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Research article

Growth, yield and quality response of Eggplant (*Solanum melongena* L.) to blended NPSB fertilizer rates and intra-row spacing in Boloso Bombe district, Wolaita zone, South Ethiopia

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ABSTRACT

Eggplant is the most important fruit vegetable crop in many countries, including Ethiopia. In spite of this, its production is hindered by low nutrient availability in soil and suboptimal intra-row spacing. In order to address these issues, a field investigation took place in the Wolaita zone during 2022/23 growing season to evaluate the effects of various concentrations of blended NPSB fertilizer and intra-row spacing on the growth, yield, and quality of eggplants. Five various blended NPSB fertilizer rates (0, 50, 100, 150, and 200 kg ha^{-1}) and three intra-row spacing distances (30, 40, and 50 cm) were used in the investigation, which was designed as a randomized complete block with three replicates. Based on an analysis of variance, it was discovered that the main effects of NPSB fertilizer rates and intra-row spacing significantly ($p < 0.01$) affected many of parameters, including dry matter content, total soluble solids, fruit number, fruit length, and days to 50 % flowering. Additionally, the interaction effect between NPSB fertilizer and intra-row spacing significantly ($p < 0.05$) impacted the number of days to first fruit harvest, plant height, leaf area, branch number, leaf number, fruit diameter, fresh fruit yield, marketable fresh fruit yield, unmarketable fresh fruit yield, and total fresh fruit yield. According to the current investigation, the highest marketable fresh fruit yield (121.04 t ha^{-1}) was obtained by 150 kg ha^{-1} NPSB with 40 cm intra-row spacing. These findings suggest that 150 kg ha^{-1} of blended NPSB fertilizer with 40 cm distance between plant spacing is optimal for eggplant cultivation in the study area and analogous agro-ecological settings. This optimized approach can effectively support eggplant growers in maximizing both yield and quality outcomes.

1. Introduction

Eggplant (*Solanum melongena* L.) is a perennial herb with a short lifespan predominantly cultivated in warm-weather tropical and subtropical regions worldwide. It categorized under the Solanaceae family and is popular by various names in several countries, such as Brinjal in England, Baigan in India, and “Deberjan” in Ethiopia [1]. It is part of the genus Solanum, one of the largest genera, encompassing over 1550 species. The primary origin of eggplant is India, and it was introduced to southern Europe and the Mediterranean region by Arabic traders [2].

Regarding its nutritional value, eggplant is low in calories and is known to be among the healthiest fruit vegetable for its high levels

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of vitamins such as B6, K, and C, minerals including K, Mg, Na, P, Cu, Cr, Fe, Mn, Ni, and Zn, and its bioactive compounds that support human health [3,4]. For optimal growth, yield and fruit quality eggplant requires an annual rainfall range of 1000–1500 mm and grows best in an altitudes range of 0–1600 m above sea level [5]. Heavy rainfall disrupts both the growth of the plant and formation of flowers. The optimum temperature for pollen germination is 20–27 °C, but below 15 °C or above 30 °C, pollen is unable to germinate [6]. For healthy development, eggplant prefers deep, fertile sandy loam soils that are well-drained, have a pH of 5.5–6.8, and contain high organic content [7]. For this reason, it is highly responsive to blended NPSB fertilizer and their deficiency will inhibit growth, yield, quality and result in low production [8]. From those fertilizers, boron and sulfur are crucial for fruit development, flowering, and whole plant growth, in addition to aiding in water absorption and the metabolism of carbohydrates in plants [9].

Apart from nutrient management, the spacing plants are another crucial component that affects the production of a vegetable crop including eggplant. The ideal intra-row plant spacing for eggplant lies between 20 and 60 cm, depending on the cultivar and cultural practices [10–12]. Eggplant is a key crop globally and in India, often referred to as the king of vegetables. China dominates eggplant production with 35.5 million tons, followed by India at 12.7 million tons. African eggplant production totaled 2,087,592 tonnes [13], but clear data for Ethiopia is unavailable.

In fact, soil fertility depletion is among the significant challenges for agricultural output in many parts of Africa, including Ethiopia. The reliance on a limited range of fertilizers, such as urea and diammonium phosphate, which primarily provide nitrogen and phosphorus, contributes to this issue. These fertilizers do not supply the full spectrum of essential nutrients that crops require, which can lead to nutrient deficiencies and suboptimal crop yields. To address this issue, it is better to use balanced fertilization, which

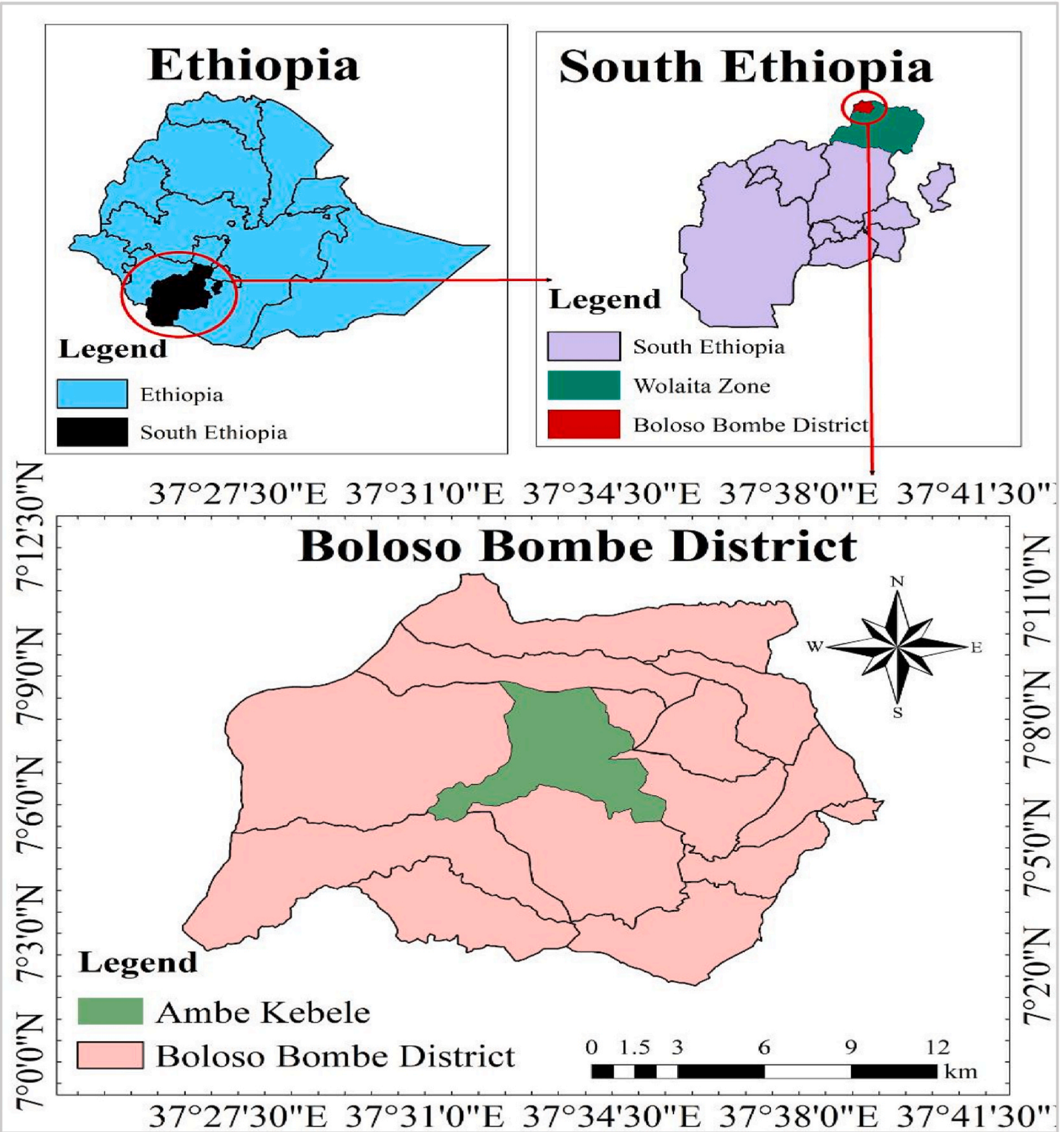

Fig. 1. Map of the study area.

includes both macro and micro nutrients such as nitrogen, phosphorus, potassium, sulfur, boron, and copper [14]. This can help ensure that crops receive all the necessary nutrients for their better growth, yield and quality, but they are lacking in Ethiopian soils [15].

According to data from the Ethiosis soil map, the study area exhibits a deficiency in NPSB fertilizer [16]. Despite this, local farmers are generally unaware of and do not utilize research recommendations, even for other Solanaceae crops such as tomatoes and potatoes. Additionally, in Ethiopia, few regions produce eggplant, and existing research has primarily focused on the biochemical composition and survey-based studies of this crop [1,17]. Notably, the study area is not traditionally known for eggplant production, and there is no recommended data on the optimal NPSB fertilizer rates or ideal intra-row spacing for this crop. Farmers typically use a blanket fertilizer recommendation (100 kg ha^{-1} Urea +150 kg ha^{-1} NPSB) or smaller amounts based on their economic capacity for Solanaceae crops. Moreover, plant spacing is a critical factor that requires area-specific recommendations to ensure optimal growth, yield, and quality. Therefore, this study was performed in the field and aimed to evaluate the impact of varying blended NPSB fertilizer rates and intra-row spacing on eggplant growth, yield, and quality.

2. Materials and methods

2.1. Overview of the study area

A field experiment was conducted at Bolosso Bombe district, Wolaita Zone, South Ethiopia.

The research site is situated at 7° 6′ 0″ North latitude and 37° 34′ 30″ East longitude, with an elevation of 1400 m.a.s.l (Fig. 1). This area gets 1500 mm of annual average rainfall, with mean lowest and maximum temperatures of 17 °C and 28 °C, respectively (Fig. 2). In the experimental area, the type of soil was clay loam and had a pH level 5.76.

2.2. Experimental materials, treatments, design, procedures and cultural practices

The eggplant variety black beauty seed was obtained from Melkasa agricultural research center and blended NPSB fertilizer was obtained from Boloso Bombe district with the ratios of N: P: S: B; 18.9, 37.7, 6.95, and 0.1 % per 100 kg, respectively, were used as fertilizer materials, along with 100 kg ha^{-1} urea fertilizer. Although, treatments were three distinct intra-row spacing (30, 40, and 50 cm) and five rates of blended NPSB fertilizer which are (0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1}, and 200 kg ha^{-1}) that give a total of 15 treatment combinations. These were set up in a randomized complete block design with three replications and factorial arrangement.

All field activities were done from November to March during 2022/23. The field was ploughed and leveled to achieve a smooth seedbed. A nursery bed of 3 m × 1 m was prepared to sow 200 g ha^{-1} of seed and sown on 10, November, 2022. Then the nursery beds was covered with mulch and watered for 5 weeks depending on temperature. The seedlings were thinned down to 5 cm spacing between plants after sowed 15 days, and other cultural practices such as mulching, shading, watering, pest control, and hardening were done at the nursery phase. The main experimental field was prepared well according to the treatments of the study with a size of the plot was 3 m by 3 m (9 m^2), had 5 rows, keeping 60 cm inter-row spacing, and included 10, 7, and 6 plants per row for 30, 40, and 50 cm intra-row spacing, respectively.

The experiment involved 45 plots in a total area of 583 m^2, with a spacing of 0.5 m spacing between plots and 1 m spacing between replications. Seedlings were transplanted to the main field after reaching 15 cm height and 4–7 leaves, 41 days after sowing, at their varying distances with fertilizer concentrations of 0 g, 45 g, 90 g, 135 g, and 180 g blended NPSB per plot. Urea was split and applied twice in each plot, except in control plots. Watering, fertilization, weeding, protection, and harvesting activities followed as recommended for the crop.

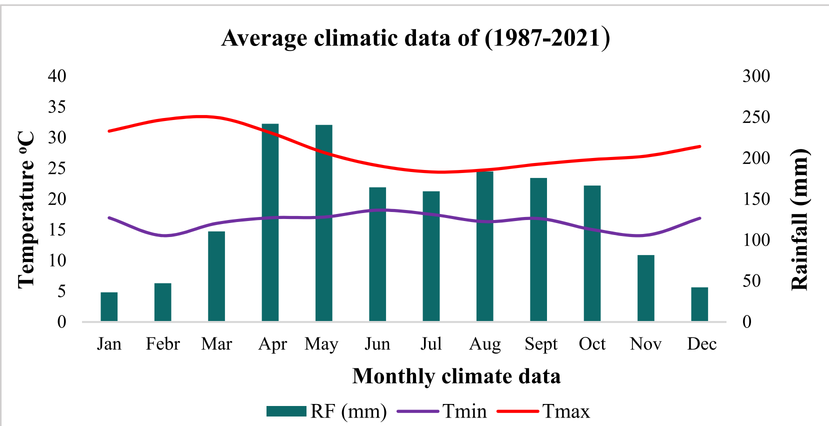

Fig. 2. Average monthly annual rainfall along with minimum and maximum temperatures (1987–2021).

2.3. Collection of data and measurements

2.3.1. Phenological parameters

Days to 50 % flowering: The days from transplanting to when 50 % of the plants began blooming were recorded, and this value was used for subsequent analysis. Days to first fruit harvest: The days from transplanting to the date of first fruit harvest was counted and these measurements were used for subsequent analysis.

2.3.2. Growth parameters

Plant height (cm): At final harvest, the plant height was measured with a meter from the soil surface to the maximum growing point of the above ground part, using ten plants chosen at random from the net plot. Number of branches per plant: At the final harvest, it was counted from the ten randomly selected plants in the net plot, and the recorded values used as a basis for further analysis. Leaves number per plant: The quantity of leaves per plant was recorded for ten randomly selected plants, and the average was used to calculate the average value.

Leaf area (cm^2): Using a ruler, measurements were taken from ten leaves gathered from ten randomly chosen plants, including those from the top, middle, and bottom of the net plot. Each leaf was measured for length and width, and the formula was used to determine the leaf area $LA = a + bLW$, where LA represents leaf area, L is leaf length, W is leaf width, and the coefficients a and b are 3.99 and 0.62, respectively [18].

2.3.3. Yield and associated parameters

The number of fruit per plant: The numbers of dark purple ripe fruit harvested from ten selected and tagged counts of plants in the net plot area were taken at each harvest and mean values were calculated. Fruit length (cm): This was measured by a veneer calliper from ten randomly chosen plant fruits in the net plot from the fruit tip to the pedicle tip during each harvest time, and mean values were calculated. Fruit diameter (cm): This was measured after harvesting fruits from ten plants selected randomly, and this was measured using a veneer calliper from the wider part of the fruit in the middle area of the fruit during each harvest time, and the average values were calculated.

Fresh Fruit Weight per Plant (kg): This was measured by weighing the fruits harvested from ten selected plants using a sensitive weighing balance, and mean values were computed. Unmarketable fresh fruit weight ($t\ ha^{-1}$): This is the yield that was derived by sorting the diseased, damaged, shrunken-shaped, and discolored fruits from marketable fruits at each harvest time from the net plot, and the recorded value was converted to $t\ ha^{-1}$. Marketable fresh fruit weight ($t\ ha^{-1}$): This was collected from the net plot at each harvesting time according to the color, shape, and size of the fruits, then the weight of the respective categories was recorded and adjusted to $t\ ha^{-1}$. Total fresh fruit weight ($t\ ha^{-1}$): The total weight of all fruits, including both marketable and unmarketable, harvested from the net plot at each subsequent harvest was measured and converted to tons per hectare.

2.3.4. Quality parameters

Dry matter content (%): Five fruit samples were randomly selected from five plants within the net plot, and the fresh fruit weight of each sample was noted. After that the fruits were chopped into bits, put in an oven, and dried for 72 h at 60 °C. The percentage of dry matter was measured using an electronic sensitive balance from the sample when the weight stabilized and calculated using [19].

$$\text{Percentage of dry matter} = \frac{\text{Dry weight of the sample}}{\text{Fresh weight of the sample}} * 100$$

Total soluble solids (TSS) (^{0}Brix); were determined by randomly selecting five fruit samples from five plants in the net plot. Juice was extracted from these samples, and three drops of the transparent juice were placed on the prism of a portable refractometer three times per sample. The mean value of these measurements was recorded and used for further analysis [20].

2.4. Statistical analysis

The analysis of variance was undertaken for the parameters following the standard statistical procedures using Statistix 8.0 version software. The least significant difference (LSD) test was applied at a 5 % significance level to distinguish between mean variations when the treatment effects were found to be significant.

3. Results

3.1. Phenological and growth parameters

3.1.1. Days to 50 % flowering

The ANOVA result revealed that both the main effect of blended NPSB fertilizer rates and intra-row spacing significantly ($p < 0.01$) influenced on the number of days required to reach 50 % flowering on eggplant. Even so, their interaction effects were non-significant (Table 6). From the recorded result, the longer duration to reach 50 % flowering (71.22 days) were obtained by 200 kg ha^{-1} NPSB fertilizer rate, In contrast, the earliest (44.00 days) were obtained by control plot. The study found that, with regard to plant spacing, 50 cm intra-row plant spacing was associated with the belated days to reach 50 % flowering (64.67 days) and 30 cm was associated with the earliest days (48.07 days) (Table 1).

3.1.2. Days to first fruit harvest

The results of the analysis of variance showed that the number of days to the first eggplant fruit harvest was significantly ($p < 0.01$) influenced by the interaction effects of blended NPSB fertilizer and intra-row plant spacing (Table 6). The delayed duration to first fruit harvest (89.33 days) were registered with the rate of 200 kg ha^{-1} NPSB fertilizer with 50 cm distance between plant spacing, while, earliest (74.00 days) was observed by the unfertilized plot with 30 cm intra-row plant spacing (Table 2).

3.1.3. Height of the plant (cm)

Regarding to the variance analysis, the result shows that the interaction effect of NPSB rates and intra-row spacing significantly ($p < 0.05$) influenced on the plant height of eggplant (Table 6). The investigation result revealed that using 200 kg ha^{-1} of blended NPSB fertilizer with 30 cm intra-row spacing resulted in the longest plant height (86.07 cm). While, the control plot with 50 cm produced the shortest plants (56.93 cm) (Fig. 3).

3.1.4. Branches number per plant

The results of the ANOVA indicated that the number of branches per plant was significantly ($p < 0.01$) impacted by the interaction between NPSB fertilizer and intra-row spacing (Table 6). When 200 kg ha^{-1} of blended NPSB fertilizer was applied with 50 cm intra-row spacing, the greatest number of branches per plant (19.37) was obtained. On the other hand, an unfertilized plot with 30 cm between plants spacing reported the lowest (8.10) (Table 2).

3.1.5. Number of leaves per plant

According to analysis of variance, the interaction effect of NPSB fertilizer and intra-row spacing had a significant ($p < 0.01$) effect on the number of leaf per plant on eggplant (Table 6). The maximum number of leaves per plant (125.27) was recorded with the application of 200 kg ha^{-1} blended NPSB fertilizer with 50 cm intra-row spacing. Conversely, the minimum number (51.17) was recorded by the narrower spaced 30 cm intra-row plant spacing with control plots (Table 3).

3.1.6. Leaf area (cm^2)

According to the variance analysis, both the main and interaction effects of blended NPSB rates and intra-row spacing had a significant ($p < 0.05$) effect on the leaf area of eggplant (Table 6). The analyzed result revealed that the application of 200 kg ha^{-1} blended NPSB fertilizer with 50 cm intra-row plant spacing revealed the broader leaf area (105.66 cm^2), While the narrower (35.07 cm^2) was recorded by control plot with 30 cm (Fig. 4).

3.2. Yield and yield related parameters

3.2.1. Number of fruits per plant

The main effects of NPSB fertilizer rates and intra-row spacing had a significant ($p< 0.001$) effect on the number of fruits per plant in eggplant, according to an analysis of variance. However (Table 6), shows that their interaction impact was not statistically significant. The control plots produced the lowest amount of fruits (7.14), while the 200 kg ha^{-1} blended NPSB fertilizer produced the highest mean fruit number (20.73) (Table 1). In terms of intra-row spacing, 50 cm generated the highest number of fruits (17.20), while 30 cm produced the lowest number of fruits (11.17) (Table 1).

Table 1
The main effect of NPSB fertilizer rates and intra-row plant spacing effect on phenology, growth and quality parameters of eggplant in study area.

Treatments	D 50 % F	NFPP	FL (cm)	DM C (%)	TSS (^{0}Brix)
NPSB fertilizer rates (kg ha^{-1})					
0	44.00^d	7.14^e	8.48^d	8.13^c	3.21^e
50	51.67^c	11.01^d	9.56^c	8.46^c	3.73^d
100	55.78^c	14.26^c	11.95^b	8.97^b	4.08^c
150	63.22^b	18.33^b	12.97^a	9.36^b	4.53^b
200	71.22^a	20.73^a	13.05^a	10.21^a	4.87^a
LSD (0.5)	4.44	1.92	0.95	0.47	0.05
Intra-row Spacing (cm)					
30	48.07^c	11.17^c	10.29^c	8.40^c	3.92^c
40	58.80^b	14.51^b	11.09^b	9.02^b	4.08^b
50	64.67^a	17.20^a	12.23^a	9.65^a	4.25^a
LSD (0.5)	3.44	1.48	0.73	0.37	0.04
CV	8.05	13.88	8.74	5.46	1.15

*Means that have similar letter (s) do not differ significantly at 5 % significance level; LSD (0.05) stands for Least Significant Difference at 5 % level; CV is for coefficient of variation. D 50 % F stands for days to 50 % flowering, FL is fruit length, NFPP is number of fruits per plant, DMC is dry matter content, and TSS stands for total soluble solids.

Table 2
The interaction influence of blended NPSB fertilizer rates and intra-row plant spacing on phenology and growth parameters of eggplant in study area.

	Days to first fruit harvest					Branches number per plant				
	NPSB rates (kg ha^{-1})					NPSB rates (kg ha^{-1})				
Spacing (cm)	0	50	100	150	200	0	50	100	150	200
30	74.00^{g}	74.67^{g}	77.00^{f}	78.67^{ef}	81.33^{cd}	8.10^{j}	8.80^{j}	9.87^{hi}	11.60^{g}	14.17^{de}
40	78.67^{ef}	78.67^{ef}	80.00^{de}	80.00^{de}	85.67^{b}	8.97^{ij}	12.70^{f}	13.93^{e}	15.63^{c}	16.07^{c}
50	79.33^{e}	83.00^{c}	85.00^{b}	86.67^{b}	89.33^{a}	10.83^{gh}	15.20^{cd}	15.90^{c}	17.20^{b}	19.37^{a}
LSD (0.05)	1.82					1.03				
CV (%)	1.34					4.69				

Whereas, means with similar letters are not differ significantly at the 5 % significance level; LSD (0.05) represents the least significant difference at this level; and CV stands for coefficient of variation.

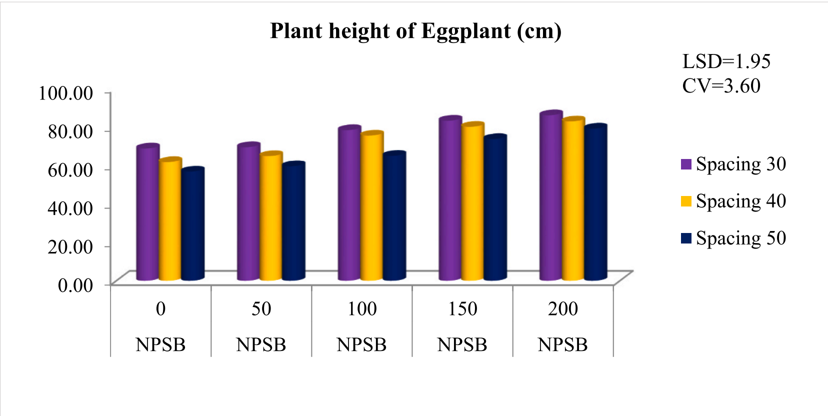

Fig. 3. Plant height of eggplant.

Table 3
The interaction effect of intra-row spacing and blended NPSB rates on eggplant growth and yield parameters in study area.

	Number of leaves per plant					Fresh fruit weight per plant (kg)				
	NPSB rates (kg ha^{-1})					NPSB rates (kg ha^{-1})				
Spacing (cm)	0	50	100	150	200	0	50	100	150	200
30	51.17^{i}	63.97^{gh}	70.13^{fg}	79.73^{de}	84.87^{cd}	1.35^{i}	2.14^{h}	3.57^{f}	4.08^{e}	4.55^{cd}
40	60.70^{h}	70.90^{fg}	92.23^{c}	102.07^{b}	117.07^{a}	2.66^{g}	2.70^{g}	3.61^{f}	4.42^{cde}	4.73^{c}
50	75.80^{ef}	84.13^{cde}	123.90^{a}	124.93^{a}	125.27^{a}	3.10^{g}	4.23^{de}	5.21^{b}	5.65^{ab}	5.91^{a}
LSD (0.05)	8.66					0.46				
CV (%)	5.85					7.08				

Whereas, means with identical letters do not differ significantly at 5 % significance level; LSD (0.05) represents Least Significant Difference at this level; and CV stands for coefficient of variation.

3.2.2. Fruit length (cm)

The ANOVA value indicated that the main effect of intra-row spacing and NPSB fertilizer has a significant ($p < 0.001$) influence on the fruit length of eggplant. However, the effect of their interaction was not significant (Table 6). The longest fruit length (13.05 cm) was obtained by blended NPSB fertilizer 200 kg ha^{-1}. Conversely, an unfertilized plot measured the shortest (8.48 cm) (Table 1).

Due to spacing, the longest fruit length of eggplant (12.23 cm) was recorded by 50 cm intra-row spacing, while, the shortest (10.29 cm) was observed by 30 cm plant spacing (Table 1).

3.2.3. Fruit diameter (cm)

According to the analysis of variance result, it revealed that there was a significant ($p < 0.05$) effect on the eggplant fruit diameter due to the main and interaction effects of blended NPSB rates and intra-row spacing (Table 6). The widest fruit diameter (11.37 cm) observed by the treatment combination of 200 kg ha^{-1} NPSB fertilizer rates and 50 cm intra-row plant spacing on eggplant. Conversely, the narrowest (3.10 cm) was derived by plants grown without the usage of NPSB fertilizer with 30 cm (Fig. 5).

3.2.4. Fruit fresh weight per plant (kg)

Analysis of variance result revealed that the fruit fresh weight per plant had significantly ($p < 0.01$) impacted by the interaction

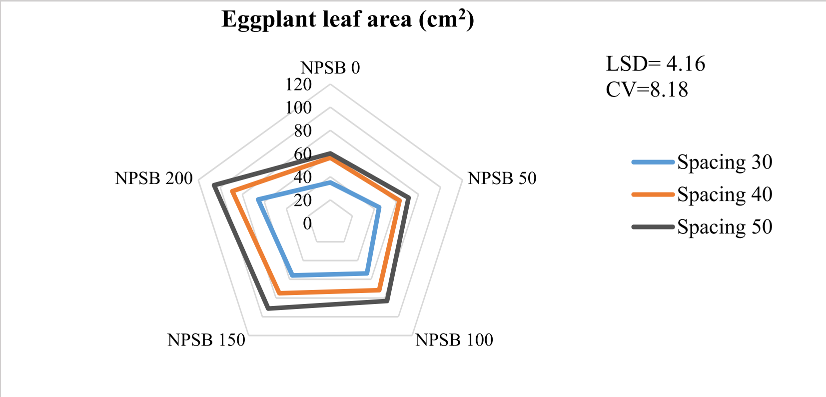

Fig. 4. Leaf area.

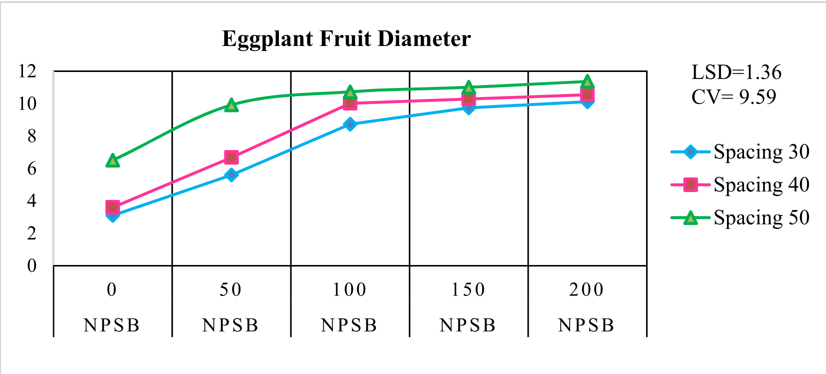

Fig. 5. Eggplant fruit diameter.

effect of intra-row spacing and NPSB fertilizer rates (Table 6). With 50 cm intra-row plant spacing and 200 kg ha^{-1} blended NPSB fertilizer, the maximum fresh fruit weights per plant (5.91 kg ha^{-1}) were observed. However, the minimum (1.35 kg ha^{-1}) were observed by plants grown without NPSB application with 30 cm spacing (Table 3).

3.2.5. Marketable fresh fruit yield (t ha^{-1})

The results of ANOVA reported that the marketable fresh fruit yield of eggplant had significantly ($p < 0.001$) impacted by the interaction effects of blended NPSB rates and intra-row plant spacing (Table 6). The maximum marketable fresh fruit yield (121.04 t ha^{-1}) of eggplant was registered by treatment combination of 150 kg ha^{-1} and plants spaced at 40 cm intra-row plant spacing. However, the minimum (24.43 t ha^{-1}) was registered by the plants grown without NPSB application and 30 cm plant spacing (Table 4).

3.2.6. Unmarketable fresh fruit yield (t ha^{-1})

According to the ANOVA result, the interaction effect of NPSB fertilizer rates and intra-row spacing significantly ($p < 0.05$) influenced on the unmarketable fresh fruit yield of eggplant (Table 6). The maximum unmarketable fresh fruit yield (49.77 t ha^{-1}) of

Table 4
The interaction effects of blended NPSB rates and intra-row plant spacing on yield parameters of eggplant in investigation area.

	Marketable fresh fruit yield (t ha^{-1})					Unmarketable fresh fruit yield (t ha^{-1})				
NPSB rates (kg ha^{-1})						NPSB rates (kg ha^{-1})				
Spacing (cm)	0	50	100	150	200	0	50	100	150	200
30	24.43^{m}	40.11^{kl}	49.91^{ij}	63.75^{gh}	58.19^{hi}	26.70^{b}	22.02^{c}	18.72^{d}	13.52^{e}	49.77^{a}
40	31.79^{lm}	68.24^{fg}	70.68^{fg}	121.04^{a}	97.86^{c}	19.52^{cd}	6.99^{f}	7.62^{f}	4.94^{f}	28.77^{b}
50	47.26^{jk}	74.80^{ef}	87.62^{d}	106.77^{b}	81.38^{df}	26.57^{b}	12.49^{e}	13.63^{e}	21.22^{cd}	48.53^{a}
LSD (0.05)	8.67					3.10				
CV (%)	7.59					8.53				

Whereas, means with the same lettering do not differ significantly at 5 % significance level; LSD (0.05) represents Least Significant Difference at this level; and CV stands for coefficient of variation.

eggplant was registered by 200 kg ha^{-1} NPSB with 30 cm plant spacing. Once more, the value of 200 kg ha^{-1} with a 50 cm intra-row spacing (48.53 t ha^{-1}) was statistically similar. However, eggplant plants grown at 150 kg ha^{-1} NPSB fertilizer rates with 40 cm reported the lowest (4.94 t ha^{-1}) (Table 4).

3.2.7. *Total fresh fruit yield (t ha^{-1})*

The results of the analysis of variance showed that the total fresh fruit yield of eggplant was significantly ($p < 0.01$) impacted by the interaction effects of blended NPSB fertilizer rates, and intra-row spacing (Table 6). The combination treatment of 200 kg ha^{-1} blended NPSB fertilizer rate with 50 cm intra-row spacing produced the maximum total fresh fruit yield (129.91 t ha^{-1}). This result was statistically similar to 200 kg ha^{-1} with 40 cm (126.63 t ha^{-1}), 150 kg ha^{-1} with 40 cm (125.98 t ha^{-1}), and 150 kg ha^{-1} with 50 cm (127.99 t ha^{-1}). Conversely, the lowest yields (51.13 t ha^{-1}) and (51.31 t ha^{-1}) were recorded by plants grown with zero NPSB application in 30 cm and 40 cm intra-row spacing, respectively (Table 5).

3.3. *Quality parameters*

3.3.1. *Dry matter content (%)*

The result of ANOVA showed that the dry matter content of eggplant was significantly ($p < 0.01$) impacted by the main effect of intra-row spacing and NPSB fertilizer rates. However, their interaction effects did not reach statistical significance (Table 6). The highest dry matter content of eggplant fruit (10.21 %) was recorded by 200 kg ha^{-1} blended NPSB fertilizer rates, however, the minimum (8.13 %) was obtained by control plot (Table 1).

Once more, the dry matter content of the eggplants was significantly impacted by plant spacing. From the analysis, the intra-row spaced at 50 cm had the highest dry matter content of eggplant fruit (9.65 %) while, the intra-row spaced at 30 cm had the lowest (8.40 %) (Table 1).

3.3.2. *Total soluble solids (^{0}Brix)*

The result of the ANOVA revealed that the total soluble solids of eggplant were significantly impacted ($p < 0.01$) by the main effect of NPSB rates and intra-row spacing, while, their interaction effect was not significant (Table 6). The highest TSS (4.87 ^{o}Brix) were recorded by 200 kg ha^{-1} blended NPSB fertilizer rates, whereas the lowest (3.21 ^{o}Brix) was observed in the control plot (Table 1).

Conversely, plant spacing has a great effect on TSS. The highest TSS (4.25 ^{o}Brix) was recorded by plant spaced at 50 cm, while the lowest (3.92 ^{o}Brix) was recorded by the plant spaced at 30 cm (Table 1).

4. Discussion

4.1. *Phenology parameters*

From phenological parameters, the delayed days to reach 50 % flowering were obtained by 200 kg ha^{-1} NPSB rate, because of the application of blended fertilizer in higher amount delayed reproductive growth by promoting the plants vegetative development. The finding agree with [20], who reported that the delayed days to reach 50 % flowering were by the higher amount of blended NPSBZn fertilizer applied plot compared to control plot. In terms of spacing, the delayed days were recorded by 50 cm plant spacing and the earliest by 30 cm, might be the closer spacing promotes rivalry for resources, such as; nutrients, water, and sunlight, which causes stress, for this reason eggplant flowered earlier to complete its life cycle in short period by lacking those important factors and wider spacing may promote luxury growth. This result was in line with [21], who noted that delayed days to reach 50 % flowering with broader spacing compared to narrower spacing.

The delayed days to first fruit harvest were observed by 200 kg ha^{-1} blended fertilizer with 50 cm plant spacing and the earliest by control plot with 30 cm, this because of nitrogen from the blend, and urea, with wider spacing, which aligned with late maturity. Those increase promoted longer vegetative growth, and secondary plant growth, but it prolonged the reproductive stage including fruit maturity. The finding was in line with [22,23], who noted delayed days to fruit maturity with higher NPSB application and wider intra-row spacing in their tomato and eggplant experiments.

Table 5
The interaction effect of blended NPSB rates and intra-row spacing on yield parameters of eggplant in study area.

Total fresh fruit yield (t ha^{-1})					
NPSB rates (kg ha^{-1})					
Spacing (cm)	0	50	100	150	200
30	51.13^{h}	62.13^{fg}	68.63^{ef}	77.27^{de}	107.96^{b}
40	51.31^{h}	75.23^{de}	78.30^{d}	125.98^{a}	126.63^{a}
50	73.83^{de}	87.30^{c}	101.25^{b}	127.99^{a}	129.91^{a}
LSD (0.05)	8.81				
CV (%)	5.85				

Whereas, the means that have the same lettering do not differ significantly at the 5 % significance level; LSD (0.05) represents Least Significant Difference at this level; and CV stands for coefficient of variation.

Table 6
Mean square value for the main and interaction effects of blended NPSB fertilizer rates and intra-row spacing on phonological, yield, yield related and quality parameters of eggplant.

Variables	Rep	NPSB	Intra-row spacing	NPSB[a]Int-r. S	Error	CV
Degree of freedom	2	4	2	8	28	
Days to 50 % flowering	28.29	1458.03[b]	213.76[c]	20.95[ns]	21.17	8.05
Days to first fruit harvest	2.47	86.97[c]	213.27[c]	4.1[b]	1.18	1.34
Plant height	2.76	709.22[c]	402.54[c]	10.97[ns]	6.80	3.60
Number of branches/plant	1.16	67.16[c]	101.77[c]	2.38[b]	0.39	4.69
Leaf area	26.31	1735.09[c]	3776.58[c]	37.24[ns]	30.97	8.18
Number of leaves/plant	40.55	3539.63[c]	5087.81[b]	195.37[b]	26.80	5.85
Number of fruits/plant	4.06	269.27[c]	136.74[c]	1.41[ns]	3.94	13.88
Fruit length	0.98	38.50[c]	14.18[c]	1.70[ns]	0.96	8.74
Fruit diameter	1.07	64.83[c]	18.74[b]	1.71[a]	0.67	9.59
MFFY	19.34	4834.39[c]	4959.75[c]	348.85[c]	26.86	7.59
UMFFY	0.25	1464.01[b]	790.12[b]	54.59[a]	3.45	8.53
FFYPP	0.22	11.63[b]	11.26[b]	0.27[b]	0.07	7.08
TFFY	22.23	5735.08[c]	3279.74[c]	336.14[b]	27.79	5.85
Dry matter content (%)	0.24	5.92[b]	5.88[b]	0.24[ns]	0.24	5.46
TSS (^{0}Brix)	0.03	3.85[c]	0.42[b]	0.014[ns]	0.002	1.15

Mean square value for the main and interaction influence of blended NPSB fertilizer and intra-row plant spacing on phonological, yield, and quality parameters on eggplant.
Whereas; MFFY = marketable fresh fruit yield, UMFFY = unmarketable fresh fruit yield, TFFY = total fresh fruit yield; TSS = total soluble solute; CV = coefficient of variation.
[a] implies significance level ($p \leq 0.05$)
[b] implies significance level ($p \leq 0.01$)
[c] implies significance level ($p \leq 0.001$)

4.2. Growth and yield parameters

The tallest height of plant were recorded by 200 kg ha^{-1} with 30 cm spacing this could be the increase of rate of fertilizer promotes plant growth and decreasing intra-row spacing lengthens internodes, which in turn causes a progressive increase in plant height. Once more, the result suggests that plants that are closer together and have higher blended NPSB fertilizer applications grow faster in competition for sunlight and air two items essential to plant growth. The results was agreed with [12,24–27], who reported that increase in blended NPSB fertilizer with narrow spacing significantly increased the height of the plant.

The maximum branches number were observed at 200 kg ha^{-1} blended NPSB fertilizer with 50 cm intra-row spacing which increased by 139.13 % as compared to control plot with the narrow spacing. This means the highest fertilizer rate with widest intra-row spacing have a great impact on the vegetative growth of eggplants because phosphorus fertilizer is essential for cell division activity, nitrogen enhanced growth and branch number, and sulfur and boron fertilizer are also essential for plant growth and physiological function. This result was in line with [26,28,29], who noted a rise in the distance between plants and blended NPSB fertilizer increased branch numbers per plant on tomatoes.

Similarly, the highest leave quantity was obtained by 200 kg ha^{-1} with 50 cm plant spacing. This could be because of the use of maximum fertilizer rates with wider distance between plant enhanced cell elongation and hence higher vegetative development in eggplant, which raised the number of leaves. This result was agreed with [27,30], who found that increasing the amount of NPSB fertilizer with intra-row plant spacing enhanced the number of leaves in eggplant. The broader leaf area were recorded by 200 kg ha^{-1} with 50 cm which may arise because of the plant increased absorption of food, less rivalry for sunlight, moisture, and other resources that promote better growth. This raises the meristematic activity of cells, increasing the quantity, length, and width of the plant's leaves. The result was corroborated with [31–33], who claimed that an increase in nitrogen, phosphorus, sulfur, and boron fertilizer with broader plant spacing increased leaf area in their tomato and eggplant field experiments.

The highest number of fruits per was observed at fertilizer rates of 200 kg ha^{-1}. This could be attributed to the readily available growth nutrients, which promoted the development of lateral branches and consequently increased the number of fruits per plant. Similar finding was agreed with [26,34], who noted that the higher quantity of fruits were observed by higher inorganic fertilizer applied plots on their tomato and hot pepper field experiment. Regarding to spacing, the highest fruit number was recorded by 50 cm intra-row spacing. This is because of wider spacing increased the whole vegetative growth on eggplant, because of less competition for nutrients and sunlight and hence the plant resulted in increasing the quantity of fruits. The finding in line with [10,33], who noted that the maximum fruit number recoded by the eggplant spaced at wider intra-row spacing.

According to fruit length the longest was obtained by 200 kg ha^{-1} fertilizer applied plot. However, the shortest recorded by un-fertilized plot. Less availability of growth resources or relatively low level of blended NPSB fertilizer rates resulted in reduced fruit length on eggplant and higher application would lead to plant growth, this might have enhanced the partitioning of assimilate among the many plant sections, which would increase the fruit length of eggplant. The results were consistent with [35], who reported that the uptake of the higher amount of inorganic fertilizer increased the fruit length. Due to spacing, the longest was recorded by wider intra-row spacing, while, the shortest narrower. This is due to the fact that narrower-spaced plants get over shaded and reduced in fruit length because of competition for resources including moisture, fertilizer, and radiation. Result agrees with [36], who noted that shortest fruit length was registered by closer plant spacing and the longest from the widest spacing.

The widest fruit diameter was obtained by 200 kg ha^{-1} NPSB fertilizer rates with that of 50 cm. Conversely though, the narrowest was recorded by control plot with 30 cm might be due to that increasing the rate of blended NPSB fertilizer with intra-row spacing significantly increased the fruit diameter of eggplants. This is because of there is less rivalry for nutrients and light with wider intra-row spacing and higher blended NPSB fertilizer rates. The result is in line with [5,36], who reported that the wider fruit diameter in their experiment increased by increasing the levels of fertilizer and plant spacing on eggplant.

The greatest fresh fruit weight per plant was achieved with 200 kg ha^{-1} blended NPSB fertilizer combined with an intra-row spacing of 50 cm. However, the lowest was observed by control plot with 30 cm spacing. Since eggplant has a higher nitrogen up-take efficiency compared to other plants, applying blended NPSB fertilizer to nutrient-deficient soil can significantly enhance its fruit production. Likewise, optimizing crop nutrient uptake with the appropriate macro and micronutrients can increase crop yield by improving nutrient use efficiency. Enhanced photosynthesis results in higher carbohydrate levels, which in turn increases the size and weight of eggplant fruits, leading to a boost in yield and yield attributes. This observation is consistent with [37,38], who reported that the highest fresh fruit weight were observed by treatments using highest inorganic fertilizer with wider spacing.

The maximum marketable fresh fruit yield of eggplant were registered by 150 kg ha^{-1} NPSB fertilizer rate with plants spaced at 40 cm. However, the lowest was obtained by the plants grown without NPSB application and 30 cm spacing. Moreover, there was increasing tendency of marketable fresh fruit yield with increasing plant spacing and rates of NPSB fertilizer up to 150 kg ha^{-1}. Generally, it was observed that marketable fresh fruit yield ranged from 24.43 t ha^{-1} up to 121.04 t ha^{-1} with a difference of 96.61 t ha^{-1} due to management effects. This revealed 395.46 % yield increment. This might be due to optimal rates of fertilizer and proper plant spacing increased healthy and attractive marketable fruit that are acceptable for the markets. This finding was in conformity with [39], who mentioned that the maximum marketable fruit yield from higher blended NPSB fertilizer application with broader intra-row spacing could be attributed to the enhanced fruit length, fruit width, and fruit quality.

The maximum unmarketable fresh fruit yield was obtained from 200 kg ha^{-1} blended NPSB fertilizer rate with 30 cm. Again, this result was statistically similar with a value of 200 kg ha^{-1} with 50 cm. In contrast, the lowest was observed by 150 kg ha^{-1} NPSB with 40 cm. The result suggests that the highest rates of fertilizer with the broadest and narrowest intra-row spacing increased the un-marketable fresh fruit yield on eggplant. This might be due to overdose use of fertilizer, and inappropriate plant spacing contributed significantly to unmarketable fresh fruit yield. Because there is a higher amount of disease transmission, succulent plant growth, and unwanted fruit development through narrow spacing, and with wide spacing, there is exposure to sun scald and discoloration. The result was in line with[34,36,40], who reported that in tomato and hot pepper field experiments, the ideal use of plant spacing and inorganic fertilizer gave the lowest unmarketable fruit.

The maximum total fresh fruit yield was registered with the application of 200 kg ha^{-1} blended NPSB fertilizer rate with 50 cm plant spacing that was statistically the same as 200 kg ha^{-1} with 40 cm. Conversely, the lowest were registered by control plot with 30 and 40 cm intra-row plant spacing. This might be a consequence of the use of fertilizer in higher rates and wider intra-row plant spacing enhanced cell elongation, hence, higher vegetative and reproductive developments in eggplant, which may be to blame for the rise in the total fresh fruit yield on eggplant fruit. This finding was agreed with [38,41], who reported that increasing the levels of inorganic fertilizers with wider intra-row plant spacing significantly raised the total fresh fruit yield of eggplant.

4.3. Quality parameters

From quality parameters, the highest dry matter content of eggplant fruit was observed with the application of200 kg ha^{-1} NPSB fertilizer rates. This may be related to nitrogen's effect on gibberellin production and other phyto-hormonal processes that directly affect plant development and the build-up of dry matter content. Eggplant fruit dry matter content was significantly affected by fruit maturity, growth character, plant nutrients, and water uptake. This result was agree with [30], who reported that the addition of blended NPSB fertilizer revealed an increase in whole quality measures, including dry matter content, compared to the control in their tomato and eggplant field investigation. Regarding to the spacing the competition between absorption of nutrients and water, which reduces the dry matter content of the eggplant. The finding aligned with [33], who reported that closer spacing led to in lowest dry matter content compared to wider spacing.

The highest total soluble solid was recorded by maximum fertilizer rates, while the lowest by control plot. This is due to the fact that total soluble solid is a measure of mineral nutrient levels in fruits and the value increased with the escalation of blended NPSB fertilizer rates. The evidence was agree with [42,43], who reported higher total soluble solid from the higher rate of blended fertilizer applied plot and the lowest from control plot. Similarly, in terms of spacing the highest total soluble solid was recorded by 50 cm, while the lowest by plant spaced at 30 cm intra-row plant spacing. This is because wider spacing enhances photosynthesis, leading to higher total soluble solid because of the starch degradation and the synthesis of glucose and fructose, enhancing the sugar content of the fruits. In this experiment, the plants were closely spaced, leading to fruit shading, which resulted in low respiration rates and reduced total soluble solids. The result is consistent with [44], who noted that increased total soluble solids with wider intra-row spacing in tomatoes.

5. Conclusion

Overall, this study highlights that eggplant responded positively to applying maximum blended NPSB fertilizer rates with wider intra-row plant spacing in terms of quality, yield, and growth parameters. Specifically, the maximum marketable fresh fruit yield of 121.04 t ha^{-1} was achieved through 150 kg ha^{-1} NPSB fertilizer rate with a 40 cm distance between plants, the highest unmarketable fresh fruit yield of 49.77 t ha^{-1} was obtained from blended NPSB fertilizer rate of 200 kg ha^{-1} with a 30 cm distance between plant spacing. These findings suggest that, applying a blended NPSB fertilizer rate of 150 kg ha^{-1} with a 40 cm intra-row spacing is optimal for eggplant cultivation in the investigation area and comparable agro-ecological settings. This optimized approach can effectively support eggplant growers in maximizing both yield and quality outcomes.

Consent to participation

Not applicable.

Consent to publication

The original research project's authors all agreed to share it with the public.

Data availability statement

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Yitbarek Abrham: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abrham Shumbulo:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Investigation.

Declaration of competing interest

The authors declared that they have no conflict of interest.

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References

[1] K. Asafew, B. Chandravanshi, Levels of major and trace metals in eggplant and soil, Bull. Chem. Soc. Ethiop. 35 (2) (2021) 243–255, https://doi.org/10.4314/bcse.v35i2.3.
[2] A.C. Zeaven, P.M. Zhukovsky. Dictionary of cultivated plants and their centre of diversity, Wageningen, Netherlands, 1975, p. 219. https://edepot.wur.nl/318076.
[3] T. Docimo, G. Francese, A. Ruggiero, G. Batelli, M. Palma, L. Bassolino, M. Tucci, Phenylpropanoids accumulation in eggplant fruit: characterization of biosynthetic genes and regulation by a MYB transcription factor, Front. Plant Sci. 12 (6) (2016) 1233, https://doi.org/10.3389/fpls.2015.01233.
[4] S. Yamaguchi, K. Matsumoto, M. Koyama, S. Tian, M. Watanabe, A. Takahashi, K. Miyatake, K. Nakamura, Antihypertensive effects of orally administered eggplant (*Solanum melongena* L) rich in acetylcholine on spontaneously hypertensive rats, Food Chem. 276 (2019) 376–382, https://doi.org/10.1016/j.foodchem.2018.10.017.
[5] J. Suge, Effect of Organic and Inorganic Fertilizer on Growth, Yield and Fruit Quality of Eggplant (*Solanum melongena* L) (Doctoral Dissertation, University of Eldoret), 2013. http://41.89.164.27:8080/xmlui/handle/123456789/851.
[6] G. Kowalska, Flowering biology of eggplant and procedures intensifying fruit set–review, Acta Scientiarum Polonorum Hortorum Cultus 7 (4) (2008) 63–76 [google scholar].
[7] N. Chen, T. Kalb, N. Talekar, J. Wang, C. Ma, Suggested Cultural Practices for Eggplant (No. AVRDC Extension Publication), AVRDC-The World Vegetable Center, 2002 [google scholar].
[8] K. Sanni, T. Okeowo, Growth, yield performance and cost benefit of eggplant (*Solanum melogena* L) production using goat and pig manure in ikorodu, Int. J. Sci. Res. Environ. Sci. 3 (4) (2016) 22–26 [google scholar].
[9] A. Pandav, M. Nalla, T. Aslam, M. Rana, J. Bommesh, Effect of foliar application of micronutrients on growth and yield parameters in Eggplant HLB 12, Significance 1 (1.63) (2016) 1–55 [google scholar].
[10] M. Degri, The effect of spacing of eggplant (*Solanum melongena* L.)(Solanaceae) on shoot and fruit borer (*Leucinodes orbonalis* Guen) Lepidoptera: Pyralidae infestation in the dry savanna zone of Nigeria, Agric. Biol. J. N. Am. 5 (1) (2014) 10–14 [google scholar].
[11] MoEA. Ministry of Ethiopian Agriculture, Fruits and Vegetable Crops Production, 2014 0851996051.
[12] F. Hassan, Y. Eisa, A. Adlan, Effect of intra-row spacing on growth and yield of two eggplant (*Solanum melongena* L.) cultivars under Blue Nile State, Sudan, Interaction 1 (0.37) (2018). http://www.netjournals.org/pdf/NJAS/2018/2/18-013.pdf.
[13] FAOSTAT Production Databases. Italy Rome, 2020 (0851996051), [google scholar].
[14] M. Toor, M. Adnan, F. Rehman, R. Tahir, M. Saeed, A. Khan, V. Pareek, Nutrients and their importance in agriculture crop production, A review, Ind. J. Pure App. Biosci 9 (1) (2021) 1–6, https://doi.org/10.18782/2582-2845.8527.
[15] Ethio S.I.S., Soil fertility status and fertilizer recommendation atlas for Tigray regional state, Ethiopia, Ethio SIS, Addis Ababa (2014). https://www.ata.gov.et/download/soil-fertility-status-fertilizer-recommendation-atlas-tigray-regional-state_jul2014/. Accessed May 11, 2022.
[16] S.I.S. Ethio, Ethiopian Soil Information Systems), Fertilizer Recommendation for Southern Nations, Nationalities, and Peoples' Regional State (SNNPRS), 2016..

[17] O. Eletta, B. orimolade, O. Oluwaniyi, O. Dosumu, Evaluation of proximate and antioxidant activities of Ethiopian eggplant (*Solanum aethiopicum* L) and Gboma Eggplant (*Solanum macrocarpon* L), J. Appl. Sci. Environ. Manag. 21 (5) (2017) 967–972, https://doi.org/10.4314/jasem.v21i5.25.

[18] C. Karaca, D. Büyüktaş, S. Şehir, Determination of leaf area of some vegetable plants grown under greenhouse condition by non-destructive methods, Horticultural Studies 38 (1) (2020) 23–28, https://doi.org/10.16882/hortis.841745.

[19] N. Ahmed, M. Mehdi, R. Narajan, Genetics of quality traits in eggplant (*Solanum melongena* L), Capsicum and Eggplant Newsletter 19 (2000) 123–126 [google scholar].

[20] T. Tsedu, W. Gelgelo, M. Wassu, G. Amsalu, Effect of blended Npsbzn fertilizer rates on growth and quality of tomatoes (*Solanum lycopersicum* L) varieties at Hawassa, southern Ethiopia, Journal of Agricultural Research Pesticides and Biofertilizers 1 (3) (2021) http;//doi.org/05.2021/1.1011.

[21] T. Temesgen, M. Getachew, Effect of blended fertilizer rates and planting density on yield and yield components of Irish potato (*Solanum tuberosum* L.) at Gombora condition, Hadiya zone, Southern Ethiopia, Heliyon 9 (7) (2023) e17450, https://doi.org/10.1016/j.heliyon.2023.e17450.

[22] S. Yeboah, J. Berchie, H. Asumadu, K. Agyeman, P. Acheampong, Influenced of inorganic fertilizer products on the growth and yield of tomatoes (*Lycopersicon esculentum* Mill), Journal of Experimental Biology and Agricultural Sciences 1 (7) (2014) 499–506. Special Issue, http://www.jebas.org/15012014/Yeboah%20et%20al%20JEBAS.pdf.

[23] M. Islam, S. Satyaranjan, H. Akand, A. Rahim, Effect of spacing on the growth and yield of sweet pepper (*Capsicum annuum* L.), J. Cent. Eur. Agric. 12 (12) (2011), https://doi.org/10.5513/jcea.v12i2.970, 328-325.

[24] A. Adekiya, T. Agbede, Growth and yield of tomato (*Lycopersicon esculentum* Mill) as influenced by poultry manure and NPK fertilizer, J. Food. Agric. (2009) 10–20, https://doi.org/10.9755/ejfa.v21i1.5154.

[25] Y. Guade, Effect of intra-row spacing on growth and development of tomato (*Solanum lycopersicum* L.) variety roma-VF under the irrigated conditions of East gojjam zone, Ethiopia, Am.-Eurasian J. Agric. Environ. Sci. 17 (2017) 174–178, https://doi.org/10.5829/idosi.aejaes.2017.174.178.

[26] D. Gezu, B. Gebisa, J. Mohammed, T. Fikadu, B. Habte, Effects of intra-row spacing and N fertilizer rates on yield and yield components of tomato (*Lycopersicon esculentum* L.) at Harawe, Eastern Ethiopia, J. Plant Sci. 7 (1) (2019) 8–12, https://doi.org/10.11648/j.jps.20190701.12.

[27] M. Rashid, Effect of Sulphur and Boron Fertilizer on the Growth and Yield of Bari Tomato-2 (*Lycopersicon Esculentum*), 2021, pp. 1–51 [google scholar].

[28] M. Zirak, H. Ganjali, A. Mehraban, Effect of row distance and variety on number of branch per plant, plant height, harvest index and seed yield in eggplant, Research Trend, Biological Forum 2 (7) (2015) 719–721 [google scholar].

[29] G. Ejigu, T. Solomon, Effect of NPS fertilizer rate and intra row spacing on growth and yield of common bean (*Phaseolus vulgaris* L.) at Metu, South western Ethiopia, Int. J. Agric. Innov. Res 10 (2) (2021) 47–70 [google scholar].

[30] B. Asefa, W. Fayera, W. Tufa, D. Hunduma, Influences of NPSB and Vermicompost application rates on yields of tomato (*Lycopersicon esculentum* Mill) at Jimma Ganati research site of Wallaga University, western Ethiopia, Advances in Agriculture (2023) 9, https://doi.org/10.1155/2023/4599133.

[31] A. Muhammad, U. Shahid, I. Ahmadi, B. Zainubi, K. Shah, Effect of biofertilizer and plant spacing on growth, yield and fruit quality of brinjal (*Solanum melongena* L.), J. Nat. Sci. Res. 7 (19) (2017) 56–62 [google scholar].

[32] C. Iwuagwu, D. Okeke, F. Onejeme, D. Iheaturu, A. Nwogbaga, M. Salaudeen, Effect of plant spacing on yield and disease assessment on two varieties of eggplant (*solanum melongena* L.) in awka, East. African, Scholars. J. Agric. Life Sci 2 (2019) 281–288 [google scholar].

[33] R. Abou Al-Azm, A. Gad, H. Zyada, H. Ismail, Growth and productivity of some eggplant cultivars as affected by different plant spacing, Plant Prod. Sci. (1) (2021) 1357–1371, https://doi.org/10.21608/zjar.2021.224599.

[34] M. Awoke, M. Wassu, K. Woldetsadik, Effect of blended NPS fertilizer rates on dry fruit yield and yield components of pepper (*Capsicum annuum* L.) varieties at Arba Minch, southern Ethiopia, Adv. Biochem. 9 (3) (2021) 74–81. https://doi:10.11648/j.ab.20210903.16.

[35] A. Gezahegn, G. Sintayehu, D. Dereje, Response of hot pepper (*Capsicum annuum* L.*)* as affected by NP fertilizer and planting method on yield and yield related traits in West Hararghe zone, Eastern Ethiopia, Am. J. Biosci. 8 (4) (2020) 113–122, https://doi.org/10.11648/j.ajbio.20200804.13.

[36] G. Amare, H. Gebremedhin, Effect of plant spacing on yield and yield components of tomato (Solanum lycopersicum L.) in Shewarobit, Central Ethiopia, Scientifica 2020 (1) (2020) 8357237. https://doi.org/10.1155/2020/8357237.

[37] M. Hintsa, B. Fantay, G. Atsbaha, M. Kassa, Evaluation of NPS fertilizer on yield and economic performance of new variety of hot pepper (*Capsicaim annum*) in Tanqua Abergelle, Central Tigray, Ethiopia, Int. J. Life Sci. 7 (2) (2019) 181–186. http://oaji.net/articles/2019/736-1561402234.pdf.

[38] M. Ndagana, Effect of plant spacing on growth and yield components of African eggplant (*solanum macrocarpon*) in the Northern Guinea Savannah of Nigeria, Niger. Agric. J. 51 (2) (2020) 233–236 [google scholar].

[39] G. Leghari, F. Oad, The effect of nitrogen fertilizer regimes on the growth and yield of pepper, Indus Journal of Plant Sciences 4 (3) (2005) 386–390 [google scholar].

[40] N. Fufa, G. Abera, Effects of blended fertilizer types and rates on fruit yield and nutrient use efficiencies of hot pepper (*Capsicum annuum* L.) at Asossa, Western Ethiopia, Afr. J. Agric. Res. 14 (33) (2019) 1737–1748, https://doi.org/10.5897/AJAR2019.14193.

[41] M. Aminifard, H. Aroiee, H. Fatemi, A. Ameri, S. Karimpour, Responses of eggplant (*Solanum melongena* L.) to different rates of nitrogen under field Conditions, J. Cent. Eur. Agric. 4 (11) (2010) 453–458 [google scholar].

[42] I. Erdal, A. Ertek, U. Senyigit, M. Koyuncu, Combined effects of irrigation and nitrogen on some quality parameters of processing tomato, World J. Agric. Sci. 3 (2007) 57–62. http://www.idosi.org/wjas/wjas.htm.

[43] M. Imtiaz, A. Rashid, P. Khan, M. Memon, M. Aslam, The role of micronutrients in crop production and human health, Pakistani Journal of Botany 42 (4) (2010) 2565–2578. http://www.pakbs.org/pjbot/PDFs/42(4)/PJB42(4)2565.pdf.

[44] A. Ashenafi, D. Kefale, Effect of intra-row spacing on plant growth, yield and quality of tomato (*Lycopersicon esculentum* Mill) varieties at Mizan-Aman, Southwestern Ethiopia, Int. J. Agr. Ext. 8 (1) (2020) 33–42, https://doi.org/10.33687/ijae.008.01.3093.