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Response of plant spacing on the morphology and yield of five hot pepper lines

Boateng E.[1], Adjei E. A.[2*], Osei M. K.[2], Offei K. O.[2] and Olympio N. S.[3]

[1]Grains and Legumes Development Board, P. O. Box 4000, Kumasi, Ghana.
[2]CSIR-Crops Research Institute, Kumasi, Ghana.
[3]Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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This study aimed to determine the effects of plant spacing on some morphological traits and yields of 5 hot pepper lines. The trial was laid out in a 5 × 3 factorial in randomized complete block design with 4 replications. Five pepper lines (ICPN16#3, ICPN16#4, ICPN16#6, ICPN16#7, and ICPN16#9) and 3 plant spacing (70 cm × 30 cm, 70 cm × 40 cm and 70 cm × 50 cm) were used. The results revealed that the closer plant spacing of 70 cm × 30 cm produced tall plants with ICPN16#4 line being the tallest. In addition, line ICPN16#4 produced narrow canopy with more branches, whilst ICPN16#9 (a short line) produced more branches with medium spread canopy. Plant spacing of 70 cm × 50 cm resulted in more spread canopy and number of branches. Closer spacing gave higher fruit yield compared to wider spacing. However, wider spacing gave the largest fruit size.

Key words: Lines, spacing, canopy, plant height, branch, and interaction.

INTRODUCTION

Hot pepper (*Capsicum frutescens* L.) is an important vegetable used in preparing dishes in almost every Ghanaian household. It is cultivated in all the agro-climatic zones either under irrigation or rain-fed. Hot pepper is among the 4 widely cultivated vegetables in Ghana (Schippers, 2000) where it is widely grown primarily for its fruits and seeds (Norman, 1992).

It is widely produced in Ghana for local consumption but has been increasingly exported to the European market. Ghana is the 5th largest exporter of chili peppers to the European Union and exports increased about 60% from 2005 to 2007 (MiDA, 2010). This trend of export has resulted in the cultivation of the crop as a main commercial / income activity for some households. Some export companies have out growers who are contracted to produce the crop to meet international standards.

In the development of new lines, the plant's architecture is vital in the determination of the spacing which has a direct effect on yield per unit area. As plant population increases per unit area, a point is reached where there is competition for essential growth factors such as nutrients, sunlight and water. However, an increase in plant density does not affect the performance of individual plants when the plant density stays below

*Corresponding author. E-mail: adjei_asamoah@yahoo.com.

the level at which competition occurs between plants (Acheampong, 2007).

It is important to consider spacing because of its effects on crop growth, development and yield. Spacing of crops varies with the plant, environment and cultural factors. Plants are spaced to achieve optimum desired population per unit area. The optimum plant population produces the greatest net return to the grower. Plant density has direct influence on yield and quality of fruits and seeds (Norman, 1992). Spacing has direct effects on the quantity, varietal purity and the quality of seed. Wider spacing permits easier entry of pathogens that can cause severe damage in fruits and seeds resulting in low yield and poor quality seeds (Williams et al., 1991).

Closer spacing creates a more humid environment that can favour the development of pathogens whose effects can be detrimental to the production of quality seed. High plant density leads to dense leaf canopy resulting to poor light penetration and aeration at the lower parts of the plant (Pedigo, 1996), and poor pollination by insects, seed deterioration, fruit shedding and incomplete seed development.

Wider spacing leads to increased competition between plants and weeds for the essential growth factors and in such situation, plants usually suffer. Wider spacing promotes the production of numerous lateral branches which delays flowering, and seeds do not mature uniformly (Van Gastel et al., 1996). An increase in plant density does not affect the performance of individual plants while the plant density stays below the level at which competition occurs between plants (Acheampong, 2007). This study compared the effect of different plant spacing on the vegetative growth and yield of 5 hot pepper lines.

MATERIALS AND METHODS

The experiment was arranged in a 5 × 3 factorial randomized complete block design (RCBD) with 4 replications. There were 5 different pepper lines (ICPN16#3, ICPN16#4, ICPN16#6, ICPN16#7 and ICPN16#9), and 3 different spacing's (70 cm × 30 cm, 70 cm × 40 cm and 70 cm × 50 cm) resulting in 15 treatment combinations. The treatments were randomly assigned to the plots in each block.

A plot size of 52.5 m × 11.4 m was used for the experiment, and this was sub-divided into 4 blocks. Each block was further divided into 15 plots, each measuring 3.0 m × 2.1 m. Data were collected on plant height, canopy spread, and number of branches, fruit yield and thousand seed yield. Plant height was taken at 2nd, 4th and 8th weeks after transplanting using a meter rule.

The measurements were taken from the soil level to the apex of the plant. Weekly mean figures of 10 plants were taken per plot. Canopy spread was taken at 2 perpendicular distances across the widest positions and the mean figures recorded. The total number of branches on tagged plants from each plot was counted and the mean figures calculated.

The total number of branches on the tagged plants from each plot was counted at the 4th and 8th weeks after transplanting and the mean figures were calculated and recorded. Fruit weight was determined by weighing ten randomly harvested fruits from the tagged plants in each plot using a sensitive electronic scale and dividing the weight by ten.

The extracted seeds from ten fruits in each plot were dried under sun for three days, and the weight of 100 seeds were determined using an electronic balance. The weight for each 100 seeds was multiplied by 10 for 1000-seed weight. Fruit yield data was obtained after the number of fruits harvested from sampled plants was counted for each plot using the formula:

$$Yf = P \times F \times Wf$$

Where:

Yf = fruit yield
P = number of plants per hectare
F = number of fruits per plant
Wf = mean weight per fruit (Source: AVRDC (1990)).

Data were analysed using Analysis of Variance (ANOVA). Differences among treatments were separated by least significant difference (LSD) at 5% level of significance for interpretation of results. The GENSTAT computer package version 9.1 was used for data analysis.

RESULTS AND DISCUSSION

Plant height of five promising pepper lines (2, 4 and 8 WAT)

The effects of variety and spacing on plant height (PH) at 2 weeks after transplanting (WAT) indicated that ICPN16#4 line was significantly ($P < 0.05$) taller than the other lines (Table 1). Mean plant height of ICPN16#4 line was 42.6 cm. Significant differences ($P < 0.05$) were observed on plant height at 4 WAT among the lines (Table 1). Line ICPN16#4 was significantly ($P<0.05$) taller than ICPN16#9 but with no difference from the other lines.

Spacing results did not show any significant differences among the lines with respect to plant height at 4 WAT. The interaction effect was significantly ($P<0.05$) different. For instance, 70 cm × 40 cm spacing gave the tallest plants when interacted with ICPN16#4 and ICPN16#3 lines, and produced the shortest plants when interacted with ICPN16#9 line.

Significant differences ($P<0.05$) in plant height occurred among the lines at 8 WAT (Table 1). Line ICPN16#4 produced significantly taller plants than ICPN16#7 and ICPN16#9 lines but it was similar to ICPN16#3 and ICPN16#6 lines, whereas spacing did not affect ($P>0.05$) plant height at 8 WAT.

Plant height as an important component helps in determining the growth during the growing period. It also helps to differentiate varieties and shows a variety's ability to withstand lodging. Taller plants tend to succumb to lodging at fruiting than shorter plants. Line and spacing combinations that produced the tallest (44.4 cm) and shortest (32.5 cm) plants were ICPN16#4 combined with 70 cm × 30 cm and ICPN16#9 combined with 70 cm × 50 cm, respectively. There were variations in plant heights among the lines and these could be attributed to the

Table 1. Effect of spacing on plant height (cm) at 2, 4 and 8 WAT of selected Hot Pepper lines.

Line	Spacing (cm²)											
	70 × 30			70 × 40			70 × 50			Line mean		
	2 WAT	4 WAT	8 WAT	2 WAT	4 WAT	8 WAT	2 WAT	4 WAT	8 WAT	2 WAT	4 WAT	8 WAT
ICPN16#3	39.1	48.2	68	43.9	52.3	75.6	35.8	43.1	60.9	39.6	48	68.3
ICPN16#4	44.4	51.8	69.5	42.9	52.8	71.6	40.8	51.8	72.1	42.7	52	71.1
ICPN16#6	40.6	50.5	67.3	35.5	45.7	62.7	36.8	50	65.7	37.6	48.7	65.2
ICPN16#7	40.1	47.7	61.9	40.1	45.2	55.8	43.9	52.3	68.3	41.4	48.5	61.9
ICPN16#9	33.5	40.6	58.9	32.7	41.4	61.2	32.5	40.6	55.8	32.9	40.8	58.6
Spacing mean	39.5	53.3	60.7	48.4	52.8	60.1	38.1	58.6	66	-	-	

2WAT: CV (%) 15.28, LSD= line 4.8, Spacing=3.5, line by spacing=8.3; 4WAT: CV(%) 14.88, LSD= line 5.8, Spacing= 4.3, line by Spacing=9.9; 8WAT: CV(%) 13.93, LSD= line 7.3, Spacing= 5.5, line by Spacing=12.9.

differences in their genetic make-up.

The height of the plant may influence fruit position with respect to the ground (Decoteau and Graham, 1994). For instance, tall tomato plants that produce more vegetative growth had reduced incidence of sunburned fruits (Eivazi et al., 2013). The heights recorded by all the lines at 8th week (Table 1) were below 1 m and this is desirable because taller plants could lodge easily resulting in mechanical damage. However, in situations where taller trait is desired like prevention of disease infection through water splashing unto the fruits, breeding programs could use the tall lines.

Abuzar et al. (2011) indicated that as in-row plant spacing decreased, plant height increased. Islam et al. (2011) also noted that the effect of plant spacing was found to be significant on plant height at different growth stages. It was also found that the narrowest spacing produced taller plant at all growth stages compared to other wider spacing. The obtained results showed similar trend as the closest spacing gave the tallest plants throughout the assessment. This is because with closer spacing, there are a greater number of plants per unit area competing for available sunlight, nutrients and water.

The combined effects of ICPN16#4 and all the spacing levels produced the tallest plant height and this can be attributed to their inherent genetic trait. Management of nutrients, water supply and pruning should be looked at critically at this level to prepare the plant for the reproductive phase. Genetic makeup in the lines regarding maturity period could also result in significant differences in plant height (Casini, 2012).

Line ICPN16#9 was consistently shorter and could be an early maturing line. Harvesting of shorter pepper varieties bring about high cost as labourers complain of waste pains as a result of bending too low to pick the fruits. The selection of lines for commercial production will have to look at the height of the plant as tall varieties which are preferred in areas where manual harvesting is the predominant management.

Canopy spread of five hot pepper lines (4 and 8 WAT)

The interaction effect between line and spacing was significant (P<0.05). Line ICPN16#7 spaced at 70 cm × 50 cm produced the widest canopy spread (69.0 cm). This is attributed to less competition for nutrients, water and sunlight, thereby making concentration of energy to the spreading canopy (Naik et al., 1992).

The canopy spread will help to reduce weed growth which is a limiting factor for both growth and yield in wider spacing. At 8 WAT, canopy spread showed significant (P < 0.05) differences between lines ICPN16#6 and ICPN16#7. Line ICPN16#7 was wider than ICPN16#6. Interaction effect between line and spacing was also significant at 8 WAT (Table 2). The canopy variation may determine the yielding potential of the crop, since lines with wider canopy could produce more fruits than lines with narrow canopy due to increased number of secondary and tertiary branches which are the locations for fruit bud formation (Delelegn, 2011).

The widest spacing 70 cm × 50 cm gave the widest spread because the plants had the opportunity of utilizing abundant supply of essential growth factors (AVRDC, 1990). The closer the plants to each other, the more they

Table 2. Effect of Spacing Canopy Spread (cm) at 4 and 8 WAT of selected Hot Pepper lines.

Line	Spacing(cm)							
	70 × 30		70 × 40		70 ×50		Line Mean	
	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
ICPN16#3	54.8	61.4	61.2	69.3	61.2	65.2	59.1	65.2
ICPN16#4	51.8	58.6	47.2	54.1	49.2	60.1	49.5	57.6
ICPN16#6	50.5	55.8	44.1	52.8	55.3	64.2	50.0	57.6
ICPN16#7	56.3	64.7	52.8	58.6	69.0	74.6	59.4	66.0
ICPN16#9	53.0	63.2	58.4	66.2	58.4	66.0	56.6	65.2
Spacing mean	53.3	60.7	52.8	60.1	58.6	66	-	-

4WAT: CV(%) 16.06, LSD= line 7.1, Spacing= 5.5, line by Spacing=12.4; 8WAT: CV(%) 16.98, LSD= line 8.6, Spacing= 6.6, line by Spacing=14.9.

shade each other resulting in lesser effective leaf area exposed to sunlight. The combined effects of ICPN16#7 and 70 cm × 50 cm gave the widest canopy spread. These findings are in accordance with those of Lima et al. (2003) who reported that an ideal population density is necessary for optimized leaf index, so that the maximum useful radiation for photosynthesis would be intercepted (Tables 1 and 2).

Number of branches of five hot pepper lines (4 and 8 WAT)

Spacing did not affect the number of branches produced by the lines (Table 3). At 4 WAT, the interaction between line and spacing was significant ($P < 0.05$) as shown in Table 3. Line ICPN16#3 at 70 cm × 40 cm spacing produced the highest number of branches of 27.8, whilst ICPN16#7 at 70 cm × 40 cm gave the least number of 16.2. The highest and lowest numbers of branches were produced by ICPN16#9 and ICPN16#6, respectively (Table 3). The highest number of branches (36.5) produced by ICPN16#9 did not differ significantly ($P>0.05$) from that of ICPN16#7 (36.3). The number of branches produced by ICPN16#3 and ICPN16#4 were not significantly different.

The interaction between variety and spacing at 8 WAT was significant as shown in Table 3. Line ICPN16#7 plants spaced at 70 cm × 50 cm gave the highest number of branches, whilst ICPN16#6 at 70 cm × 40 cm spacing gave the least number of branches. Islam et al. (2011) observed similar results where maximum average number of branches per plant was recorded from plants of the widest spacing. The wide spacing promotes the production of numerous lateral branches which delays flowering resulting in a uniform maturity (Van Gastel et al., 1996). Generally, the widest spacing was consistent in producing more branches.

The observed differences in branching of pepper plants might have been due to genetic variations among the lines. Thus, branch formation could be line dependent, and this could be the reason why ICPN16#9 and ICPN16#7 produced more branches at 8 WAT. The other lines varied in number of branches which is an indication of their genetic differences. Line ICPN16#6 recorded the least number of branches 8 WAT (Table 3) probably because it was genetically developed to produce fewer branches. The increase in number of branches per plant under medium and wider spacing noticed in this study was mainly attributed to its better improvement in plant growth and development (Anilkumar, 2004) due to less competition for nutrients, space, light and moisture.

Fruit yield per hectare

Significant yield differences were recorded among the lines as shown in Table 4. The obtained yield from line ICPN16#4 (10.2 t/ha) was significantly ($P<0.05$) higher than the yields produced by ICPN16#6 and ICPN16#3 but similar to lines ICPN16#7 and ICPN16#9. There was significant spacing effect on yield (Table 4). The closest spacing (70 cm × 30 cm) gave significantly higher yield than the other spacing. The 70 cm × 40 cm spacing also gave significantly higher yield than the 70 cm × 50 cm spacing. The interaction between variety and spacing was significant as shown in Table 4. Line ICPN16#4 plants spaced at 70 cm × 30 cm produced the highest fruit yield (12.9 t/ha), while line ICPN16#6 planted at 70 cm × 50 cm spacing produced the lowest yield (5.7 t/ha).

The lines showed significant differences in number of seeds per fruit at 8 WAT. Since the same cultural practices were applied to the plants, the differences found may be due to their genetic make-up. Line ICPN16#7 recorded the highest number of seeds per fruit (108.0), whilst ICPN16#4 gave the least number of seeds per fruit (83.0). This result is in line with those of Lemma (1998), who pointed out that seeds per fruit is one of the factors that determine fruit size. Linear increase in individual fruit size and weight with seed number has been observed (Lemma, 1998). The widest spacing (70 cm × 50 cm) gave the highest value because the pepper

Table 3. Effect of spacing on number of branches (cm) at 4 and 8 WAT of selected hot pepper lines.

Line	Spacing (cm^2)							
	70 × 30		70 × 40		70 × 50		Line mean	
	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
ICPN16#3	22.8	31.1	27.8	39.6	21	33.8	23.9	34.8
ICPN16#4	18.9	29.7	20.1	29.8	26.4	33.8	21.8	31.1
ICPN16#6	19.5	29.3	16.8	26.2	23.5	29.2	19.9	28.2
ICPN16#7	19.4	35.5	16.2	29.9	27.6	43.5	21.1	36.3
ICPN16#9	21.5	35.9	25.9	37.5	21.2	36.2	22.9	36.5
Spacing mean	20.4	32.3	21.4	32.6	23.9	35.3	-	-

4WAT: CV (%) 25.19, LSD= line 4.5, Spacing= 3.5 line by Spacing=7.8; 8WAT: CV(%) 24.56, LSD= line 6.7, Spacing= 5.2, line by Spacing=11.7.

Table 4. Effect of spacing on fruit yield (tons) per hectare of selected hot pepper lines.

Line	Spacing (cm)			Line mean
	70 × 30	70 × 40	70 × 50	
ICPN16#3	8.6	8.1	5.7	7.5
ICPN16#4	12.9	10.1	7.5	10.2
ICPN16#6	11.3	7.2	5.7	8.1
ICPN16#7	11.6	8.7	10.1	10.1
ICPN16#9	11.0	10.7	6.6	9.4
Spacing mean	11.1	9.0	7.1	-

CV (%) 27.76; LSD (0.05) Line =2.0; Spacing=1.6; Line × spacing=3.6.

Table 5. Effect of spacing on 1000-seed weight (g) of selected hot pepper lines.

Line	Spacing (cm)			Line mean
	70 × 30	70 × 40	70 × 50	
ICPN16#3	5.0	4.2	4.2	4.5
ICPN16#4	4.2	5.0	4.2	4.5
ICPN16#6	4.7	4.2	4.2	4.4
ICPN16#7	4.2	4.5	3.7	4.1
ICPN16#9	3.5	2.5	3.2	3.1
Spacing mean	4.3	4.1	3.9	-

CV (%) 18.93; LSD (0.05) Line =0.6; Spacing=0.4; Line × spacing=1.11.

plants exhibited high vegetative growth due to effects of spacing, gained high leaf area, increased photosynthetic capacity and assimilate partitioning that resulted in large fruit size (Table 4).

Thousand seed weight

There were significant differences among the lines regarding the (1000) seed weight as shown in Table 5. The highest 1000-seed weight (4.5 g) was produced by ICPN16#3 and ICPN16#4 which were significantly higher than that of ICPN16#9, but similar to ICPN16#6 and ICPN16#7. The variation in 1000-seed weight might be attributed to the varieties genetic make-up. Fruits with higher seed weight can be considered as those receiving higher percentage of assimilate. Good combination of number of seeds and seed weight per fruit could improve fruit quality which makes it an important economic part of the crop as reported by Bosland and Votava (2000).

Interaction between line and spacing was significant (Table 5). Line ICPN16#3 at 70 cm × 30 cm and ICPN16#4 at 70 cm × 40 cm gave the highest 1000-seed weight (5.0 g), while ICPN16#9 at 70 cm × 40 cm produced

Table 6. Effect of spacing on fruit weight (g) of selected hot pepper lines.

Line	Spacing (cm)			Line mean
	70 × 30	70 × 40	70 × 50	
ICPN16#3	5.6	4.7	4.9	5.1
ICPN16#4	4.4	5.2	3.4	4.3
ICPN16#6	6.2	5.4	3.4	5.0
ICPN16#7	7.3	8.1	8.3	7.9
ICPN16#9	3.6	4.6	4.4	4.2
Spacing mean	5.4	5.6	4.9	-

CV (%) 20.53; LSD $_{(0.05)}$ Line =0.9; Spacing=0.7; Line × spacing=1.5.

the least weight (2.5 g). This result differs from other authors who had reported that the increase in fruit weight per plant was due to the increase in plant spacing (Islam et al., 2011; Asaduzzaman et al., 2012). The yield of onion for example is reported to be influenced by many factors including cultivars, soil and climate, seedling age, bulb weight, spacing, date of planting and seed quality which were collectively considered as very important factors (Asaduzzaman et al., 2012).The difference could be attributed to genetic make-up as lines ICPN16#3 and ICPN16#4 had higher seed yielding even in closer spacing than the other lines (Table 5).

Mean fruit weight

There were significant (P<0.05) differences among the lines with respect to mean fruit weight (Table 6). While line ICPN16#7 produced heaviest fruit (7.9 g), and line ICPN16#9 gave the least fruit weight (4.2 g). Significant differences were not found among fruit weight produced by ICPN16#3, ICPN16#6, ICPN16#4 and ICPN16#9. There were significant differences among the spacing treatments with respect to mean fruit weight. Plants at 70 cm × 40 cm spacing produced fruits with the highest mean weight (5.6 g), while fruits with the least mean weight (4.9 g) were recorded from 70 cm × 50 cm. Interaction effect of variety and spacing was significant as shown in Table 6. Line ICPN16#7 at 70 cm × 50 cm spacing gave the highest mean fruit weight (8.3 g), while ICPN16#4 and ICPN16#6 at 70 cm × 50 cm spacing gave the least mean fruit weight (3.4 g). This finding differs from other results where fruit weight is reported to decrease with increasing density (Islam et al., 2011; Kamboj and Sharma, 2015). This result indicates that wider plant spacing with larger fruit size will not always result in high weight due to genetic differences.

Conclusion

From the study, line ICPN16#9 is considered as a short line. This should be cultivated at plant spacing of 70 cm × 50 cm where short plant is a desired parameter. For plant height spacing alone did not show any significant difference and therefore, a particular spacing should not be considered without taking into consideration the height of the line. Line ICPN16#7 is a spreading line and will require wider spacing to exhibit this trait. The 70 cm × 50 cm spacing generally produced significantly better area for wider canopy spread compared to the other two treatments. Closer spacing resulted in the highest fruit yield and seed production, it will be economical to use 70 cm × 30 cm in the cultivation of ICPN16#4.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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