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EFFECTS OF SPACING ON SEED YIELD, SEED QUALITY AND ABOVE-GROUND BIOMASS OF COWPEA (*Vigna unguiculata* L. Walp.) UNDER RAIN-FED CONDITIONS AT CENTRAL GONDAR ZONE, ETHIOPIA

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Abstract

The productivity and quality of forage cowpea are very low due to the use of inappropriate spacing for the selected varieties used in the study area. The study was conducted for two years (2022 and 2023) on-farm to determine the effects of inter- and intra-row spacing on biomass and seed yield and yield-related traits of selected cowpea variety IT92KD258-9. The experiment was laid in a randomized complete block design with three replications in a factorial arrangement of three inter-rows (40, 50 and 60 cm) and three intra-rows (20, 30 and 40 cm) spacing. Data on growth attributes, biomass yield, reproductive parameters and harvest index were recorded. All data were subjected to analysis of variance procedures, with a significance test at p<0.05. The interaction effects of inter- and intra-row spacing either positively or negatively influenced all parameters except dry matter percent (%), leaf-to-stem ratio, hundred seed weight (g) and seed moisture content (%). Every increase in inter- and intra-row spacing was accompanied by a corresponding decrease in biomass yield with related attributes and an increase in seed yield, some seed quality traits and harvest index. The maximum fresh herbage yield (46.04 t ha^{-1}) and dry biomass yield (10.69 t ha^{-1}) were obtained at a spacing combination of 40 cm inter and 20 cm intra-rows. The highest haulm yields (2.78 t ha^{-1}) and (2.64 t ha^{-1}) were recorded at 50 and 40 cm and 50 and 30 cm inter and intra-row spacing combinations, respectively. The better seed yield (1697.31 kg ha^{-1}) with better seed germination (95.83%) was attained at 50 and 40 cm inter and intra-row spacing combinations. Based on the study results, a combination of 40 and 20 cm inter and intra-row spacing appears preferable regarding biomass yield production and a 50 and 40 cm inter and intra-row spacing combination is a recommendable optimum spacing for cowpea seed production with a better quality.

Key words: *biomass yield, harvest index, inter-row spacing, intra-row spacing, seed yield.*

INTRODUCTION

In most tropical countries, particularly in Ethiopia, an inadequate supply of feed is the bottleneck to livestock production. This is due to the dependence of livestock on naturally available feed resources and little development of forage crops for feeding to animals. Feed shortage both in terms of quantity and quality is a major problem hindering the development of the livestock industry in Ethiopia. The shortage of improved forage, the poor quality of existing feed resources and fluctuating feed supply are major constraints to increasing livestock productivity (Sere et al., 2008; Mamaru & Lemma, 2023).

Similar to other parts of the country, natural pasture and crop residues are the main feed sources in the study area. Feedstuffs of such composition are insufficient to provide a year-round supply of nutrients beyond maintenance (Hindrichsen et al., 2001). This suggests the need to search for alternative feed sources and feeding strategies that would help to enhance the quality of these low-quality feeds. Among the options that can improve the nutritional quality of poor roughages are legume forages particularly cowpea. Cowpea is a forage legume and the most important forage crop that substantially improves the quality of feed available for livestock (Akinlade et al., 2005).

Cowpea (*Vigna unguiculata* L. Walp.) is the most popular and widely cultivated annual legume grown throughout the semi-arid tropics, where it is valued and potential to produce high levels of fodder for livestock in addition to grain for people. Both the fodder and the haulm are valuable dietary proteins for the livestock (Fatokun, 2002). Biomass yields in DM bases averaged from 4.68 to 6.61 t ha^{-1} which can sustain more than 5 to 7 lactating crossbred dairy cows per year that weigh 400 kg and produce 10

L of milk per day (Bilatu et al., 2012; Alemu et al., 2022). Crop residue from cowpea is a very important fodder resource that produces a 3.37 t ha^{-1} haulm yield with a crude protein of 21% in the dry haulm (Alemu et al., 2022). The crop is adaptable to harsh environments and withstands extreme temperatures, water-limiting conditions and poor soil fertility. It yields comparably high in harsh environments where other food legumes do not thrive (Shiringani & Shimelis, 2011) and it is tolerant to moisture stress areas (Nkongolo, 2003). In addition to its feed and food value cowpea is an important crop in improving soil fertility through the process of nitrogen fixation (Abayomi, 2008; Gwanzura et al., 2012). The crop can fix 240 kg ha^{-1} of atmospheric nitrogen and make available 60-70 kg ha^{-1} nitrogen for succeeding crops grown in a rotation with it (Amira & Oduwaye, 2007).

In line with the advantage the crop had, Gondar Agricultural Research Center, Livestock Technology Supply directorate tried to identify the most promising cowpea varieties with some agronomic practices. In this regard, promising results were obtained related to its biomass production and the technology has been transferred to the extension wing. However, quality seed production and maintaining its maximum biomass production remain the most persistent challenges to expanding the production and consumption of cowpea in the study area. Besides using selected improved varieties, both the seed and biomass yield levels of cowpea also vary depending on the quantity of agronomic practices employed. Among these, plant density and row spacing are important management tools where a farmer can strongly influence early-season light interception and crop growth (Ball et al., 2000). The use of different inter and intra-row spacing determines plant population per unit area which would enhance optimum utilization of growth factors (light interception, nutrient, moisture, space and carbon dioxide) to improve its regeneration, increase the crop potential, crop productivity and reduce competition among crops (Tolossa & Gizawu, 2020). The current study was, therefore, conducted with the objectives to determine the optimum inter and intra-row spacing for better quality cowpea seed production and to investigate the effects of varying inter and intra-row spacing on the growth and fodder yield of cowpea in the midlands of central Gondar zone.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted during the 2022 and 2023 cropping seasons, on-farm conditions and in two districts: Gondar Zuria and West Dembia from Central Gondar zone, Ethiopia. Gondar Zuria ranged at a latitude of 12º 25' 47″ N and longitude of 37º 35' 01" E at an elevation of 2023 m.a.sl., and West Dembia at 12º 17' 42″ N latitude and 37º 13' 25" E, at an altitude of 1856.4 m.a.sl. Based on 10-year (2013-2022) meteorological data, the area has an annual temperature with a range of 15.6-29.5 and 16.7-30.5ºC and average rainfall vary from 641-1678 and 718-1804 mm for Gondar Zuria and West Dembia districts, respectively, in bimodal type with the erratic rainfall distribution. The soil texture of the study area is sandy loam, good in water-holding capacity and fertility. The pH (H_2O) of the initial soil for the two study sites rages from 5.1 to 5.3 indicating the soil is moderately acidic. The total N content of the initial soil ranges from 0.23 to 0.26% which could be rated as medium and the available P in the soil ranged from 25.86 to 27.35 ppm which also is appreciable, while had lower K (0.02 to 0.03%) (Hartz, 2007; Alemu et al., 2022). The overall cation exchange capacity (CEC) of the soil is from 11.94 to12.13 $cmol_c$ kg^{-1}, which is very low (Hazelton, 2007).

Cultivation practices and crop management

Before the commencement of the experiment, the experimental sites were ploughed, harrowed and leveled out to maintain a well-prepared seed bed. Planting was done at the beginning of the rainy season (first week of June 2023) with an optimum level of moisture. Two to three seeds were sown per stand using the dibbling method. Plants were later thinned to one plant per stand two weeks from planting to reduce plant competition. To maintain best plant establishment NPS fertilizer at the rate of 100 kg ha^{-1} was applied at the time of planting.

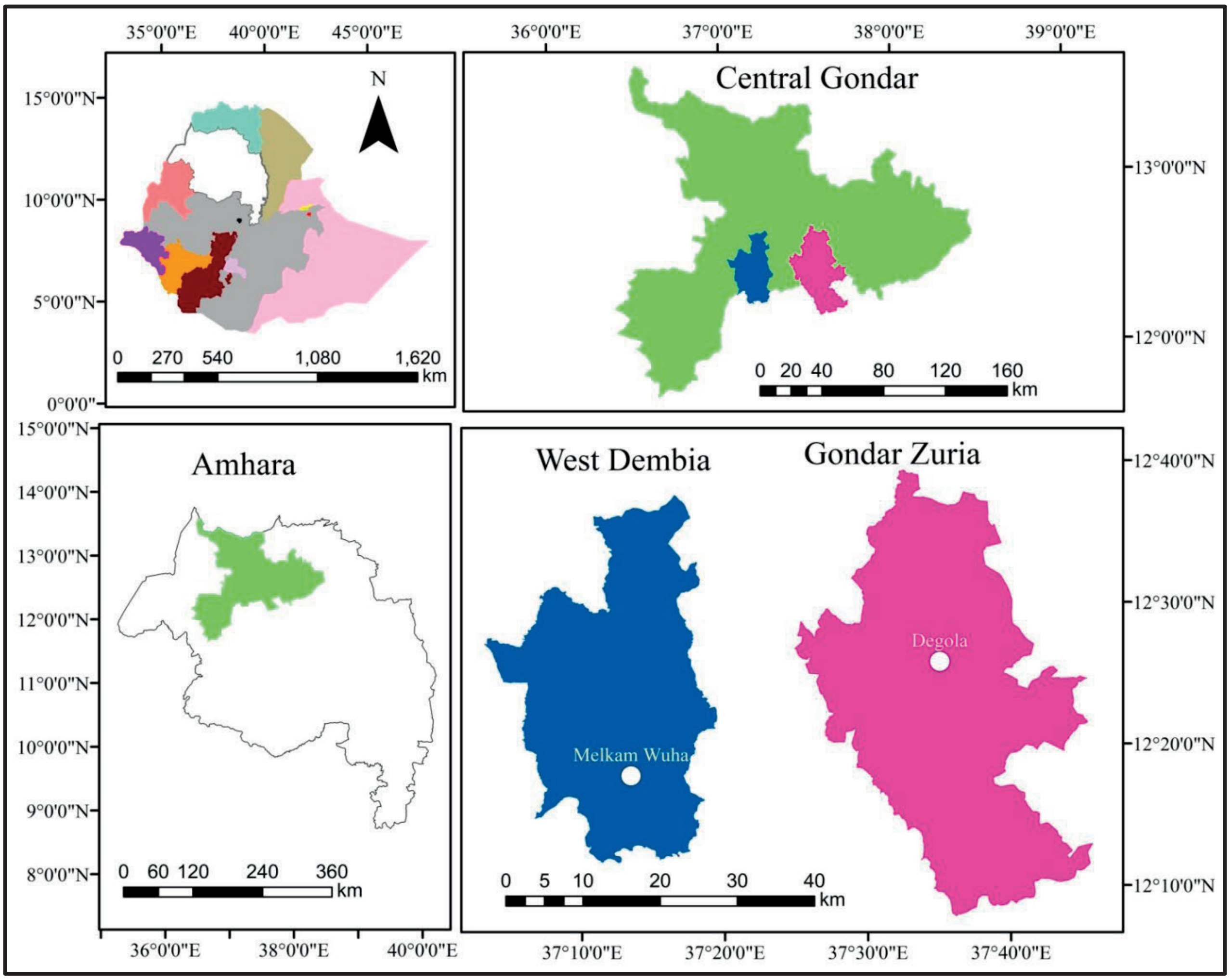

Figure 1. Map of the study area in Gondar Zuria and West Dembia districts, Central Gondar zone, Amhara region, Ethiopia

Hand weeding of an experimental unit was done at 4 weeks after germination and subsequently at 4-week intervals and kept weed-free throughout the growth period according to the weed management requirements of the crop (Dugje et al., 2009). Continual insect pest and disease monitoring was done for the entire experimental period, but no noticeable insect pest and disease incidence was observed on the plants for the entire growing period.

Treatments and experimental design

One cowpea variety (IT92KD258-9) adaptive to the area was used as a potential planting material. Cowpea seed was obtained from the center. Three inter-row spacings (40, 50 and 60 cm) were applied to the three intra-row spacings (20, 30 and 40 cm) and tested in a factorial arrangement. The experimental plot was laid down in a randomized complete block design with three replications. Plot size was 4.8 **x** 3.2 m. The spacing between plots and replications was 1 and 1.5 m, respectively.

Data collection and sampling techniques

During sampling, each plot was divided into two halves crosswise with an effective plot size of 2.4 **x** 3.2 m. One half was used for forage sampling and the other half for seed sampling. Forage sampling was done at 50% blooming stage and the seed yield of cowpea was determined at 12.5% moisture content.

Growth traits and biomass yield

In this experiment, after planting growth and biomass yield were evaluated such as plant height (cm) at forage harvest, number of branches per plant, fresh biomass yield (t ha^{-1}), dry matter percent (%), dry matter yield (t ha^{-1}), leaf to stem ratio and haulm yield (t ha^{-1}).

Plant height (cm) was measured by averaging the natural standing height of ten plants per plot.

The number of branches per plant was determined by counting the number of primary branches on the stem of ten plants per plot. Fresh herbage yield (t ha^{-1}) was obtained by cutting all the plants in the net plots at about 8 cm above the ground surface and immediately after forage sampling, the fresh samples were weighed by using a Salter balance having a sensitivity of 0.1 kg for green biomass yield estimation. A minimum of 500 g of individual fresh samples were collected and dried in a forced air draft oven at 65° C for 72 hours for partial dry matter (DM) determination. The dry matter yield (t ha^{-1}) was estimated by multiplying the fresh herbage yield (t ha^{-1}) with that of the sample dry matter content divided by 100. The leaf-to-stem ratio was determined by taking samples from five randomly selected plants, dried in a paper bag and the leaves then were carefully stripped from the stems. The ratio was obtained by dividing the weight of a leaf by the weight of the stem. Haulm yield (t ha^{-1}) was calculated after air-drying the cowpea residue until constant weight was obtained.

Seed yield and quality parameters and harvest index

Cowpea seeds were harvested at the full maturity stage when the plants started showing signs of yellowing, drying and withering. Seed yield and quality indicators were evaluated: the number of pods per plant, pod length (cm), number of seeds per pod, seed yield (kg ha^{-1}), hundred seed weight (g), seed purity (%), seed moisture content (%) and seed germination (%). The number of pods per plant was determined by counting the average pods of the five randomly selected plants. Pod length (cm) was measured by averaging the length of thirty pods from the five randomly selected plants. The number of seeds per pod was recorded by counting the total number of seeds in a pod from thirty randomly sampled pods taken from the five randomly selected plants. Pods picked from plants at the entire rows were threshed and the seed obtained was adjusted to standard moisture level (12.5%) per plot in grams and converted into kilogram per hectare. Hundred seed weight (g) was estimated by counting 100- seeds at random from each plot four times and weighed by using a sensitive balance having a sensitivity of 0.01 g. Finally produced seeds were further cheeked for their quality in terms of their purity (%), seed moisture content (%) and germination (%). The Harvest index was calculated as the ratio of seed yield to total above-ground biomass yield.

Data analysis

Data collected were subjected to Analysis of variance (ANOVA) using the R statistical software (Team and DC, 2019). When the difference is significant ($p<0.05$), Least Significant Difference (LSD) test was used to locate differences between the treatment means. Pearson's correlation coefficients were determined among the important growth traits, biomass yield, seed yield and quality indicators and harvest index using R statistical software.

RESULTS AND DISCUSSIONS

All of the obtained results represent the mid-values acquired during a 2-year experimental period (Tables 1 and 2). The two years (2022 and 2023) combined analysis results of the experiment at West Dembia and Gondar Zuria districts indicated a significant ($P<0.05$) interaction, especially at most important parameters measured with the inter and intra-row spacing.

Growth traits at forage harvest

Results of the interaction effects of inter and intra-row spacing on growth traits are presented in Table 1. The analysis of variance result depicted that plant height was significantly ($P<0.05$) affected due to the interaction between inter and intra-row spacing. The tallest plant height (128.50 cm) was attained when the cowpea forage planted at 50 and 40 cm inter and intra-row spacing, respectively, but significantly closer with the cowpea planted at 40 and 30 cm, 40 and 40 cm, 60 and 30 cm, and 60 and 40 cm inter and intra-row spacing while the shortest plant height (107.93 cm) recorded from cowpea forage planted at 50 and 30 cm inter and intra-row spacing. The variations might be mostly because wider spacing results in reduced competition over soil nutrients and light resulting in taller plants at forage harvest.

Table 1. Mean interaction effects of inter and intra-row spacing on biomass yield and yield components of Cowpea (*Vigna unguiculata* L. Walp.) in 2022 and 2023 growing seasons at central Gondar zone

Inter-row spacing	Intra-row spacing				Intra-row spacing			
	20 cm	**30 cm**	**40 cm**	**Mean**	**20 cm**	**30 cm**	**40 cm**	**Mean**
	Plant height (cm)				**Number of branches per plant**			
40cm	107.97^{bc}	119.30^{ab}	121.50^{ab}	116.26	9.00^{a}	8.03^{b}	8.37^{ab}	8.47
50cm	111.37^{b}	107.93^{c}	128.50^{a}	115.93	8.10^{b}	7.30^{c}	8.70^{a}	8.03
60cm	110.87^{b}	122.33^{ab}	124.10^{ab}	119.10	9.13^{a}	8.23^{b}	8.07^{b}	8.48
Mean	110.07	116.52	124.70	117.10	8.74	7.85	8.38	8.33
CV (%)	24.30				14.88			
LSD (5%)	16.30				0.71			
LS	*				*			
	Forage biomass yield (t ha^{-1})				**Dry matter percent (%)**			
40cm	46.04^{a}	32.83^{b}	27.65^{bc}	35.51	23.26	22.31	22.58	22.72
50cm	36.06^{b}	29.45^{bc}	24.78^{c}	30.10	22.79	22.59	22.87	22.75
60cm	34.59^{b}	27.14^{c}	24.24^{c}	28.66	22.60	22.98	22.61	22.73
Mean	38.90	29.81	25.56	31.42	22.88	22.63	22.69	22.73
CV (%)	8.18				4.19			
LSD (5%)	5.47				0.96			
LS	**				ns			
	Dry matter yield (t ha^{-1})				**Leaf-to-stem ratio**			
40cm	10.69^{a}	7.35^{b}	6.24^{bc}	8.09	1.12	1.39	1.21	1.24
50cm	8.22^{b}	6.65^{bc}	5.65^{c}	6.84	1.27	1.36	1.22	1.28
60cm	7.80^{b}	6.23^{bc}	5.48^{c}	6.50	1.31	1.42	1.21	1.31
Mean	8.90	6.74	5.79	7.15	1.23	1.39	1.21	1.28
CV (%)	8.37				18.41			
LSD (5%)	1.69				0.32			
LS	***				ns			
	Hulm yield (t ha^{-1})							
40cm	2.15^{b}	2.53^{ab}	2.59^{ab}	2.42				
50cm	2.33^{ab}	2.64^{a}	2.78^{a}	2.58				
60cm	2.46^{ab}	2.53^{ab}	2.32^{ab}	2.44				
Mean	2.31	2.57	2.56	2.48				
CV (%)	20.81							
LSD (5%)	0.48							
LS	*							

Means both within columns and rows having different superscript letters are significantly different at ***= P<0.001; **= P<0.01; *= P<0.05; ns= non-significant at (P>0.05) by LSD test.
CV = coefficient of variation; LS = level of significance; LSD = least significant difference.

Higher plant height for the Sefinesh cowpea variety planted under higher inter and intra-row spacing was supported by Dahmardeh et al. (2010), who expressed that cultivar x row spacing interactions, affected plant height character which was greater when wide rows were used. These results are also comparable with El Naim et al. (2012) and Khamis et al. (2018) who noted that increasing plant spacing resulted in significantly increased plant height; other reports from El Naim et al. (2010) and Boateng & Wilson (2019) showed that narrow spacing had an insignificant effect on plant height. Similarly, Adigun et al. (2014) reported that the plant height of cowpea was shorter, especially at narrow inter and intra-row spacing. Shiferaw et al. (2018) also observed a reduction in plant height under close spacing. This result is contrary to those of Tuba (2009) and Tuarira & Moses (2014), who noted plant height of chickpea and green beans was taller in higher plant population (closer spacing) treatments due to more competition for light. Similarly, the study carried out by Yayeh et al. (2018) also found that plant height increased linearly by increasing plant population (decreasing intra and inter-row spacing) due to competition of plants in higher densities on light, resulting in taller plants was contrary to our research. The discrepancy between current results from previous findings could be due to the differences in crop types used, edaphic factors, environmental temperature and precipitation in different study locations.

There was a significant (P<0.05) interaction among the treatments on the number of branches per plant. Plant spacing had a significant effect on number of branches per plant. The highest number of branches per plant was obtained at cowpea variety IT92KD258-9 planted at 40 and

20 cm, 50 and 40 cm and 60 and 20 cm inter and intra-row spacing, respectively while, the smallest number of branches (7.30) from cowpea crop planted at 50 and 30 cm inter and intra-row spacing. This could be attributed to the reaction of cowpea variety to the combination of different inter and intra-row spacing. The increased numbers of branches at the wider inter and intra-row spacing could also be attributed to more interception of sunlight and nutrients that might have resulted in higher axillary bud formation and differentiation leading to a higher number of branches per plant (Biraj et al., 2024). Similarly, Tesfay et al. (2018) reported a mean number of branches per plant of 8.52 for the same variety at the Southern lowlands of Tigray planted at 40 and 20 cm inter and intra-row spacing. Aryal et al. (2021) also reported that the number of branches per plant decreased as plant density increased with lowering spacing. This can be achieved with optimum spacing which not only utilizes soil moisture and nutrients more effectively but also avoids excessive competition among the plants. However, beyond a certain limit yield cannot be increased with decreasing/increasing spacing. Hence, optimum intra and inter-row spacing induces the plant to achieve its potential in attaining several branches per plant. Contrary to the current result, Tessema (2018) reported number of branches per plant ranges from 10 to 17 at the Salayish 1 experimental site in the Lowlands of Southern Ethiopia. The discrepancy between current results from previous findings could be due to the differences in inter and intra-row spacing employed, edaphic factors, environmental temperature and precipitation in different locations.

Biomass yield and leaf-to-stem ratio

The two-year combined analysis results of the experiment at Gondar Zuria and West Dembia districts indicated that there was no significant ($P>0.05$) interaction observed with the inter and intra-row spacing on forage dry matter percent (Table 1). Mean dry matter percent was 22.73 for the combined inter and intra-row spacing.

The analysis of variance result depicted that fresh herbage yield (t ha^{-1}) was significantly ($P<0.001$) highly affected due to the interaction effects of inter and intra-row spacing and dry matter yield (t ha^{-1}) also highly ($P<0.01$) affected with the interaction between inter and intra-row spacing (Table 1). The highest mean fresh and dry biomass yield was recorded as the inter and intra-row spacing decreased.

The tested cowpea variety IT92KD258-9 when planted at 40 and 20 cm inter and intra-row spacing produced the highest fresh biomass (46.04 t ha^{-1}) and dry matter yield (10.69 t ha^{-1}) as compared to the other treatments. This is due to the highest plant density attained at the smallest inter and intra-row spacing that resulted in the achievement of better fresh herbage and dry matter yield accompanied by other biomass yield-related traits. However, if the number of plants per unit area keeps on increasing, the fresh herbage and dry biomass will reduce as there is a lodging problem and lower photosynthetic efficiency in a highly crowded plant population (Aryal et al., 2021; Ingle et al., 2021; Biraj et al., 2024). The average fresh herbage and dry biomass yields obtained in our study for the narrow inter and intra-row spacing were considerably higher than those reported by Ayana et al. (2013) and Khamis et al. (2018), but lower than El Naim et al. (2010) and Boateng & Wilson (2019) who attained an average fresh herbage and dry biomass yield of 34.04 and 29.94 t ha^{-1}, and 7.68 and 5.49 t ha^{-1}, respectively from different cowpea varieties tested with the narrower inter and intra-row spacing. Variations in the yields could be attributed to the differences in cowpea varieties and spacing used and also differences in the level of soil fertility, climatic zones, seasons and agronomic practices adopted at different study areas. The results of fresh biomass and dry matter yield achieved at a narrower spacing in this study are in line with the results of cowpea biomass yield for the same cowpea variety at the same spacing at the Dilla Sub-Station of the Southern Nation, Nationalities and Peoples' Regional State (Ingle et al., 2021).

There was no significant ($P>0.05$) interaction observed with inter and intra-row spacing in leaf-to-stem ratio across years (Table 1). The mean leaf-to-stem ratio was 1.28 which agrees with the finding of Tesfay et al. (2018) who reported leaf to stem ratio that ranges from 1.10 to 1.41 for the ILRI 9333, ILRI 9334 and Temesegen cowpea varieties at Southern lowlands of Tigray. The analysis of variance result revealed that there was a significant

($P<0.05$) interaction among inter and intra-row spacing on cowpea haulm production (Table 1). The highest haulm yield (2.78 t ha^{-1}) was recorded from cowpea crop residue obtained at 50 and 40 cm inter and intra-row spacing, respectively, but statistically similar with others spacing except at 40 and 20 cm inter and intra-row spacing combined. The lesser cowpea haulm production at narrower inter and intra-row spacing might be due to the loss of leaves especially from the bottom part of the plants as the plant density increases causing overheating and suffocation leading to serious leaf shattering and ultimate low cowpea haulm production. The current result is in agreement with Alemu et al. (2022), who found lower haulm yield (2.07 t ha^{-1}) at 40 and 20 cm inter and intra-row spacing combined for the same variety tested at different fertilizer use under irrigation at central Gondar zone, Ethiopia. Khamis et al. (2018) also reported a sharp decline in cowpea haulm production as inter and intra-row spacing decreased.

Seed yield and yield-related traits

The interaction effects of inter and intra-row spacing on the measured seed yield and quality indicators are shown in Table 2. Significantly ($P<0.001$) and ($P<0.01$) higher inter and intra-row spacing interactions were observed for seed yield and all yield-related traits (Table 2). Plant spacing had a significant effect on number of pods per plant. As plant spacing increases the number of pods per plant was noted to increase. From the analysis, we observed that a significantly ($P<0.001$) higher number of pods (53.40 $plant^{-1}$) were noted on wider spacing especially at 50 and 40 cm inter and intra-row spacing, respectively while, the least (28.17 $plant^{-1}$) at the narrow spacing (40 and 20 cm inter and intra-row spacing, respectively). This may be due to better availability of water, nutrients and better translocation of photosynthesis from source to sink that resulted in a higher number of pods per plant especially at wider spacing. The increase in the number of pods per plant in wider spacing may be due to vigorous plants as in wider spacing; plants grew vigorously and produced more branches which resulted in a high number of pods per plant. On the other hand, in closer spacing, the plant growth was decreased which resulted in less number of pods per plant (Aryal et al., 2021; Biraj et al., 2024). The current result is consistent with previous reports of El Naim et al. (2012) and Alemu et al. (2022) in different cowpea varieties tested at different inter and intra-row spacing in different years and locations. Ingle et al. (2021) also found the highest number of pods per plant in wider spacing as compared to closer spacing. Similarly, El Naim and Jabereldar (2010) reported that increasing population density decreased the number of pods per plant and the seed yield.

In this study, it was observed that pod length was significantly ($P<0.001$) affected by the interaction between inter and intra-row spacing. The highest pod length (19.85 cm) was achieved from the wider spacing (50 and 40 cm inter and intra-row spacing combined) while the least (15.62 cm) was obtained at 40 and 20c m inter and intra-row spacing. The observed variation in pod length in the current study might be due to the variations in the availability of plant production resources as a result of plant density. In contrast, Jakusko et al. (2013) reported relatively lower pod length (13.6 to 16.08 cm) in cowpea varieties IT89KD-288, IT89KD-391 and IT97K-499-35 tested at 75 x 25, 60 x 25 and 445 x 25 cm inter and intra-row spacing in Adamawa State, Nigeria. The observed variation in pod length could be attributed to the differences in cowpea varieties and spacing used and also differences in level of soil fertility, climatic areas, seasons and agronomic practices adopted at different study areas. The overall mean value obtained in this study was comparable with the pod length (17.21 cm) reported by Khamis et al. (2018) when the cowpea varieties were planted at different inter and intra-row spacing under rain-fed conditions in Darfur, Sudan.

The results from the analysis of variance for number of seeds per pod and seed yield (kg ha^{-1}) with the interaction between inter and intra-row spacing showed highly significant ($P<0.01$) and very highly significant ($P<0.001$) differences, respectively (Table 2). The number of seeds per pod and seed yield ranged from 10.22 to 15.27 and 608.66 to 1697.31 kg ha^{-1}, respectively. The highest number of seeds per pod and seed yields were obtained from 50 and 40 cm inter and intra-row spacing combined, while the lowest was attained at 40 and 20 cm inter and intra-row spacing, respectively. The highest number of seeds per pod might be because in wider intra and inter-row spacing the pod length was maximum resulting in a maximum number of seeds per pod in these plots and vice versa.

Table 2. Mean interaction effects of inter and intra-row spacing on seed yield and quality of Cowpea (*Vigna unguiculata* L. Walp.) in 2022 and 2023 growing seasons at Central Gondar zone

Inter-row spacing	**Intra-row spacing**				**Intra-row spacing**			
	20 cm	**30 cm**	**40 cm**	**Mean**	**20 cm**	**30 cm**	**40 cm**	**Mean**
	Number of pods per plant				**Pod length (cm)**			
40cm	28.17^{d}	30.83^{d}	36.97^{bc}	31.99	15.62^{c}	15.62^{c}	16.63^{c}	15.96
50cm	31.30^{d}	34.30c^{d}	53.40^{a}	39.67	16.73^{c}	17.78^{bc}	19.85^{a}	18.12
60cm	35.77^{c}	42.67^{b}	39.67^{b}	39.37	18.00^{bc}	18.52^{b}	17.57^{b}	18.03
Mean	31.75	35.93	43.35	37.01	16.78	17.31	18.02	17.37
CV (%)	12.13				2.96			
LSD (5%)	3.57				1.29			
LS	***				***			
	Number of seeds per pod				**Seed yield ($kg\ ha^{-1}$)**			
40cm	10.22^{c}	11.58^{c}	12.27^{bc}	11.36	608.66^{c}	890.91^{bc}	1004.77^{bc}	834.78
50cm	10.77^{c}	11.78^{bc}	15.27^{a}	12.61	764.60^{bc}	946.20^{bc}	1697.31^{a}	1136.04
60cm	11.80^{bc}	12.67^{b}	12.67^{b}	12.38	829.53^{bc}	1127.28^{b}	1155.50^{b}	1037.44
Mean	10.93	12.01	13.40	12.11	734.26	988.13	1285.86	1002.75
CV (%)	9.55				12.30			
LSD (5%)	2.66				470.67			
LS	**				***			
	Hundred seed weight (g)				**Seed purity (%)**			
40cm	20.17	20.83	21.17	20.72	96.83^{b}	98.83^{ab}	99.17^{a}	98.28
50cm	20.17	21.17	22.00	21.11	98.67^{ab}	98.33^{ab}	99.67^{a}	98.89
60cm	19.83	21.50	22.00	21.11	98.33^{ab}	98.83^{ab}	98.83^{ab}	98.66
Mean	20.06	21.17	21.72	20.98	97.94	98.66	99.22	98.61
CV (%)	6.66				0.87			
LSD (5%)	2.80				1.49			
LS	ns				*			
	Seed moisture content (%)				**Seed germination (%)**			
40cm	12.75	13.26	13.68	13.23	69.67^{b}	85.50^{ab}	88.83^{ab}	81.33
50cm	11.94	12.69	13.10	12.58	77.67^{b}	86.67^{ab}	95.83^{a}	86.72
60cm	12.68	12.79	12.52	12.66	69.50^{b}	84.33^{ab}	82.67^{ab}	78.83
Mean	12.46	12.91	13.10	12.82	72.28	85.5	89.11	82.30
CV (%)	5.35				8.63			
LSD (5%)	1.78				17.07			
LS	ns				**			
	Harvest Index (%)							
40cm	30.45^{c}	37.59^{bc}	39.55^{bc}	35.86				
50cm	33.63^{bc}	58.16^{a}	64.45^{a}	52.08				
60cm	34.33^{bc}	45.36^{b}	52.49^{a}	44.06				
Mean	32.80	47.04	52.16	44.00				
CV (%)	13.72							
LSD (5%)	11.98							
LS	*							

Means both within columns and rows having different superscript letters are significantly different at ***= $P<0.001$; **= $P<0.01$; *= $P<0.05$; ns= non-significant at ($P>0.05$) by LSD test.
CV = coefficient of variation; LS = level of significance; LSD = least significant difference.

The greater number of seeds per pod that leads to better seed yield production in wider spacing especially at 50 and 40 cm inter and intra-row spacing combined might be due to the increased photosynthetic area and activity of the crop leading to better growth and yield components contributing to more seed yields. This showed that seed yield attributing parameters were significantly influenced by the interaction between inter and intra-row spacing. Malami and Sama'ila (2012) also reported that the interaction between inter and intra-row spacing had a significant effect on the number of pods per plant and seed yield in semi-arid north-western Nigeria. The mean number of pods per plant and seed yield was relatively higher than the result achieved by Tekle (2014) at Alduba, Southern Ethiopia. This could be due to the genetic differences between the different cowpea varieties, differences in inter and intra-row spacing used and the suitability of the production environment for the varieties. However, a similar result was observed for the same variety planted at 40 and 20 cm inter and intra-row spacing and tested at different fertilizer use under irrigation in the central Gondar zone, Ethiopia (Alemu et al., 2022).

Seed quality performance and harvest index

There was no significant (P>0.05) interaction observed between inter and intra-row spacing in attaining hundred seed weight (Table 2). This is because the cowpea variety used across treatments was the same and the mean hundred seed weight was 20.98 g. The combined analysis of variance results showed a significant (P<0.05) interaction among the treatment groups in seed purity percentage (Table 2). The highest seed purity (98.33 to 99.67%) was obtained from seeds harvested at the wider inter and intra-row spacing (40×30, 40×40, 50×20, 50×30, 50×40, 60×20, 60×30 and 60×40 cm). This could be attributed to the lesser presence of chaffs and broken seeds that could reduce seed purity, especially at wider inter and intra-row spacing. The mean seed purity was 98.61% which agrees with the finding of Alemu et al. (2022) who reported a mean seed purity percentage of 98.89 from different cowpea varieties tested at central Gondar zone. The two-year combined analysis results of the experiment at Gondar Zuria and West Dembia districts indicated that there was no significant (P>0.05) interaction observed with the inter and intra-row spacing on cowpea seed moisture content (Table 2). This is because the moisture content of seeds was adjusted to the standard and closely the same to maintain the seed quality. The mean moisture content of cowpea seeds was 12.82%.

The mean combined analysis result of seed germination for the same cowpea variety tested at different inter and intra-row spacing is given in Table 2. The differences among inter and intra-row spacing, and seed germination percentage were found statistically highly significant (P<0.01). Seed germination percentage varied between 69.50 and 95.83% over 60×20 and 50×40 cm inter and intra-row spacing, respectively. This was due to the differences in pure seed produced, seed size and amount of endosperm contained in seeds related to the spacing difference at which the seeds were produced. The values recorded in this study were higher than the values reported by Alemu et al. (2022) in different cowpea varieties tested at different inter and intra-row spacing in different years and locations at central Gondar zone. This might be due to the differences in cowpea varieties and differences in inter and intra-row spacing used and also the suitability of the production environment for the varieties. In line with the current result, Tesfay et al. (2018) and Khamis et al. (2018) also reported that seed germination percentage ranges from 71.06 to 94.71% for other cowpea varieties tested at different areas and locations. The interaction between inter and intra-row spacing in this study was found significant (P<0.05) on the harvest index (Table 2). This might be due to differences in the partitioning of dry matter to the forage and seeds across the treatments. The overall mean value obtained in this study was comparable with the harvest index (43.79) reported by Jakusko et al. (2013) but higher than the previous results (39.26) of El Naim et al. (2012). The observed variations in harvest index might be due to the variations in forage dry matter and seed yield attained in different study areas.

Correlation between traits

The simple linear correlation analyses among morphological characteristics, biomass production, seed yield and harvest index of cowpea (*Vigna unguiculata* L. Walp.) variety IT92KD258-9 are presented in Table 3. Plant height was positively correlated with the number of branches per plant, pod length, seed yield, hundred seed weight and harvest index but negatively correlated with dry matter yield, leaf-to-stem ratio and number of seeds per pod. However, no correlation was observed between the plant height and the number of pods per plant. On the other hand, the number of branches per plant was positively correlated with dry matter yield, number of pods per plant, pod length, seed yield, hundred seed weight and harvest index. The dry matter yield was negatively correlated with leaf-to-stem ratio, number of pods per plant, number of seeds per pod, pod length, seed yield, hundred seed weight and harvest index. The leaf-to-stem ratio was positively correlated with the number of pods per plant, number of seeds per pod, pod length, seed yield, and harvest index while negatively correlated with hundred seed weight. The number of seeds per pod was positively correlated with other seed yield-related components and harvest index. The number of seeds per pod also positively correlated with other seed yield-related components except a hundred seed weight. Pod length also positively correlated with seed yield, hundred seed weight and harvest index. Seed yield positively correlated with hundred seed weight and harvest index and hundred seed weight also positively correlated with harvest index.

Table 3. Correlation coefficients among morphological characteristics, biomass production, seed yield and harvest index of cowpea (*Vigna unguiculata* L. Walp.) in 2022 and 2023 growing seasons at central Gondar zone

	PH	NBPP	DMY	LTSR	NPPP	NSPP	PL	SY	HSW	HI
PH	1	0.29*	-0.06	-0.40**	0.00	-0.44**	0.13	0.10	0.80**	0.02
NBPP		1	0.13	-0.15	0.12	-0.10	0.08	0.21	0.25	-0.22
DMY			1	-0.20	-0.62**	-0.56**	-0.57**	-0.69**	-0.24	-0.58**
LTSR				1	0.21	0.35*	0.14	0.12	-0.47**	0.07
NPPP					1	0.72**	0.70**	0.81**	0.10	0.57**
NSPP						1	0.48**	0.67**	-0.32*	0.51**
PL							1	0.74**	0.16	0.54**
SY								1	0.24	0.62**
HSW									1	0.25
HI										1

DMY = dry matter yield; HI = harvest index; HSW = hundred seed weight; LTSR = leaf to stem ratio; NBPP = number of branches per plant; NPPP = number of pods per plant; NSPP = number of seeds per pod; PH = plant height; PL = pod length; SY = seed yield.

CONCLUSIONS

From the study results, it can be concluded that there is no study factors interaction effect on forage cowpea dry matter percent, leaf-to-stem ratio, hundred seed weight (g) and seed moisture content (%). However, a significant interaction effect of the study factors was observed on the most important growth attributes, biomass yield, seed yield and seed quality traits as well. Closer spacing (40×20 cm inter and intra-row spacing) gave more plant population and biomass yield than wider spacing combinations. The highest haulm production was attained at 50×40 cm and 50×30 cm inter and intra-row spacing combinations. Among the spacing combinations tested on cowpea variety IT92KD258-9, a combination of 50×40 cm inter and intra-row spacing produced a relatively higher number of pods per plant, pod length (cm), number of seeds per pod and seed yield (kg ha^{-1}). Concerning seed quality parameters, significantly lesser seed purity percent attained only at 40×20 cm inter and intra-row spacing combination while, the least seed germination (%) was recorded at 40×20, 50×20 and 60×20 cm inter and intra-row spacing combinations. Harvest index increased with increasing spacing, especially at 50×30, 50×40 and 60×40 cm inter and intra-row spacing combination. Hence, according to the results of this study use of a combination of 40×20 cm inter and intra-row spacing appears to be optimum and preferable regarding biomass yield production and a combination of 50×40 cm inter and intra-row spacing is a recommendable optimum spacing for cowpea seed production with a better quality under the study locations and other similar areas.

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