta*	0.58	3.03
12	*Snowdenia polystachya*	0.39	2.03
13	*Oxalis latifolia*	0.36	1.88
14	*Chenopodium spp*	0.33	1.72
15	*Amaranthus spp*	0.23	1.20

7.2 Appendix Figures

Appendix Figure 1. Picture showing intercropping Hibiscus-Sudan variety with common bean at Hawassa, Southern Ethiopia

Appendix Figure 2. Picture showing intercropping Hibiscus-Jamaica variety with common bean at Hawassa, Southern Ethiopia

Appendix Figure 3 Picture showing roselle at seedling stage before intercropping common bean (left) and sowing common bean (right)

Appendix Figure 4 Picture showing roselle calyx yield collection

Appendix Figure 5 Picture showing sun drying roselle calyx yield