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Research Article

Effect of Interrow Spacings on Growth, Yield, and Yield Components of Common Bean (*Phaseolus vulgaris* L.) Varieties in the Central Rift Valley of Ethiopia

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The common bean is the crop used as food, feed, and to improve soil fertility. However, the production and productivity were affected by poor nutrition and fertilizer management, inappropriate interrow spacings, and the poor genetic makeup of the crops in Ethiopia. Hence, a study was conducted in two research stations at Arsi Negele and Melkasa Agricultural Research Center (MARC), during 2019 cropping season. The treatments consisted of three interrow spacings (30 cm, 40 cm, and 50 cm) and three common bean varieties (Dame, SER-119, and KAT-B9) combined in a factorial arrangement laid out in the field using (randomized complete block design) RCBD with three replications. Data on growth and yield parameters obtained were subjected to analysis of variance. Regarding the interaction effect, leaf area, number of seed pods^{-1}, and grain yield were significantly influenced by the interrow spacings and common bean varieties at both locations. Plant height, number of pods plant^{-1}, total dry biomass, leaf area index, hundred seed weight, and harvest index were significantly influenced by the interrow spacings and common bean varieties at Arsi Negele, whereas they were nonsignificant for MARC. In this study, the highest grain yields (2.23 and 2.17 tons/ha) were obtained from narrow interrow spacings (30 and 40 cm) combined with variety SER-119 at both locations. Hence, the highest net benefits (30848.7 and 29970.4 ETB) were obtained from SER-119 (30 cm × 10 cm, and 40 cm × 10 cm) at Arsi Negele and MARC, respectively. It was recommended that the narrow (30 cm) interrow spacing be used with variety SER-119 for common bean production in the study areas and similar agro-ecologies. On the other hand, the use of wider interrow spacings (40 cm or 50 cm) had a significant importance in improving hundred seed weight, seed quality, and disease incidences of common bean varieties at the given studied sites.

1. Introduction

Common bean is a major grain legume consumed worldwide for its edible seeds and pods, the ability to enhance soil fertility, and its fast-maturing characteristics that enable households to get cash income [1]. Plant densities were affecting the utilization of environmental resources (radiation interception and moisture utilization from soil), which impacts interrow competitions [2]. These competitions may occur when common recourses are inadequate for all the plants of an alike species, such as between the established crop plant with a given crop canopy. To evade nutrient competition, adequate spacing between plants and rows is necessary to get maximum yield on a given plot of land.

Row spacing also alters plant architecture, the photosynthetic ability of leaves, and dry matter partitioning in numerous field crops [3]. For these reasons, choosing improved common bean varieties and optimal plant densities is essential to increase crop yield, as plants growing in a too wide row may not efficiently utilize light, water, and nutrient resources [4].

In wider interrow spacing, there was enough growth resources availability for crop plants which can convert biological yield to economic yield [5]. In addition to these wider spaced plants, we improve the supply of assimilates to be stored in the seed; hence, the weight of the seeds increased [6].

Therefore, a study was conducted using three improved common bean bush types, each having distinct growth habits: early (KAT-B9), intermediate (SER-119), and late (Dame) maturing characteristics, in order to determine the effect of different interrow spacings on growth, yield, and yield components of common bean varieties at two contrasting sites in the central rift valley of Ethiopia.

2. Materials and Methods

2.1. Description of the Study Sites. Field experiments were conducted in Arsi Negele (7°35′N latitude and 38°65′E longitude, at an altitude of 1890 m above sea level) and Melkasa Agricultural Research Center (8°30′N latitude and 39°21′E longitude, at an altitude of 1550 m above sea level) in the 2019 cropping season in the Central Rift Valley, which represent the major common bean cultivating areas of Ethiopia (Figure 1). The areas had an average annual rain fall of 763 and 807 mm during the main cropping season, respectively. The average minimum and maximum temperatures were 13.8 and 33.3°C. The rainfall patterns at the Arsi Negele and Melkasa Agricultural Research Center sites were monomodal in nature.

The common bean requires an average rainfall of 500–1500 mm throughout the growing season [6]. Therefore, the rainfall is ideal for the production of legumes including common bean in the study sites. The average temperature was slightly higher at the Melkasa Agricultural Research Center than the Arsi Negele site (Table 1). The soil textures of both experimental sites were silty clay loam (Hawassa Soil Testing Laboratory, 2019). The experiments were conducted between June and October, 2019, main cropping season. The experimental fields were previously cultivated with cereals, maize and sorghum, respectively.

2.2. Treatments, Experimental Design, and Procedures. The factors studied were three varieties of common bean (Dame, SER-119, and KAT-B9) obtained from the Melkasa Agricultural Research Center, three interrow spacings (30, 40, and 50 cm), and a constant plant spacing of 10 cm between plants. Treatments were arranged in a factorial combination using a randomized complete block design (RCBD) with three replications. The treatments were randomly assigned to each plot within the replication (block). Each plot contains six (6) equal numbers of rows. Each plot had a uniform length of 3 m. However, the width varied as 2 m, 2.6 m, and 3.2 m for 30 cm, 40 cm, and 50 cm row spacing, respectively. The distance between the block and plot was 1 m and 0.8 m, respectively. The total gross plot is $30.2 * 10.6 = 320.12\ \text{m}^2$. The land was ploughed twice using a tractor and pulverized by a human laborer. The crops were sown on July 05 and July 09 during the 2019 cropping season at Arsi Negele and MARC, respectively. The number of seeds per row was 30 for each row spacing treatment. The source of fertilizers NPS was used at the recommended rate of 100 kg per hectare and applied for each plot at the rate of 0.072 kg.

The total plot area of each plot can be $3 * 2 = 6\ \text{m}^2$, $3 * 2.6 = 7.8\ \text{m}^2$, and $3 * 3.2 = 9.6\ \text{m}^2$ for 30, 40, and 50 cm row spacing, respectively. The seed rate used for sowing ranged from 75 to100 kg·ha^1 for small and large seed sized of common bean varieties, respectively. Weed management and cultural practices were done equally for the given locations from crop emergence up to harvesting.

2.3. Soil Sampling and Analysis. Before planting, twenty surface soil samples (0–20 cm) were randomly collected from the entire field using an augur to determine the physiochemical properties of each site. The collected soil samples were mixed well in a plastic bag and sieved, and one composite representative sample was taken for analysis of physical (soil texture) and chemical (pH), total N, available P, organic carbon (OC), and cation exchanging capacity (CEC) properties of soils at each site. All intended parameters were analyzed at the Hawassa University College of Agriculture soil laboratory, and the analysis was done using the standard procedure for each sample.

The soil texture was determined by the modified Bouyoucos hydrometer method, and the texture class was designated based on the mass ratio of the three particles (clay, silt, and sand) with the help of a soil textural triangle [7]. The pH of the soil was measured by a glass electrode pH meter using soil and water suspension in 1 : 2.5 ratios [8].

Total N was determined by treating the sample with a mixture of concentrated sulfuric acid and digestion catalysis following the modified Kjeldhal method [8, 9]. Available P contents of the soil were determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) according to the procedure described by [9, 10]. The organic C content of the soil was determined by the wet combustion procedure of [11]. The CEC was measured after saturating the soil with 1N ammonium acetate (NHOAc) solution by using the modified Kjeldhal 16 method as described by [10, 11].

2.4. Data Collected

2.4.1. Growth Parameters. Plant height (cm): it was measured from six randomly selected plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area. Leaf area (cm^2) was recorded from a randomly selected destructive sample of six plants from a net plot. It was measured at the mid-flowering stage using a portable leaf area meter (model = CI-3000A, USA). The leaf area index was calculated as the ratio of total leaf area plant^{-1} to the respective ground area occupied by the crop canopy as described by Marschner [11].

2.4.2. Yield and Yield Components. The number of pods plant^{-1} was determined by counting the number of pods plant^{-1} of 10 randomly selected plants from each net plot area at harvest. The number of seeds pod^{-1} was counted from 10 randomly selected pods from each net plot at harvest. The hundred seed weight (g) was determined by taking the weight of 100 randomly sampled seeds after harvesting and threshing from each net plot area and

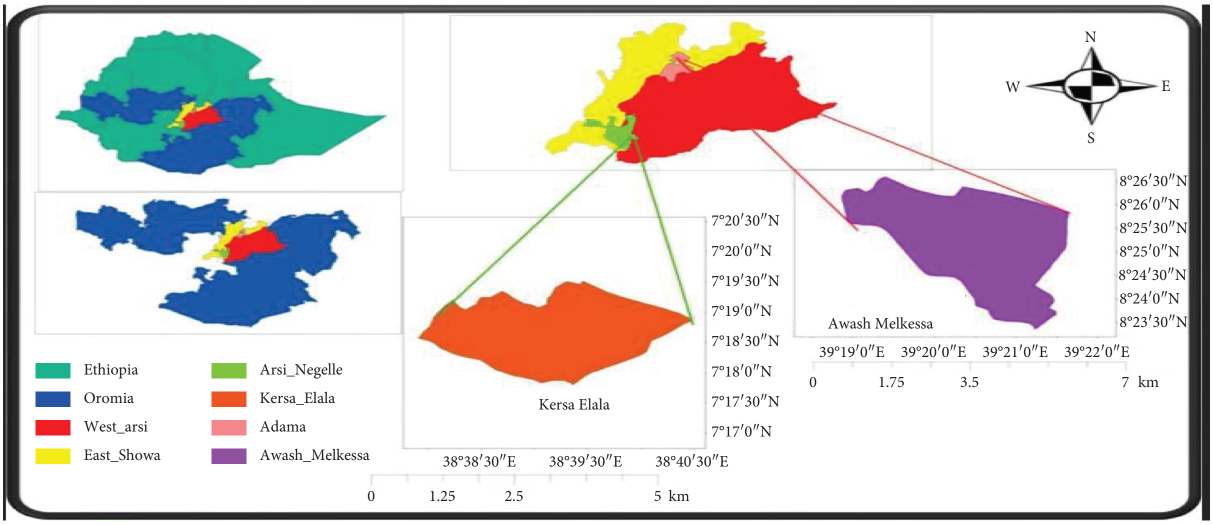


Figure 1: Administrative map of the study sites (Google Map: ARC GIS, 2019).

Table 1: Mean monthly temperature and rainfall of experimental sites during 2019 cropping season.

Month	*Precipitation (mm)*		*Max. temperature (°C)*		*Min. temperature (°C)*	
	Arsi Negele	Melkasa	Arsi Negele	Melkasa	Arsi Negele	Melkasa
June	87.2	63.1	30.1	30.38	16.0	17.4
July	190.1	158.3	25.2	26.82	14.5	16.6
Aug	91.6	68.6	22.2	26.79	13.5	16.3
Sep	318.3	275.3	20.0	27.45	13.0	14.1
Oct	107.8	73.3	19.0	22.1	12.0	12.1
Mean	159	123.9	23.3	26.708	13.8	15.298

(Source: Melkasa Agricultural Research Center and National Meteorological Agency, Adama Branch, 2019).

adjusting to a 10% moisture level. Above ground total dry biomass at harvest, plants from three central rows were manually harvested. The harvested plants straw were sun-dried in open air until constant weight was attained and weighed to determine above ground total dry biomass yield and the average above ground total biomass yield was reported in ton ha^{-1}. Grain yield, the three central rows were manually harvested and threshed to determine grain yield $plot^{-1}$ and the average yield was reported in kg or $tons/ha^{-1}$.

Moisture contents: it was determined to calculate adjusted grain yield ha^{-1} using a moisture meter for hundred seeds. Adjusted grain yield was calculated by multiplying the actual yield downwards to 10% to meet the field experimental yield to farmers' yield. Actual yield $*$ (100 – mc)/(100 – Dmc) $*$ 100, where mc = measured moisture contents, and Dmc = designated moisture contents (10%) for common bean crops). The harvest index was calculated as the ratio of grain yield to aboveground total biomass yield.

$$\mathbf{HI}\,(\%) = \frac{\textbf{Grain yield}}{\textbf{Total above ground biological yield}}\,\mathbf{x100}. \quad (1)$$

2.5. Partial Budget Analysis. The partial budget analysis was done as described by CIMMYT [12] wherever the variable cost that differ included the cost of fertilizer and labor involved for application. The total costs that varied included the seed rate cost and the field price of the crop. However, for simplicity in the estimate, in place of the field price of the crop, the cost earned for harvesting, threshing, winnowing, packing, and transportation was added to the variable input cost. Actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield of farmers could expect from the same treatment.

There was optimum plant population density, timely labor accessibility, and better management (e.g., weed control, better protection) under experimental sites.

2.6. Statistical Analysis. The collected data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System Software [13] version 9.1.3. Significant treatment means were compared using the least significant difference test (LSD) at the 5% probability level.

3. Results and Discussion

3.1. Soil Physicochemical Properties of Study Sites. The results of soil analysis revealed that the textural class of experimental sites belongs to silty clay loam with the proportions of 20 and 12% sand, 34 and 32% silt, and 46 and 56% clay for Arsi Negele and Melkasa Agriculture Research Center

Table 2: Soil physicochemical properties of the experimental sites.

Sites	*Particle size distribution (%)* Sand	Silt	Clay	*pH* H_2O	*Total N* (%)	*OC* (%)	*Available* P (mg·kg^{-1})	*CEC* (cmol·kg^{-1})
Arsi Negele	20	34	46	6.0	0.06	0.98	24.6	27.3
Melkasa	12	32	56	6.7	0.05	0.97	27.3	24.6

Source (Hawassa soil laboratory, 2019 laboratory results).

(MARC) sites, respectively (Table 2). The pH values of both sites were 6.00 and 6.75, making them slightly acidic and suitable for common bean production [14]. Total N in the experimental soils was 0.06 and 0.05%, respectively. It was rated as very low (<0.1), low (0.1–0.15), medium (0.15–0.25), and high (>0.25) [15]. Hence, total N of the soil of the experimental fields were in very low ranges. This shows the importance of applying externally sourced nitrogen fertilizers to improve crop growth and productivity [16].

According to references [17, 18], the soil OC content was rated as very low (<2%), low (2–4%), medium (4–10%), high (10–20%), and very high (>20%). Thus, the soil at experimental sites had very low OC content. According to P content (mg·kg^{-1}) [19], <5 is very low, 5–15 is low, 15–25 is medium, and >25 is high. Therefore, the available P in the soils at the experimental sites (24.6 mg·kg^{-1} and 27.3 mg·kg^{-1}) was medium at Arsi Negele and high at MARC. The cation exchange capacity (CEC) is a major controlling factor of the stability of soil structure, nutrient availability for plant growth, the soil's reaction to fertilizers, and other ameliorants. The soil CEC content ranges of 5–15, 15–25, and 25–40 cmol·kg^{-1} are rated as low, medium, and high, respectively. Based on these ratings, the CEC values of 27.3 cmol·kg^{-1} at Arsi Negele and 24.6 cmol·kg^{-1} at MARC, before planting of the experimental field was in the high ranges, respectively.

3.2. Growth Parameters

3.2.1. Plant Height. The plant height was highly influenced by the main effects of interrow spacing and common bean varieties at the Arsi Negele and Melkasa sites (Table 3). The taller plant height was recorded with narrower interrow spacing (30 cm) with Dame variety at both sites. However, the shortest plant height was gained from wider interrow spacing of (40 cm and 50 cm) with variety KAT-B9, followed by SER-119 varieties at both locations. The plant height decreased as interrow spacing increased from 30 cm to 50 cm (Table 3). As interrow spacing becomes narrower and narrower, there is high competition among plants for growth resources, which leads to increments in plant height at given sites. At narrower interrow spacing, there was high competition among plants for nutrients, water, and sunlight, which led to excessive vegetative growth caused increased crop plant height [20].

On the other hand, at wider interrow spacing, there were less competition of plants for resource allocation and high nutrient availability for crop growth at the studied sites [21]. In addition, increased interrow spacing brings a high intensity of photosynthetic active radiation (PAR), which causes destruction of auxin hormones, which initiate cell division and elongation, leading to stunted growth in plant height [22]. There was also a significant interaction effect between interrow spacing and common bean varieties at Arsi Negele, whereas it was nonsignificant at Melkasa Agricultural Research Center (Table 3 and Figure 2(a)).

3.2.2. Leaf Area. The main effects of interrow spacings and common bean varieties significantly influenced the leaf area at both sites (Table 3). The highest leaf areas were noted with wider interrow spacing (50 cm) with varieties Dame and SER-119 at Arsi Negele and Melkasa, respectively. However, the shortest leaf areas were obtained from the narrower interrow spacing (30 cm and 40 cm) with varieties KAT-B9 at both sites (Table 3). As plants grew at wider interrow spacings, there was a high availability of growth factors with low competition. In line with this result, the authors of reference [23] reported that the leaf area of common bean definitely increased as interrow spacings increased because high growth resources are available for crops as a result of less competition between plants for resource utilization.

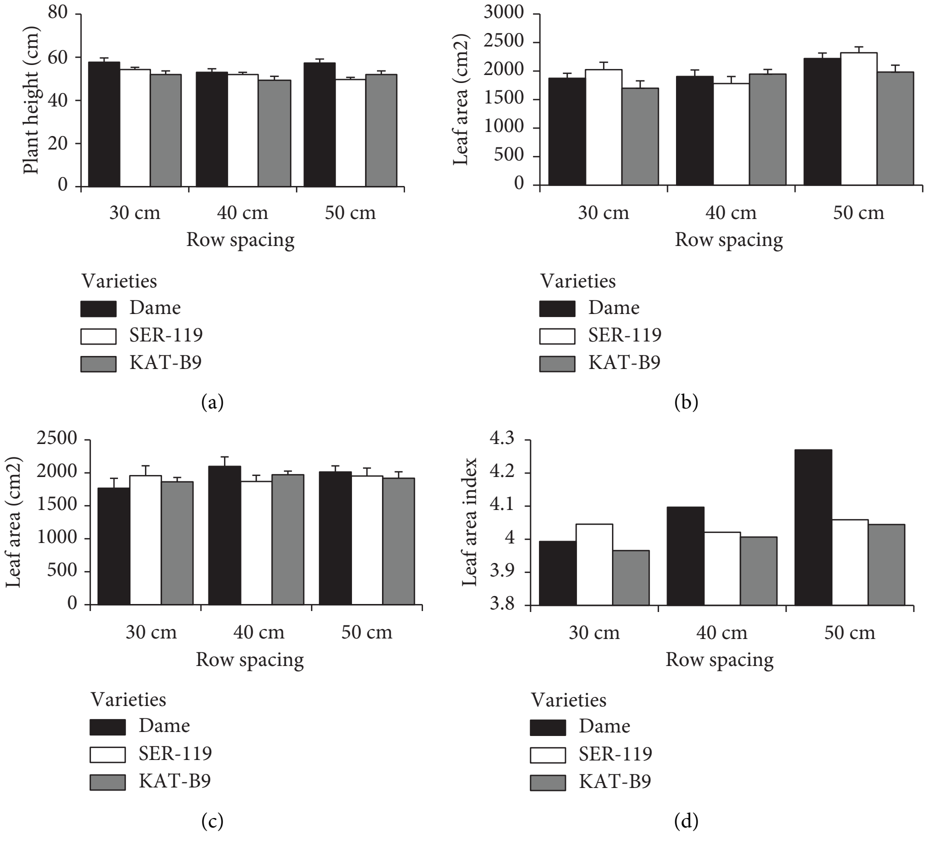
At wider interrow spacing, there was a higher number of branches that were formed, which led to a better crop assimilation rate and photosynthetic active radiation as a result of the increase in leaf area. In agreement with these ideas [24], the increase in leaf area increases the assimilation rate of carbon and nutrients by common bean varieties, which drives the biological yield into economic yield. Conversely, on the plants spaced at narrower interrow spacings, there was high competition between crop plants for growth resources. At narrower interrow spacings, there were high accumulation of auxin hormone which involve cell division and elongation due to higher vegetative growth mass that enhances lower interception of light at the bottom than the upper layer. On the other hand, leaf area was influenced by the interaction effects of interrow spacing and common bean varieties at both studied sites (Table 3, Figures 2(b) and 2(c)). In contrast to these ideas, the authors of reference [25] stated that, leaf area development is critical for light interception and drives several related physiological processes, which include leaf addition, expansion, and senescence for the given crops.

3.2.3. Leaf Area Index. The leaf area index was significantly influenced by the main effects of inter-row spacing at Arsi Negele, whereas nonsignificant effects were observed at

Table 3: Effect of interrow spacing on plant height, leaf area, and leaf area index of common bean varieties at the Arsi Negele and Melkasa sites.

Parameters	*Plant height (cm)*		*Leaf area (cm^2)*		*Leaf area index*	
Locations	Arsi Negele	Melkasa	Arsi Negele	Melkasa	Arsi Negele	Melkasa
Plant spacing (cm)						
30	56.67 ± 1.6^{a}	59.41 ± 5.6^{a}	1862.25 ± 105^{b}	2104.0 ± 152.0^{a}	3.98 ± 0.2^{b}	4.12 ± 0.2^{ns}
40	53.50 ± 1.6^{b}	54.11 ± 3.6^{b}	1961.05 ± 98.9^{a}	1852.9 ± 119.2^{c}	4.00 ± 0.3^{ab}	4.00 ± 0.3^{ns}
50	50.44 ± 1.9^{c}	59.27 ± 3.4^{a}	1979.00 ± 94.7^{a}	2077.8 ± 109.7^{b}	4.07 ± 0.3^{a}	4.05 ± 0.2^{ns}
LSD	**2.39*****	**4.27***	**94.03*****	**210.92*****	**0.07****	**0.29** $^{\mathbf{ns}}$
CV%	**4.63**	**10.98**	**3.033**	**5.52**	**2.78**	**4.50**
Varieties						
Dame	55.15 ± 1.7^{a}	71.57 ± 3.3^{a}	1975.11 ± 100^{a}	1998.80 ± 136^{b}	4.04 ± 0.2^{a}	4.12 ± 0.3^{a}
SER-119	53.15 ± 1.6^{b}	53.61 ± 1.6^{b}	1928.30 ± 105^{b}	2041.90 ± 131^{a}	4.04 ± 0.3^{b}	4.08 ± 0.3^{ab}
KAT-B9	50.81 ± 1.6^{c}	49.20 ± 2.1^{c}	1845.37 ± 99^{c}	1875.60 ± 118^{c}	3.96 ± 0.3^{b}	4.00 ± 0.2^{b}
LSD	**0.31*****	**2.68*****	**38.59***	**69.89****	**0.039****	**0.071***
F value						
Row spacing (PS)	45.14^{***}	13.93^{***}	10.33^{**}	13.93^{***}	5.23^{**}	0.76^{ns}
Variety (Var)	144.14^{***}	12.38^{***}	16.69^{***}	12.38^{***}	3.58^{*}	5.15^{**}
Rs $*$ Var	50.29^{***}	1.22^{ns}	10.13^{*}	23.97^{***}	1.53^{ns}	4.59^{**}

Values (Mean ± SE) followed by dissimilar letters in column are significantly different at $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; and Ns = nonsignificant.



(a) (b) (c) (d)

Figure 2: Interactive effect of interrow spacing × variety on (a) plant height at Arsi Negele; (b) leaf area at Arsi Negele; (c) leaf area at Melkasa; and (d) leaf area index at leaf area at Melkasa.

Melkasa (Table 3). The common bean varieties significantly influenced the given parameter at both experimental sites. The highest leaf area index was verified by the wider interrow spacing at both sites. This is due to the higher number of branches per plant at wider interrow spacings as a result of available growth resources and less crop competition that leads to excessive crop growth and increases the leaf area index. The leaf area index, which is involved root nodulation, stomata conductance, carbon dioxide concentration, photosynthetic rate, transpiration, and chlorophyll content, was higher at lower planting densities. In line with this result, the authors of reference [26] stated that the light extinction

Table 4: Effect of interrow spacing on number of pods plant^{-1} and number of seeds pods^{-1}of common bean varieties at the Arsi Negele and Melkasa sites.

Parameters	*Number of pods plant^{-1}*		*Number of seeds pod^{-1}*		*Hundred seeds weight (g)*	
Locations	Arsi Negele	Melkasa	Arsi Negele	Melkasa	Arsi Negele	Melkasa
Plant spacing (cm)						
30	13.94 ± 1.9^{c}	16.34 ± 1.8^{b}	4.75 ± 0.4^{ns}	4.12 ± 0.4^{ns}	42.58 ± 4.0^{b}	41.89 ± 3.0^{ns}
40	15.56 ± 1.5^{b}	18.56 ± 2.2^{a}	4.80 ± 0.3^{ns}	4.01 ± 0.3^{ns}	44.92 ± 3.6^{ab}	43.11 ± 3.5^{ns}
50	16.87 ± 1.3^{a}	18.27 ± 1.5^{a}	4.94 ± 0.4^{ns}	4.05 ± 0.3^{ns}	47.94 ± 5.1^{a}	43.78 ± 3.4^{ns}
LSD	**3.05*****	**2.04****	**0.64^{ns}**	**0.63^{ns}**	**4.72**	**9.03**
CV%	**6.18**	**7.48**	**13.62**	**13.74**	**1.20**	**7.64**
Varieties						
Dame	13.15 ± 1.4^{c}	14.74 ± 1.1^{b}	4.24 ± 0.3^{b}	4.64 ± 0.3^{b}	53.05 ± 3.1^{a}	50.44 ± 2.4^{a}
SER-119	15.98 ± 1.3^{b}	18.58 ± 2.2^{a}	5.09 ± 0.4^{a}	5.03 ± 0.4^{a}	33.21 ± 1.5^{c}	32.11 ± 1.5^{c}
KAT-B9	17.79 ± 1.7^{a}	17.65 ± 1.6^{a}	4.96 ± 0.4^{a}	4.02 ± 0.3^{c}	46.19 ± 3.4^{b}	46.22 ± 1.3^{b}
LSD	**0.52*****	**1.63*****	**0.57*****	**0.23*****	**1.15*****	**1.77*****
F value						
Row spacing (PS)	21.14***	4.51***	0.65^{ns}	1.72^{ns}	7.83***	0.80^{ns}
Variety (Var)	41.42***	12.03***	8.13**	24.70***	157.32***	80.64***
Rs ∗ Var	34.06***	1.22^{ns}	10.16***	49.42***	12.51***	1.35^{ns}

Values (Mean ± SE) followed by dissimilar letters in column are significantly different at $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; and Ns = nonsignificant.

coefficient is an important variable to quantify the relationship between leaf area index with light interception by a canopy and estimate light use efficiency for C assimilation. Regarding the effects of common bean varieties, they have significantly influenced the leaf area index at both sites (Table 3).

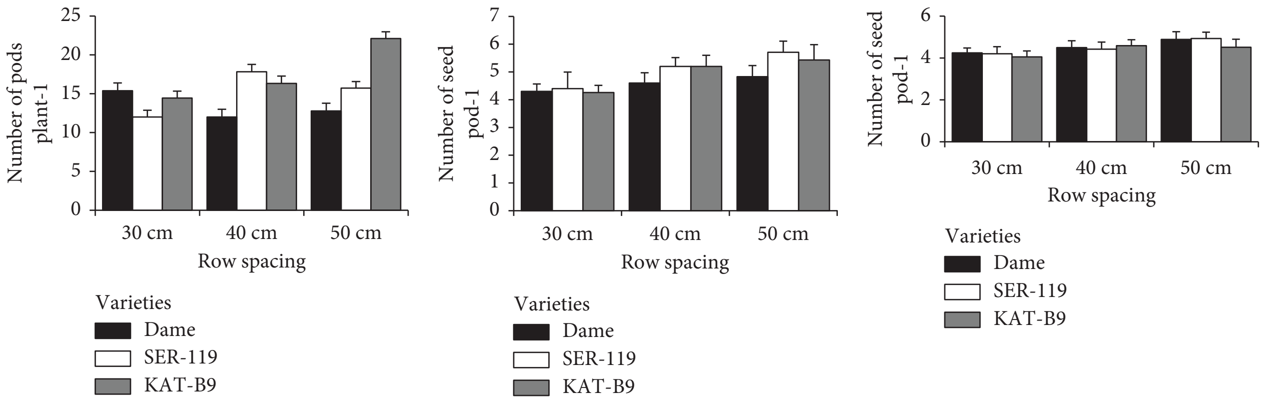
The highest leaf area index was recorded from Dame Variety, followed by SER-119 at both locations. However, the lowest was noted from KAT-B9 variety at the studied sites (Table 2). Moreover, the difference in plant growth among common bean varieties might be attributed to inherent genotypic differences [27–29]. The leaf area index was significantly influenced by the interactions of inter-row spacing and common bean varieties at Melkasa, while being nonsignificantly influenced by the given parameters at the Arsi Negele site (Table 3 and Figure 2(d)).

3.3. Yield and Yield Components

3.3.1. Number of Pods Plant^{-1}. The main effects of interrow spacings had a significant influence on number of pods plant^{-1} at Arsi Negele and Melkasa sites (Table 4). The higher number of pods plant^{-1} was recorded from wider interrow spacing (50 cm) at both experimental sites. This is due to the higher growth resources available for the plant with less competition as a result of a lower plant population, which enhances excessive branch formation which leads to higher pods production. In contrast to this, the authors of references [20, 29] reported that the number of pods plant^{-1} increased as interrow spacings increase from 30 cm–50 cm, due to low competition for growth resources and high utilization of nutrients by the crop plants. On the other hand, the common bean grows excessive branches and leaves, which increases the efficiency of light intensity that results in a high crop assimilation rate, leading to an increased number of pods plant^{-1} [30, 31]. Similarly, the efficient use of growth resources without severe competition between common bean varieties increases the number of pods plant^{-1} [32, 33].

However, the lowest number of pods plant^{-1} was verified from narrower interrow spacing (30 cm) at both locations (Table 4). As interrow spacing decreased, there was an increased plant population that enhanced higher competition for growth resources among crop plants. In agreement with this evidence, the authors of reference [34] found that narrow plant spacing limits individual plant branch formation and increased plant node numbers, and increased individual plant leaf area and vegetative mass that resulted in formation of higher number of pods plant^{-1}. Concerning the varieties, the number of pods plant^{-1} significantly influenced by the common bean varieties at both sites. The highest number of pods plant^{-1} was recorded from KAT-B9 and SER-119 at the Arsi Negele and Melkasa sites, respectively. On the other hand, the lowest number of pods plant^{-1} was recorded for variety Dame at both locations. This is due to differences in genetic makeup that existed among the given varieties at the stated locations [34]. On the other hand, the number of pods plant^{-1} significantly influenced by the interaction effect of interrow spacings and common bean varieties at only the Arsi Negele site (Figure 3(a)).

3.3.2. Number of Seeds Pod^{-1}. The number of seeds pod^{-1} at both sites was not influenced by the main effects of interrow spacing. But the common bean varieties significantly influenced the number of seeds pod^{-1} (Table 4). The highest number of seeds pod^{-1} was obtained from wider interrow spacings (50 cm) and the lower number was noted from narrower interrow spacings (30 cm) at the studied sites. The number of seeds pod^{-1} increased as interrow spacings got wider and wider, with sufficient growth resources available for crop plants and less competition between them [35]. In line with the above ideas, the authors of reference [36] stated that due to higher branches and leaves plant^{-1}, the number of seeds pod^{-1} increased, resulting in the partitioning of



(a) (b) (c)

Figure 3: Interaction effect of inter-row spacing × varieties. (a) Number of pods plant^{-1} at Arsi Negele; (b) number of seeds pod^{-1} at Arsi Negele; and (c) number of seeds pod^{-1} at MARC.

assimilates to the economic parts of the seeds. Regarding the common bean varieties, it has significantly influenced the number of seed pod^{-1} at the studied sites (Table 4). The highest number of seeds pod^{-1} was recorded from variety SER-119 at both sites. However, the lower seeds, pod^{-1} was recorded from Dame and KAT-B9 at the Arsi Negele and Melkasa sites, respectively. On the other hand, the interactions between inter-row spacing and common bean varieties had significant effects on the number of seeds pod^{-1} at both sites (Table 4, Figures 3(b) and 3(c)).

3.3.3. Hundred Seeds Weight (gm). The weight of the hundred seeds was significantly influenced by the common bean varieties at both sites. Regarding the interrow spacing, it significantly influenced the hundred seed weight at Arsi Negele and was nonsignificant at the Melkassa site (Table 4). The higher hundred seeds weight was recorded from wider (50 cm) with Dame variety and the lowest was noted from narrower (30 cm) interrow spacing with SER-119 (Table 4). These differences might be due to the genetic makeup of the given varieties [37]. On the other hand, there was a significant interaction effect of interrow spacings and common bean varieties on hundred seed weight at Arsi Negele, whereas it was nonsignificant at the Melkasa site (Table 4).

3.3.4. Total aboveground Dry Biomass (kg/ton). The total aboveground dry biomass was influenced by the main effects of common bean varieties and interrow spacings at Arsi Negele and MARC sites (Table 5). The highest yield of total dry biomass was obtained from narrower (30 cm) interrow spacings, whereas the lowest was from wider (50 cm) interrow spacings at the given study sites (Table 5). The total above ground dry biomass increases as interrow spacings get narrower and narrower for the given common bean varieties in the studied areas. This was due to the narrower interrow spacings, which brought excessive branches and leaves because of the higher accumulation of auxin hormones as a result of the higher crop canopy at the lower layer that enhanced cell division and elongation and better interception of light at the upper layer of the canopy, which had the ability to convert biological yield into economic yield that further caused the increment in total aboveground dry biomass for given crops [38]. Concerning the common bean varieties, it was significantly influenced the total aboveground biomass at both sites (Table 5).

The highest yield of total above ground biomass was noted at SER-119, followed by Dame variety, whereas the lowest was from KAT-B9 at both locations. These differences may be due to their genetic makeup among the varieties and across the locations [26]. Arsi Negele has a better grain yield than Melkasa. This was due to the higher availability of growth factors that contributed to the increment in total above ground biomass at the Arsi Negele site than at Melkasa. There was significant influence of common bean and interrow spacing on total dry biomass at Arsi Negele, whereas there was no significant interaction effect at the Melkasa site for the intended parameters (Table 5 and Figure 4(a)).

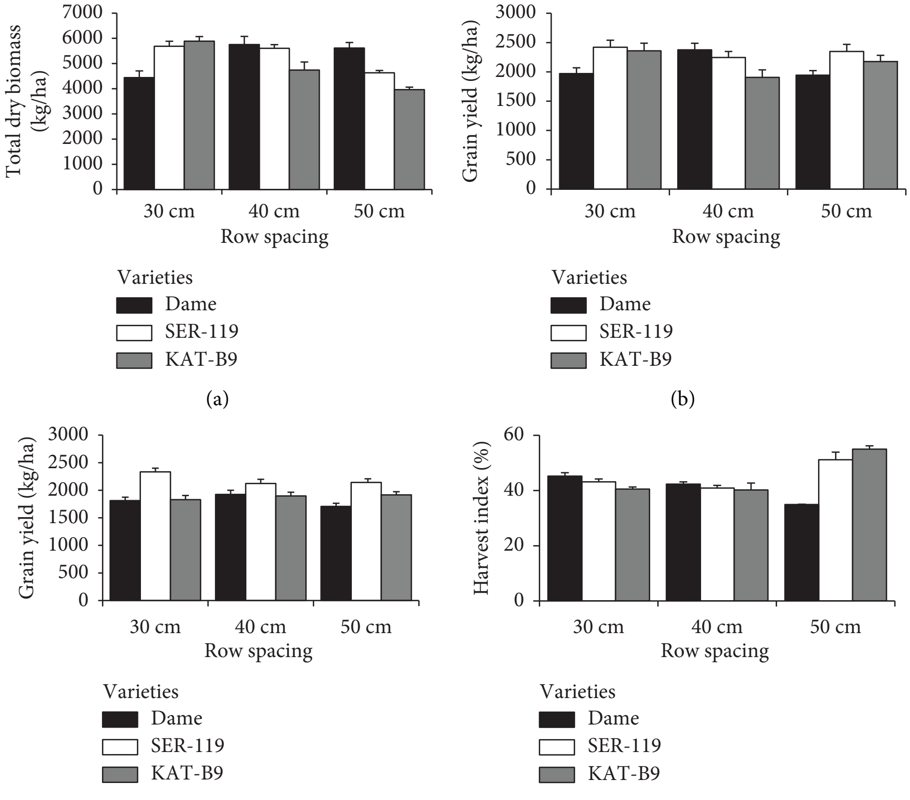
3.3.5. Grain Yield (kg/ton). The interrow spacings and common bean varieties had significant influences on grain yield at both locations (Table 5). The highest grain yield was obtained from the narrower interrow spacings (30 cm), whereas the lower yield was obtained from the wider (50 cm) interrow spacings at both sites (Table 5).

Because of the high competition for growth factors, crops planted at narrower interrow spacing had high growth and vegetative mass due to the production of auxin hormones and higher light interception at the upper layer of the canopy that enabled the higher total biomass and grain yields. As the authors of reference [39] found, the grain yield increased as interrow spacings became narrower and narrower due to increased vegetative growth of crop which resulted in a high assimilation rate of crops for further conversion of biological yield into economic yield. In agreement with these ideas, the

Table 5: Effect of interrow spacing on total dry biomass, grain yield, and harvest index of common bean varieties at the Arsi Negele and Melkasa sites.

Parameters	*Total dry biomass (kg/ha)*		*Grain yield (kg/ha)*		*Harvest index (%)*	
Locations	Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa
Plant spacing(cm)						
30	5439.8 ± 1.5^{a}	4282.9 ± 453.4^{a}	2253.2 ± 126.7^{a}	2076.9 ± 126^{a}	42.9 ± 1.2^{ns}	46.9 ± 3.6^{ns}
40	5468.3 ± 1.6^{a}	4253.0 ± 309.7^{b}	2185.8 ± 145.6^{b}	2030.1 ± 133^{a}	41.2 ± 1.3^{ns}	48.2 ± 3.5^{ns}
50	4739.8 ± 1.9^{b}	3582.2 ± 337.2^{c}	2048.1 ± 120.4^{c}	1901.5 ± 189^{b}	47.1 ± 3.4^{ns}	54.3 ± 2.2^{ns}
LSD	**607.43*****	**670.36****	**97.18****	**127.76****	**6.44****	**8.84***
CV%	**5.44**	**19.57**	**6.71**	**9.49**	**8.76**	**18.83**
Varieties						
Dame	5400.4 ± 1.7^{a}	3812.7 ± 399.3^{b}	2019.4 ± 107.2^{b}	1574.6 ± 126^{c}	40.8 ± 1.7^{ns}	47.4 ± 3.5^{ns}
SER-119	5563.91 ± 1.6^{a}	4791.1 ± 379.7^{a}	2333.1 ± 127.8^{a}	2366.7 ± 130^{a}	45.1 ± 2.2^{ns}	52.3 ± 4.2^{ns}
KAT-B9	4715.3 ± 1.5^{b}	3214.3 ± 198.2^{c}	2254.5 ± 144.7^{ab}	1826.1 ± 189^{b}	45.3 ± 2.8^{ns}	49.8 ± 1.3^{ns}
LSD	**214.04*****	**373.30****	**217.71*****	**252.34****	**6.61**$^{\mathbf{ns}}$	**9.05**$^{\mathbf{ns}}$
F value						
Row spacing (PS)	14.40^{***}	6.42^{***}	55.73^{**}	11.83^{*}	1.58^{ns}	0.64^{ns}
Variety (Var)	6.89^{***}	8.52^{***}	6.19^{*}	29.15^{***}	0.83^{ns}	0.41^{ns}
Rs ∗ Var	27.10^{***}	1.22^{ns}	7.99^{***}	5.47^{**}	10.36^{***}	1.97^{ns}

Values (Mean ± SE) followed by dissimilar letters in column are significantly different at $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; and Ns = nonsignificant.



(a) (b)

(c) (d)

Figure 4: Interactive effect of inter-row spacing × variety on (a) total biomass at Arsi Negele; (b) grain yield at Arsi Negele; (c) grain yield at MARC; and (d) harvest index at Arsi Negele.

authors of reference [40] stated that, as interrow spacings increased the grain yield plant^{-1} increased and grain yield ha^{-1} decreased due to low plant populations per a given area and higher nutrient availability to the crops to enhance excessive vegetative growth. The grain yield significantly influenced by an interaction of interrow spacings and common bean varieties at both locations (Figures 4(b) and 4(c)). The highest grain yields were recorded from interrow spacing of 30 cm with SER-119 variety and the lowest were from 50 cm with Dame variety at both locations. Regarding the common bean varieties, the highest grain yield was recorded from the SER-119,

Table 6: Partial budget analysis for Arsi Negele and Melkasa Agricultural Research Center.

Trts	Trts comb.	*Average grain yield*		*Adjusted grain yield*		*Total cost*	*Gross benefit*		*Net benefit*		*Dominance and MRR (%)*	
		AN	MARC	AN	MARC	Both sites	AN	MARC	AN	MARC	AN	MARC
1	$R1 * \mathrm{Ps} * \mathrm{v1}$	1999.07	1652.83	1799.10	1487.54	207.07	25188.24	20825.56	24981.17	20618.49	0	0
2	$R1 * \mathrm{Ps} * \mathrm{v2}$	2465.31	2117.50	2218.78	1905.75	214.07	31062.92	26680.50	30848.85	26466.43	838.24	835.42
3	$R1 * \mathrm{Ps} * \mathrm{v3}$	2393.32	2017.72	2153.99	1815.95	234.07	30155.86	25423.30	29921.79	25189.23	*D*	*D*
4	$R2 * \mathrm{Ps} * \mathrm{v1}$	2422.03	2004.24	2179.82	1803.82	207.07	30517.48	25253.48	30310.41	25046.41	*D*	5.29
5	$R2 * \mathrm{Ps} * \mathrm{v2}$	2301.62	2395.59	2071.46	2156.03	214.07	29000.44	30184.42	28786.37	29970.35	*D*	703.43
6	$R2 * \mathrm{Ps} * \mathrm{v3}$	1937.61	1818.33	1743.84	1636.50	234.07	24413.76	22911.00	24179.69	22676.93	*D*	*D*
7	$R3 * \mathrm{Ps} * \mathrm{v1}$	1962.76	1542.17	1766.48	1387.96	207.07	24730.72	19431.44	24523.65	19224.37	*D*	127.87
8	$R3 * \mathrm{PS} * \mathrm{v2}$	2385.64	2289.77	2147.08	2060.80	214.07	30059.12	28851.20	29845.05	28637.13	760.20	1344.68
9	$R3 * \mathrm{PS} * \mathrm{v3}$	2188.33	1656.93	1969.49	1491.24	234.07	27572.86	20877.36	27338.79	20643.29	*D*	*D*

NB: ($R1$ = row1 = 30 cm, $R2$ = row2 = 40 cm, $R3$ = row3 = 50 cm, Ps = plant spacing = 10 cm and V1 = variety Dame, V2 = variety SER-119, V3 = variety KAT-B9).

followed by the KAT-B9, and the lowest was noted from the Dame at both locations (Table 5). This might be due to genetic makeup differences among the varieties used for experiments [41, 42].

3.3.6. Harvest Index (%). The harvest index was not influenced by the main effects of common bean varieties and interrow spacing at Arsi Negele and MARC sites (Table 5). The highest harvest index was obtained from wider (50 cm) interrow spacings and the lowest was obtained from narrower (30 cm) interrow spacings at both sites (Table 5). As references [43, 44] indicated, the harvest index increases as inter-row spacings increase from 30 cm–50 cm due to higher nutrients availability for crops with less crop competition and transforms higher dry matter to the economic parts of the seeds, which improve grain yields and hundred seeds weight. The interaction effects of common bean and interrow spacings significantly influenced the harvest index at the Arsi Negele site. However, at MARC, there was a non-significant influence of the interaction of interrow spacing and common bean varieties on the harvest index (Table 5 and Figure 4(d)).

3.3.7. Partial Budget Analysis. Based on a partial budget analysis, the highest net benefit (30848.79 and 29970.35 ETB) was obtained from SER-119 at (30 cm × 10 cm and 40 cm × 10 cm), with a marginal rate of return (838.24% and 703.43%) at the Arsi Negele and MARC sites, respectively (Table 6).

4. Conclusion and Recommendation

The results of experiments obviously showed a significant influence of interrow spacings on majority of growth, yield and yield component parameters on the given common bean varieties at the studied sites. The narrower interrow spacing produced a higher yield than others due to higher light interception, which can drive biological yield into economic yield. Additionally, wider interrow spacings had an economic importance in gaining higher hundred seeds weight, seeds quality and reduced incidences of diseases for the given common bean varieties at both locations.

Data Availability

The data were recorded from the conducted research at both locations for the given parameters and it was original data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors significantly contributed in executing this experiment, analyzing and interpreting the data as well as writing and editing the manuscript.

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