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Effect of Inter-Row Spacing on Growth and Yield of Fenugreek (*Trigonella Foenum-Graecum L.)* Varieties at Woliso Woreda, Central Ethiopia

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ABSTRACT

Fenugreek (Trigonella foenum-graecum L.) is a legume crop that is used as a spice, vegetable, and medicinal plant. Interrow spacing and varieties were factors affecting the production of fenugreek crops in Ethiopia. The experiment was conducted with the objective of evaluating the effect of inter-row spacing of fenugreek varieties with their combination on the growth, yield, and yield component at Woliso district. A field experiment was conducted at Woliso Polytechnic College during the main cropping season 2023 cropping season with RCBD design arranged in factorial arrangement and replicated three times. 10cm, 20cm, 30 and 40cm inter-row spacing and four improved fenugreek varieties Burqa, Chala, Ebbisa, Wereilu, and local variety for the check were used during the experiment. The collected data were analyzed using SAS software version 9.2. The statistical analysis shows that days of 50% germination were not significant (P≤ 0.05) but days of 50% flowering, days of 90% maturity, higher primary branch (6.36), higher number of grain pod^{-1}(21.6), higher pod length, 1000g grain weight, above-ground biomass, grain yield were highly significant in main effect and their interaction (P≤ 0.01). The higher number of primary branches(6.73) and, number of grain pod^{-1}(21.6), pod length (19.3), 1000g grain weight(20g) and grain yield (1563.7kg ha^{-1}), days of 90% maturity (117.9days), higher primary branch(6.73), number of grain pod^{-1}(26.25), pod length, 1000g grain weight, above ground biomass (3568.33Kg ha^{-1}), and grain yield and the shorter days of 50% flowering (44.6days) were recorded from Burka interacted with 40cm followed by Chala, Wereilu, and Ebbisa verities. In contrast, the lower grain yield was recorded with the interaction of 10cm. From the current research on yield and yield component planting of the Burka variety with 40 cm inter-row spacing is performing well and recommended to the local farmer to increase the yield of fenugreek crop**.**

Keywords: Fenugreek varieties, inter-row spacing, Yield component, Yield.

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L*)* family - Leguminoceae an annual herb is well known as flavor, curry powder, and spice (Dhull *et al*., 2021). The crop is autogenous flowers occasionally attracted to insects (Davoud *et al*., 2010). Mainly Eastern Mediterranean parts are indigenous countries for the growing fenugreek crop widely cultivated in India, Egypt, Ethiopia, Morocco, and England (Davoud *et al*., 2010). In Ethiopia, fenugreek is growing in the range of 1800-2300 m.a.s.l. the crop is growing in a subtropical climate, including wet and dry seasons (Getu and Biruk 2022**;** Roba *et al*., 2024*)*. Fenugreek is grown on a wide range of soils with well-drained loams or sandy loams (Minjaro *et al*., 2023).

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Ethiopia is home to the fenugreek subspecies its distribution extends from Eritrea to Somalia (Bekele *et al.*, 2020). The production and distribution of fenugreek in Ethiopia is almost similar to that of other cool-season food legumes **(**Roba and Simion, 2022**).** In Ethiopia, fenugreek cultivation covered about 32,507.42 hectares of agricultural land with an annual production of over 28,925.21 tons of fenugreek seeds (CSA, 2021). In the Oromia region, fenugreek covered 2,449 hectares of the total production 0.06% covered by all pulses grown in the 2015/16 cropping season (CSA, 2021).

Fenugreek is a multipurpose crop used as food, feed, spices, and medicinal plant, and the oil is also used in perfumery in France (Roba and Simion, 2022). It enriches soil through symbiosis with microorganisms, which fix atmospheric nitrogen (Mehta, *et al* 2011; VanInsberghe *et al.,* 2015; Meena *et al.,* 2017**).** In Ethiopia, the crop is produced either as a spice or for other special purposes, such as food for nursing mothers and infants as a breakfast beverage (Roba and Simion, 2022). Locally it is known as the "Abish" flavoring of the traditional bread and medicinal plant to lower blood glucose levels, treats gastric disease, and abdominal discomfort, boost milk production in lactating mothers, and increase body weight (Roba and Tana, 2018). The crop is rich in protein (25.5%), fats (5-10%), and carbohydrates (45-60%) (Sharma 2021; Roba *et al.,* 2024). In South Western part of Ethiopia, fenugreek is used in crop rotation, and income generation (Roba and Simion, 2022). In southwestern Ethiopia, fenugreek is used in income generation (Agize et al., 2016; Hordofa and Tolossa, 2020**).** The crop is used as green manuring; green leaves have been used as vegetable and seed production for the international market of condiments or feed (Melese *et al.*, 2020; Camlica *et al.*, 2021). Currently, its seeds are highly demanded in the market and it can have great economic value for both producers and countries (Melese *et al.*, 2020). Currently, its seeds are highly demanded in the market and it can have great economic value for both producers and the country (Kebede, 2020).

Fenugreek productivity in Ethiopia is very low compared to the world average which is 1.29ton ha^{-1} (Alemu *et al.,* 2017; Getu and Hirko, 2022). Shortage of improved varieties, lack of certified seed, inadequate fertilizer, inadequate knowledge on production and management systems, poor agronomic practices, poor marketing system and presence of diseases and insect pests are the major factors that have contributed to the lower crop yield in the country **(**Serbessa *et al.,* 2019; Kebede, 2020).

Row spacing has a significant influence on the majority of agronomic traits of Fenugreek varieties (Melese *et al.,* 2020). Row spacing influences on the majority of agronomic traits of Fenugreek varieties (Minjaro *et al.,* 2023). Row spacing also modifies plant architecture, leaf photosynthetic capacity, and dry matter partitioning in many spice crops **(**Seyedi *et al.,* 2024). Proper row spacing prevents the development of foliar diseases (Singh *et al.,* 2021). The wider rows improve air penetration and reduce moisture through the crop canopy (Singh *et al.,* 2021). Optimum spacing ensures proper growth of both aerial and underground parts of the plant through efficient utilization of solar radiation, branch capacity, better light interception and penetration into the crop canopy and enhances light utilization efficiency, nutrients and land as well as air spaces and water enhance Fenugreek yield (Sharanya *et al.,* 2018; Bajwa *et al.*, 2019; Chapepa *et al.*, 2020; Sarkar, 2021; Amiriyan *et al.*, 2023**).** Sowing at the appropriate row spacing increases yield and yield component Fenugreek crop (Aasim *et al.*, 2018; Jaidka *et al.,* 2020). The interaction of variety and inter-row space affects crop phenology, growth, yield, and yield components of Fenugreek (Mohammed *et al.*, 2019) Fenugreek varieties are generally selected for higher yields and greater tolerance to adverse conditions and early maturity (Hassan *et al.,* 2018). Every variety does not perform well with the same plant spacing (Tiwari *et al.*, 2016). Therefore, the study was conducted with the general objectives of evaluating the effect of inter-row spacing on growth yield and yield component of fenugreek (*Trigonella foenum-graecum* L.) varieties at Woliso District, Central Ethiopia.

To evaluate the effect of row spacing and their interaction on growth, yield, and yield components of fenugreek varieties at Woliso District and evaluate the growth and yield performance of fenugreek varieties at the Woliso District

MATERIALS AND METHODS

Description of the Study

The experiment was conducted at Woliso Technical, Vocational Educational and Training College field in the South-West Shoa Zone of Oromia Region, and Central Ethiopia during the 2023 cropping season. The site is located 114km far from Addis Ababa, geographically the experimental area is Located at 8°31'60" N latitude with 37°58'60" E longitude and at an elevation of 2049 m.a.s.l. The area receives 1400mm rainfall with mean minimum and maximum temperatures of 12.9°C and 25°C, respectively. The area is a bimodal rain type the main rainy season is started from between June and September while the main rainy season starts in June and terminates in September. According to phenotypic soil classification, the experimental area is clay soil character.

Planting material

The five Fenugreek varieties namely: Burqa, Ebbisa, WereIlu, Chala, and Local variety were used in the experiment. These verities were obtained from Ambo Agricultural Research Center. (table 1)

Table 1. List of Fenugreek varieties

Name of Varieties	Released Research Center	Released Year	Growing Altitude(m)	Rainfall (mm)	Productivity ton/ha
Burqa	SARC	2016	1650	20-500	12.2
Ebbisa	SARC	2012	1650-2400	120-500	1.5
Wereilu	SARC	2016	2300-2800	868- 1000	1.2
Chala	DARC	2005	1650-2400	948	1.65
Local Variety					

Source: Ministry of Agriculture (2022)

Treatments and Experimental Design

The experiment was conducted with four inter-row spaces (10cm, 20cm, 30cm, and 40cm and five fenugreek varieties (Burqa, Ebbisa, Chala, Wereilu, and local variety) with a total of 20 treatment combinations. The experiment was laid out in a randomized complete block design arranged factorial with three replications. The plot size was 6m^2 which was 2m wide and 3m long with 0.50m space between plots and 1m between blocks.

Experimental Procedure and Management

The experimental site was prepared by oxen-driven local plow in accordance with the local farming practices of the farmers. The plots were prepared as per the layout, leveled manually and the treatments were assigned randomly and seeds were drilled in each furrow. All agronomic practices including sowing and seeding rate, watering, weeding, soil cultivation, and application of fertilizers were applied at the rate of 25 kg ha^{-1} N, 25 kg ha^{-1} Nps according to the recommendation.

Data Collected

Five healthy plants were randomly selected in each plot as per treatment. Plastic-coated labels were tagged for identification and recording of various observations. The following data were recorded:

Days to 50 % emergence: Days to 50 % emergence were determined by counting the number of days from sowing to the time when 50 % seedlings emerged.

Days to 50% of flowering (DF): The date of first and 50% flowering on the sample plants was recorded, and the period required in days from the date of sowing was calculated.

Days to 90% maturity (DM): Days to maturity were recorded by counting days from emergence to days on which about 90% of the plant on the plot attained physiological maturity using maturity indices of fenugreek based on visual observation i.e. when leaves and pods of the plants on the plots were turned to yellowish-green color.

Plant height (m): The height of five randomly taken plants from each plot was measured in centimeters (cm) from the ground to the top of the plant by a ruler at the physiological maturity stage.

Number of primary branches per plant: The number of primary branches in five randomly selected plants was recorded at physiological maturity and their average was expressed as the number of primary branches per plant.

Number of pods per plant: The number of pods per plant was counted from five randomly taken plants at harvest

Number of grains per pod: The total number of pods from five randomly taken plants were threshed the number of seeds was counted and the total number of seeds was divided by the total number of pods to compute the average number of seeds per pod.

Thousand-grain weight: Thousand seed weight was determined based on the weight of 1000 seeds sampled from the seed yields of each plot by manual counting and weighed with an electronic balance.

Above-ground dry biomass yield (kg ha^{-1}): Above-ground dry biomass yield was determined at physiological maturity from five randomly taken plants of the rows of each plot after sun drying till constant weight. The dry biomass per plant was then multiplied by the total number of plants per net plot. This value was used to calculate the harvest index as well.

Grain yield: Harvesting was performed at maturity when the color of leaves and pods changed to yellowish-green. The plants were then threshed and separated into seeds and straw to make the seeds ready for laboratory analysis. To determine seed yield, yield was adjusted to a moisture level of 10%. Finally, yield per plot was converted to per hectare, and average yield was reported in kg ha^{-1}.

Harvest index: Harvest index was recorded as the ratio of dry seed yield to the aboveground biomass yield per plot. The harvest index (HI) of fenugreek was calculated using the Bange *et al.* (1998) equation as follows and expressed by %.

$$\text{Harvesting Index} = \frac{\text{Grain yield}}{\text{Above-ground biomass yield}} \times 100$$

Data analysis

All agronomic data were subjected to analysis of variance (ANOVA) using the SAS software methods version 9.2. Means were Compared by 5% probability level. The correlation analysis was analyzed by SAS software methods as the procedure of proc corr. (SAS. 2009).

RESULTS and DISCUSSION

Days to 50% Emergence

Analysis of variance showed that both inter-row spacing, fenugreek varieties, and their interactions do not have significant ($P \leq 0.05$) effects on days to 50% emergence (Table, 2).

Table 2. Effect of row spacing and fenugreek varieties on main factors of Days of 50% emergency, Days of 50% flowering, Days of 90% physiological maturity, Number of primary branches, Total ground biomass and Harvesting index

Interrow space(cm)	DE 50%	DF 50%	DM 90%	number of pods plant^{-1}	TGBM Kg/ha^{-1}	HI%
10	5.26a	51.86a	128.3ab	20.13d	1588.33d	32.2c
20	5.26a	49.26b	133.1a	23.86c	2215.47c	35.73b
30	5.26a	45.33c	122.6bc	27.066b	3345.67b	39.2a
40	5.27a	44.6c	117.86c	29.33a	3568.33a	40.2a
Mean	5.26	47.76	128.33	25.1	2679.45	36.83
LSD (5%)	0.039	2.59	10	1.55	143.84	1.87
Varieties						
Ebbisa	5.283a	49b	122bc	26.9a	2611.83b	41.66a
Wereilu	5.266a	53.58a	140a	24.83b	2849.67a	35.25c
Chala	5.250a	46.16b	132ab	25.25ab	2715ab	38.33b
Burka	5.258a	46.83b	121bc	26.25ab	2616.17b	40.58a
Local Variety	5.258a	43.25c	112c	22.25c	2604.58b	28.33d
Mean	5.26	47.76	125.48	25.1	2679.45	36.83
LSD (5%)	0.044	2.9	11.2	1.73	160.82	2.09
CV (%)	1.02	7.35	10.82	8.38	7.26	6.87

Means in a column with the same letter are not significantly different at 5% probability level;
Keys;- CV= Coefficient of variation, DE 50% days of 50% emergency, DF 50% days of 50% days of 50% flowering, DM 90% days of 90% physiological maturity, TGBM, Total ground biomass, and HI, harvest index

Days of 50% flowering

Analysis of variance showed that inter-row spacing and varieties had a highly significant (P<0.01) effect on days to 50% flowering days, while their interaction was not significant (P<0.05) (Table, 2). The shortest days to 50% flowering days were recorded from planting of Fenugreek varieties at 30cm and 40cm which is 44.6 and 45.33 days, respectively followed by 20cm whereas the longest days to 50% flowering was recorded from inter-row of 10cm which is 51.86 days (Table 2). The wider spacing is the shortest days of flowering this may be because the wider spacing reduces competition for resources such as water, nutrients, and sunlight among plants. The result agrees with Abdel *et al.,* (2008); Mahama, (2011) and Minjaro *et al.* (2023) who reported that the wider plant spacing and narrow plant spacing affect days to 50% flowering.

The shortest days of 50% flowering were recorded from the local variety which is (43.25 days) followed by Burka, Ebbisa, and Chala varieties whereas the longest 50% flowering days was recorded from the Wereilu varieties which are 53. 58 days (Table, 2). This is may be adaptability and genetic variability from fenugreek varieties. The result is in agreement with the report of Sharanya *et al*. (2018); Tesfahun *et al.* (2018) and Nchimbi *et al.* (2010) who reported that day to 50% flowering of highly significant fenugreek varieties, chickpea, and common bean genotypes.

Days to 90% Physiological Maturity

Analysis of variance showed that both inter-row spacing and fenugreek varieties were a highly significant ($p<0.01$) effect on 90% physiological maturity days, but their interaction was not significant ($p<0.05$) affecting days to physiological maturity (Table, 2). The shortest 90% physiological days were recorded from the planting of fenugreek at 40cm and 30cm which is 117.86 and 122.6 respectively whereas the longest 90% maturity days were recorded from 20cm and 10cm which is 133.1 and 128.3 days (Table, 2). The result is in line with the result, of Oad *et al*. (2002) who reported significant variation in wider inter- and intra-row spacing hastened the maturity of safflower. Holshouser *et al.* (2002) reported no significant effect of row spacing on the maturity of soybeans.

Among fenugreek varieties Local, Burka, and Ebbisa varieties had the shortest 90% maturity which is 112, 121, and 122 days respectively whereas the longest 90% maturity was recorded from Wereilu and Chala which is 140 and 132 days respectively (Table, 2). This may be genetic variability and environmental adaptability of the fenugreek varieties. The result is in line with the result of Sharanya *et al*. (2018) who reported significant variation in days taken for maturity of different fenugreek varieties. Fenugreek Varieties are generally selected for higher yields and greater tolerance to adverse conditions and early maturity (Yaldiz *et al.*, 2021; Amany (2014) reported that the increase of planting density from 25 to 33 plant m^{-2} increased plant height while decreasing the number of branches $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, 100 seed weight, and seed yield $plant^{-1}$.

Number of Pods Plant^{-1}

Analysis of variance showed both inter-row space and varieties were a highly significant ($p < 0.01$) effect on the number of pods per plant, their interaction was not significant ($p < 0.05$) (Table, 2). The higher number of pods per plant (29.33) was recorded from wider row spacing (40cm) followed by 30cm while the lower number of pods per plant (20.13) was recorded from 10cm narrower row spacing (Table, 2). The result in line with Mahasi *et al.* (2010) reported that narrow plant spacing limits individual plant branch formation and increased plant node numbers, and increased individual plant leaf area and vegetative mass resulted in the formation of a higher number of pods $plant^{-1}$. Tiwari *et al*. (2016) reported that higher number of pods per plant with inter and intra-row spacing of 30 cm x 10 cm than to 25 cm x 10 cm plant spacing of fenugreek, pod number $plant^{-1}$ increased with increasing row spacing. Mohamed (1990) number of pods increased by increasing row spacing in fenugreek. Gendy (2013) observed the seed rates of 30kg ha^{-1} and 30cm inter-row spacing, are the highest number of pods per plant (19.7) and (17.4), respectively as compared with a seed rate of 60 kg ha^{-1}.

Number Pod per plant highly significant ($P\leq0.01$) effect on the fenugreek varieties. The highest number of pods per plant was recorded from Burka, Chala, and Ebbisa varieties which are 25.25, 26.25, and 26.9 respectively followed by the Wereilu variety while the lower number of pods per plant (22.25) was recorded from the local variety (Table, 2). This might be due to differences in genetic makeup which indirectly govern the pod formation of the plant. The result is in agreement with Kizil and Toncer (2005); and Giridhar *et al.* (2017) who reported that the higher yield $plant^{-1}$ from wider spacing. Mohammed *et al.*(2019) also reported significant variety and inter-row space interaction on the phenology, growth, yield, and yield components of Fenugreek. Tiwari *et al.* (2016) varieties do not perform well in the same plant spacing.

Aboveground Biomass

Analysis of variance showed that the inter-row spacing was highly significant ($P< 0.01$) and affected the aboveground dry biomass. However, their interaction effect was not significantly affected (Table, 2). The highest total ground biomass (3568.33kg/ha) was recorded from (40cm) inter-row spacing whereas the lowest ground biomass (1588.33kg/ha) was recorded from (10cm) inter-row spacing. Moderate ground biomass was recorded from planting of fenugreek at 20cm and 30cm (Table, 2). The increase in biomass yield at maximum inter-row spacing might be due to the presence of optimum plant population at optimum spacing, which brought improvement in vegetative growth. Ouji *et al. (*2022) the crop environment with light intensity and concentration of carbon dioxide can play a vital role in the photosynthesis of the plant and thus increase dry matter accumulation and vegetative growth of the plant. Optimum spacing ensures proper growth of both aerial and underground parts of the plant through efficient utilization of solar radiation, nutrients, and land as well as air spaces and water.

Highly significant (P<0.01) variation was recorded from the total aboveground biomass of Fenugreek varieties (Table, 2). The highest total above-ground biomass was recorded at variety Wereilu and Chala which is 2849.67kg/ha and 2715 respectively. Followed by local varieties, Ebbisa and Burka fenugreek varieties (Table, 2). These results are in agreement with Miah *et al.* (1990) who reported that the higher biological yield (4152 kg/ha) gained wider row spacing in coriander. Dema *et al.* (2023) reported that the higher aboveground biomass yield (4152 kg ha^{-1}) was gained with a row spacing of 30 cm as compared with 20 in coriander. Sarkar (2021) variations were clearly evident in the case of dry matter with different plant spacing.

Harvest index

The result showed that the harvesting index is a highly significant (P<0.01) difference in both inter-row spacing and varieties but non-significant variation was observed among their interaction effect among fenugreek varieties (Table, 2). The highest harvest index (40.2% and 39.2%) was recorded from the wider inter-row spacing at 40cm and 30cm respectively followed by planting at 20cm inter-row spacing while the lower (32.2%) harvesting index was recorded from the narrower inter-row spacing at (10cm) (Table, 2). This reduction in harvest index in narrower spacing might be due to the higher plant population per unit area which might have increased the flower abortion due to competition for nutrients, moisture, and solar radiation.

The result shows that a high significant (P<0.01) effect on the harvest index among fenugreek varieties was observed (Table, 2). The highest harvest index was recorded from the Ebbisa and Burka varieties which are 41.66% and 0.58%) followed by the Chala and Wereilu fenugreek varieties, whereas the lowest harvesting index was recorded from the variety local which is 28.33(Table, 2). A similar result reported by Khan *et al.,* (2010) indicated a maximum harvest index (41.66%) in the highest row spacing (45cm) of chickpeas than 15cm row spacing.

Plant Height

The analysis of variance showed that the interaction of inter-row spacing and varieties had a highly significant (P>0.01) effect on plant height (Table, 3). The highest plant height was recorded from the ebbisa variety with the interaction of 10cm, 20cm, and 30cm which is 50.6 cm,48.6cm, and 47.3cm respectively followed by Ebbisa with 40cm, Wereilu with 10cm, 20cm, and 30cm (Table, 3). Moderate plant height was recorded from the interaction of Wereilu with 40cm, Chala with 10cm, 20cm, 30cm, and 40cm, and Burka with 10cm, 20 cm local variety with 10cm. Whereas the shortest plant height was recorded from the local variety with 40cm, 20cm, 30 cm, and Burka with 30cm, and 40cm inter-row spacing (Table, 3). The higher plant height was recorded from the narrow inter-row spacing this may be competition for light and space. The results were in line with Singh *et al.* (2005) reported that the highest plant height was recorded in 22.5 cm row spacing on lentil crops, while Halesh *et al.* (2000) and Gowda *et al.* (2006) reported the highest plant heights from the 30 cm row spacing. Singh *et al*. (2013) reported that the denser plant population increased the plant height of faba bean due to competition among plants. Sharar et al., (2001) reported that the plant height of chickpeas and green beans was taller in higher plant population treatments due to more competition for light. Similarly, Minjaro *et al.* (2023) reported that the highest plant height (58.77 cm) was recorded for the Ebbisa variety at a row spacing of 20 cm followed by 57.13 cm at a row spacing of 25 cm and the shortest plant height was recorded a at row spacing of 30 cm. [Singh *et al.*, (2013) was reported that plant height significantly increased with increase in plant density, which is mainly caused by a reduction in the amount of light that a single plant is able to intercept resulting into increased internode length soybean, faba bean, and green bean.

Number of Primary Branches per Plant

Analysis of variance showed that the interaction of inter-row spacing with varieties had a highly significant ($p<0.01$) effect on the number of primary branches of the fenugreek crop. (Table, 3). The highest number of primary branches per plant Ebbisa with 40cm (6.46), Wereilu with 30cm (6.5), Wereilu with 40cm (6.73), Burka with 40cm (6.36), Chala with 30cm (6.4) followed by the interaction of all varieties with 20cm and 30cm whereas the lower primary branches numbers were recorded with the interaction of all varieties with 10cm inter-row spacing (Table, 3). The wider spacing increases the number of primary branches per plant whereas the lower inter-row spacing reduces the total number of primary branches within a plant. This may be competition with natural resources such as attributed to more interception of sunlight for photosynthesis with wider spacing. The result agrees with Mohamed (1990); Halesh *et al*. (2000 and Gowda *et al*. (2006) reported that the number of branches in the fenugreek variable in planting the crop wider inter-row spacing. Mehmet (2008) and Dereje (2014) reported that increased number of branches at the wider plant spacing from 4.47 in 30cm inter-row spacing to 5.95 in 60cm inter-row spacing for soybean varieties. Mahama (2011) also reported that soybean variety and row spacing showed significant effect on the number of primary branches per plant and gave higher number of primary branches at wider spacing (60cm and 50cm) than narrow spacing (40cm and 30cm). Togay *et al.* (2005) reported that the number of primary branches decreased with the increase in the density of chickpeas.

Table 3. Interaction effect of row spacing and fenugreek varieties on, plant height, number of primary branches, pod length, number of grains per pod, 1000g grain weight and grain yield

Combination	Plant Height (cm)	Number of primary Branches	Pod Length (cm)	Number of Grain pod^{-1}	1000g Grain weight	Grain Yield (kg ha^{-1})
Ebbisa*10cm	50.6a	3.03ghf	13.3def	14f	14.3bcd	623hi
Ebbisa*20cm	48.6ab	3.5egdf	13.6cde	15.6de	15bc	833.6g
Ebbisa*30cm	47.3abc	5.36c	16.6b	18.3b	20.6a	1439cd
Ebbisa*40cm	46.6bcde	6.46ba	19a	18.6b	20a	1466.7bc
Wereilu*10cm	47bcd	2.9gh	13def	13fg	13.3cde	527.6i
Wereilu*20cm	46bcdef	3.3egf	14cde	14.3ef	14.6bcd	821g
Wereilu*30cm	46.6bcde	6.5ba	17.3b	16.6cd	20.6a	1350d

Wereilu*40cm	43fgh	6.73a	19a	18.6b	20.6a	1434cd
Chala*10cm	45cdef	3.73edf	14.3cd	13fg	13cde	525.3i
Chala*20cm	43.6defg	3.73edf	15c	14.3ef	14.6bcd	812.6g
Chala*30cm	40.3ghij	6.4ba	17.3b	17.3bc	19.3a	1433cd
Chala*40cm	38.3ij	5.76bc	18ab	18.6b	19.6a	1541ab
Burka*10cm	43.3efg	3.3egf	12.6ef	14.3ef	14.3bcd	558hi
Burka*20cm	40.3ghij	3.96ed	15c	16.3cd	15.6b	805g
Burka*30cm	37.6j	5.53c	18ab	18.6b	19a	1386cd
Burka*40cm	38.3ij	6.36ba	19.3a	21.6a	20a	1586a
Local*10cm	41.3ghi	2.23h	10h	10i	10.3f	324.6j
Local*20cm	39.6hij	2.4h	10.6gh	10.6hi	11.6ef	639.3h
Local*30cm	38.6ij	4.16d	12fg	11.3hi	12.6de	971.6f
Local*40cm	29.6k	4.1ed	12.6ef	11.6gh	12.6de	1116e
Means	42.61	4.475	15.05	15.36	16.11	1009.73
LSD (5%)	3.49	0.8	1.55	1.47	2.11	100.38
CV	4.95	10.89	6.26	5.82	7.92	6.01

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; CV=Coefficient of variation

Pod Length

Analysis of variance showed that the interaction of inter-row spacing with varieties was a highly significant (P≤0.01) effect on the pod length of fenugreek plants (Table, 3). The longest pod length was recorded from the interaction of variety Ebbisa (19), Wereilu (19), Chala (18), and Burka (19.3) with 40cm row spacing Burka with the interaction of 30 inter-row spacing. Followed by Ebbisa, Wereilu, and Chala improved varieties with the interaction of 30cm while the shortest pod length was recorded from the interaction of 10 and 20cm row spacing (Table, 3). The wider row spacing is a higher length than the narrow spacing this is may be a competition for space, nutrients, and sunlight. This result is in line with the work of Tuncturk *et al*. (2011); and Habib *et al*. (2019) who reported that increased inter-row spacing increases pod length in fenugreek varieties. (Tafese *et al*., 2023) planting of fenugreek at 30x10 cm increase in pod length (11.28 cm) as compared to 22.5 cm x 13.3 cm (10.24 cm). Jamal *et al*. (2010) also noted that 30x10 cm inter and intra-row spacing crop geometry produced longer pod length in fenugreek crop. Brar *et al*. (2005) reported that sowing date and row spacing (22.5 and 30 cm) the closer spacing resulted in significantly higher pod length. Kumar et *al*. (2018) a fenugreek seeded at 40cm row spacing with a seed rate of 16 kg/ha had sowed a significantly increased pod length.

Number of grains per Pod

The analysis of variance showed that the interaction of inter-row space with varieties had a highly significant (p<0.01) effect on the number of grains per pod (Table, 3). The highest number of grains per pod (21.6) was recorded from the interaction of Burka with (40cm) row spacing. Followed by Ebbisa at 30cm and 49cm, Wereilu at 40cm, Chala at 30cm and 40cm Burka at 30 cm the pod length ranging from 17.3 ± 18.6. Interaction of fenugreek with 20cm is moderate pod length. The shortest pod length was recorded from the interaction of fenugreek with 10cm (Table 3). The number of grains per pod increased as inter-row spacing wider this is might be due to competition for light interception and natural resources. The results were in line with Sharma (2000) who reported that the maximum number of grains per pod was recorded from wider row spacing. Minjaro *et al*. (2023) reported that the maximum number of seeds plant^{-1} was 11.9% planting with a row spacing was 25 cm, while the lowest number of seeds plant^{-1} was 3.75 with a row spacing was 20 cm. Almaz *et al. (*2016) stated that due to higher branches and leaves per plant, the number of grains per pod increased in fenugreek seeds. Abdel *et al.,* (2008) reported that the number of seeds per pod increased with decreased plant density of faba bean.

Thousand Grain Weight

The analysis of variance showed that the interaction of inter-row space with variety had a highly significant (p<0.01) effect on thousand-grain weight (Table, 3). The highest 1000 grain weight was recorded from the interaction of Ebbisa and Wereilu, Chala, and Burka varieties with the interaction of 30 and 40cm row spacing with the range of 19g to 20g grain weight followed by the interaction of fenugreek with 20cm. However, the lowest 1000-grain weight was recorded from the interaction of a variety of local treats with 10cm row spacing (Table, 3). This may be due to decreasing plant density might have caused more sunlight to penetrate the canopy which made plants benefit more from the natural environment. The results are in line with Khan *et al.,* (2010) higher hundred seed weight (29.87g) was reported in the wider inter-row spacing of 45cm than 30cm inter-row spacing of chickpeas. Nandal *et al.*, (2007) reported that the crop geometer (30 cm x10 cm) produced the maximum seed weight, while the fenugreek produced the lowest values (5 cm x10 cm). Similarly, Matthews, *et al*., (2008) also reported that the hundred seed weight of the faba bean was negatively related with plant density. Disasa (2009) who reported that the highest hundred seed weight of 27.47g at the lowest plant population of 133, 333 plants ha^{-1} and the lowest 24.99g at the highest plant population of 333,333 plants ha^{-1} of common bean. Aasim *et al. (*2018) fenugreek varieties sowing at the appropriate row spacing significantly increase the number of branches, number of pods, number of seed per pod, the pod length, seed weight per pod and 1000g^{-1} seed weight and then finally produce high seed yield (Sarkar, 2021) reported 1000 seed weight of black cumin was significantly influenced by different level of spacing.

Grain Yield

Analysis of variance showed that the interaction of inter-row spacing with variety was a significantly (P<0.01) effect on grain yield (kg/ha) of Fenugreek verities (Table, 3). The highest grain yield (1586kg/ha) was recorded from the interaction of 40cm row spacing with the Burka variety and Chala variety with 40cm1586 kgha^{-1} and 1541kgha^{-1} respectively followed by the interaction of Ebbisa with 40cm fenugreek verities. Whereas the lower grain yield was recorded from the interaction of 10cm inter-row spacing (Table 3). As inter-row spacing increases the grain yield increases while increasing inter-row spacing decreases the yield decreases this may be due to competition with resources, sunlight, and space. The result is in line with the findings of Meena *et al*. (2003) and Nandal *et al.* (2007) who noticed that sowing of fenugreek crop at wider spacings 30 and 40 cm, increased the seed yield over sowing at narrow spacing at 20 cm. Tuncturk (2011) reported the highest seed yield (777.0-785.0 kg ha^{-1} was recorded from 30 cm than 20cm row spacing. Ouji *et al. (*2022) Optimum row spacing is one of the important factors for securing good yield of spice crop. Moghbeli *et al. (*2019) Optimum row spacing and suitable cultivars together play an important role in achieving the potential yield of Fenugreek varieties. Meena *et al. (*2016) wider row spacing, and solar radiation that falls between crop rows remain unutilized;

plants become crowded and suffer from mutual shading if the row distance is too narrow. Moreover, yield may be reduced in narrow spacing due to increased competition of plants for nutrients and moisture. Bajwa *et al.* (2019) reported that fenugreek yield by optimizing branch capacity and the efficient utilization of other available resources. Bekele and Geleta (2021**)** reported that higher grain yield of chickpeas at wider row spacing than at narrower row spacing.

Correlation Coefficient among yield and yield component of fenugreek varieties

Correlation analysis results revealed that there were significant positive correlations ($P < 0.05$) among parameters of growth, grain yield, and yield components of fenugreek (Table, 3). Grain yield was positively correlated with a number of primary branches, number of pods per plant, pod length, number of grains per pod, thousand seed weight, above-ground biomass, and harvest index. The higher positive correlation was recorded from Grain yield with number of primary branch (r=0.89**), number of pods per plant (r=0.84**), pod length (r=0.77**), number of seed per pod (r=0.78**), thousand seed weight (r=0.82**) above-ground biomass (r=0.97**) and harvest index (r=0.86**) but grain yield was a negative correlation with days of 50% flowering(Table, 4). Days to 90% physiological maturity also had a negative correlation with the number of primary branches, number of pods per plant, pod length, number of seeds per pod, thousand seed weight, above-ground biomass, grain yield, and harvest index, and days of 50% flowering was negative correlation except for plant height and days of 90% maturity (Table, 4). The result agrees with Appiah *et al. (*2014); Gebeyehu, (2019) the use of appropriate inter-row spacing promotes high growth traits and yield components which have a positive influence on grain yield.

Table 4. The correlation coefficient among parameters of phonological, growth, yield, and yield component of fenugreek at Woliso

	DF50%	DM	PH	NB	NP	PL	SPP	TSW	TGBM	GY	HI
DF	1										
DM	0.42*	1									
PH	0.65**	0.46*	1								
NB	-0.21ns	-0.05ns	-0.21ns	1							
NP	-0.34*	-0.12ns	-0.22*	0.76**	1						
PL	-0.04ns	0.1ns	0.05*	0.82**	0.74**	1					
SPP	-0.005ns	-0.05ns	0.12ns	0.82**	0.75**	0.82**	1				
TSW	-0.07ns	-0.01ns	-0.08ns	0.86**	0.76**	0.82**	0.90**	1			
TGBM	-0.36*	-0.16ns	0.35*	0.90**	0.87**	0.79**	0.80**	0.82**	1		
GY	-0.38*	-0.15ns	0.38*	0.89**	0.84**	0.77**	0.78**	0.82**	0.97**	1	
HI	-0.40*	-0.09ns	0.40*	0.69**	0.61**	0.53**	0.56**	0.65**	0.73**	0.86**	1

Where; *, ** indicate significance and high significance at 5% and 1% of probability level respectively, NS: non-significance, DF: Days to flowering, DM: physiological maturity, PH: Plant height, NB: Number of primary branches, NP: number Pods per plant, PL: pod length, SPP: number of Seed per pod, TSW: thousand seed weight, AGBM: above-ground dry biomass, GY: Seed yield, HI: Harvest index

SUMMARY AND CONCLUSIONS

Fenugreek (*Trigonella foenum-graecum* L.) is a multipurpose spice crop; every part of the plant is used as a leafy vegetable, fodder, and condiment. In Ethiopia, fenugreek-growing regions are the high plateaus (1800-2300 m.a.s.l.) characterized by a subtropical climate of wet and dry seasons. Both inter-row and varieties are one of the factors affecting the yield potential of fenugreek crops.

Analysis of variance revealed that days to 50% flowering, days to 90% physiological maturity, number of primary branches per plant, number of pods per plant, above-ground biomass, thousand, and seed weight were significantly affected due to the main effect of inter-row spacing.

The shortest days of 50% flowering (44.6), days of 90% maturity (44.6), the higher above-ground biomass (3568.33 Kg/ha^{-1}), the higher number of pods per plant^{-1}(29.33) were recorded from the planting of fenugreek at 40cm followed 30cm and 20cm. Whereas the lower yield and yield attributes were recorded from 10cm inter-row spacing. fenugreek verities. The shortest days of 90% maturity (121 days), and the higher above-ground biomass (2849.67 Kg/ha^{-1}) were recorded from Wereilu fenugreek verities.

Interaction of row spacing with fenugreek varieties had significantly (P≤0.01) affected yield and yield component fenugreek crops. The shortest plant height(38.3cm), the higher primary branch (6.36), pod length (19.3), grain per pod (21.6), 1000g grain weight(20g), and grain yield (1586 Kg/ha^{-1}) were recorded from Burka variety planted with 40cm followed Chala variety whereas Wereilu and Ebbisa had moderate performance. The lower interaction result was recorded at planting of local fenugreek variety with 10cm inter-row spacing.

In general, this study provided evidence that the yield of fenugreek varieties could be increased by planting at optimum inter-row spacing. Among the fenugreek varieties, the Burka variety planted with 40 cm inter-row spacing is performing well and is recommended to the local farmer to increase the production of fenugreek crops.

List of Abbreviations

ANOVA	**Analysis of Variance**
CSA	**Central Statistical Agency**
DAP	**Diammonium phosphate**
LSD	**Least Significant Difference**
SARC	**Sirinka Agricultural Research Center**
SAS	**Statistical Analysis System**
th^{-1}	**tons per hectare**

Data Availability

The data used to support this study's findings are available and can be requested from the corresponding author.

Conflict of Interests

The authors have not declared any conflict of interest.

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Authors' Contributions

This work was carried out in collaboration with all authors. Author **Leta Abebe** is an M. Sc student who designed the study, performed the statistical analysis and wrote the first Thesis. Co-authors Dr. **Gizachew W/Senbet** and Ashenafi Mitiku are an advisor. For publication, the manuscript was written by Ashenafi Mitiku.

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تأثير التباعد بين الصفوف على نمو وإنتاجية أصناف الحلبة (.Trigonella foenum-graecum L) في منطقة ووليسو وريدا، وسط إثيوبيا

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ملخص

الحلبة (.Trigonella foenum-graecum L) هي محصول بقوليات يستخدم كتوابل وخضروات ونبات طبي. كانت التباعد بين الصفوف والأصناف من العوامل التي تؤثر على إنتاج محاصيل الحلبة في إثيوبيا. أجريت التجربة بهدف تقييم تأثير التباعد بين الصفوف لأصناف الحلبة مع تركيبتها على النمو والإنتاجية ومكون الإنتاج في منطقة ووليسو. أجريت تجربة ميدانية في كلية بوليتكنيك ووليسو خلال موسم الزراعة الرئيسي موسم الزراعة 2023 بتصميم RCBD مرتبًا في ترتيب عاملي ومكررًا ثلاث مرات. تم استخدام مسافات 10 سم و20 سم و30 و40 سم بين الصفوف وأربعة أصناف محسنة من الحلبة وهي برقا، تشالا، إيبسا، وويريلو، وصنف محلي للاختبار أثناء التجربة. تم تحليل البيانات المجمعة باستخدام برنامج SAS الإصدار 9.2. يُظهر التحليل الإحصائي أن أيام الإنبات بنسبة 50٪ لم تكن ذات دلالة إحصائية ($P \leq 0.05$) ولكن أيام الإزهار بنسبة 50٪، وأيام النضج بنسبة 90٪، وارتفاع الفرع الأساسي (6.36)، وارتفاع عدد قرون الحبوب -1 (21.6)، وارتفاع طول القرون، ووزن الحبوب 1000 جرام، والكتلة الحيوية فوق الأرض، وإنتاج الحبوب كانت ذات دلالة إحصائية عالية في التأثير الرئيسي وتفاعلهما ($P \leq 0.01$) . تم تسجيل أعلى عدد من الفروع الأولية (6.73) وعدد قرون الحبوب -1 (21.6) وطول القرون (19.3) ووزن الحبوب 1000 جرام (20 جرام) ومحصول الحبوب (1563.7 كجم هكتار -1) وأيام نضج 90٪ (117.9 يومًا) وفرع أولي أعلى (6.73) وعدد قرون الحبوب -1 (26.25) وطول القرون ووزن الحبوب 1000 جرام والكتلة الحيوية فوق الأرض (3568.33 كجم هكتار -1) ومحصول الحبوب وأيام الإزهار الأقصر بنسبة 50٪ (44.6 يومًا) من أصناف بوركا المتفاعلة مع 40 سم تليها أصناف تشالا وويريلو وإيبسا. في المقابل، تم تسجيل أقل محصول حبوب مع تفاعل 10 سم. من خلال البحث الحالي حول الغلة ومكون الغلة فإن زراعة صنف البركة بمسافة 40 سم بين الصفوف تؤدي بشكل جيد ويوصى بها للمزارع المحلي لزيادة غلة محصول الحلبة.

الكلمات الدالة: أصناف الحلبة، المسافة بين الصفوف، مكون الغلة، الغلة.

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