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CONTENTS

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PRODUCTIVITY AND PROFITABILITY OF BRINJAL - ONION INTERCROPPING RELAY WITH SNAKE GOURD

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Abstract

The experiment was carried out on brinjal-onion intercropping with relay snake gourd without trellis at Regional Agricultural Research Station (RARS) Jamalpur during 2020-21 and 2021-22 to find out the suitable crop combination for increasing crop productivity, profitability and maximization of land utilization.The treatments were.T_1 = Brinjal (100 %) + 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%) + 6 row onion + relay snake gourd (2m×1.5m), T_3 = Brinjal (100%) + 6 row onion + relay snake gourd(3m×1.5m), T_4 = Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m) and T_5 = Sole brinjal (100cm×60cm), T_6 = Sole onion (10cm×6cm) and T_7 = Sole snake gourd (1m×1.5m).Brinjal (BARI Begun-8), Onion (BARI Piaj-4) and Snake gourd (BARI Chichinga-1) were used as test materials. The experiment was laid out in a randomized complete block design with five compact replications. Brinjal was the main crop, onion and snake gourd were intercrop and relay crop in the study. Significantly the higher yield was obtained in sole crops. Treatment, brinjal paired row + 12 row onion with relay snake gourd (T_4) gave the highest equivalent yield of brinjal, onionand snake gourd 51.28, 42.74 and 51.28 tha^{-1}, respectively which provided yield advantages of 85, 128 and 142 % over their respective sole crops. The highest land equivalent ratio (2.16), gross return (Tk 12,82,000 ha^{-1}) and benefit cost ratio (5.13) were achieved in T_4.

Keywords: Intercropping, equivalent yield, relative yield and benefit cost ratio.

Introduction

In Bangladesh economy agriculture is the single largest producing sector and contributes about 11.38 % to the total Gross Domestic Product (GDP). Majority of the farmers are marginal and smallholders and their land size is on an average 0.05 to 2.49 acres for marginal and 1.50 to 2.49 acre for small, respectively (MoA, 2022). Demand for food has been increasing with the rapid population increase while land accessibility has been diminishing. Thus, the only way to increase agricultural production is to increase yield per unit area (Hirpa, 2014). Increasing

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food demand for the over population is creating challenge to the country for increasing productivity of the limited land. Thus, cultivation of long duration crops is discouraged, instead short duration intercrops, relay crops and mixed crop are emphasized for cultivation to ensure food security for a large number of populations. Accordingly, relay intercropping is a time demanding technology for crop cultivation with efficient time budgeting.

Brinjal (*Solanum melongena* L.) is one of the utmost common and extensively cultivated vegetable crops in Bangladesh. It is a wide spaced (100 cm × 60 cm) crop and life span ranges 240-280 days. It is a long duration crop grows slowly in first growth stage and establishment of full canopy takes 6-8 weeks. This privilege can be taken for growing onion in between the rows as intercrops. Onion crop can easily be intercropped with brinjal at early growth stage for their short stature and quick growing habit. Intercropping has been considered advantageous in terms of economy of space, saving on tillage, as well as utilization of available nutrients and moisture in unused space. Intercropping is an effective and the economical production system as it not only increases the production per unit area and time, but also increases the resource use efficiency and economic stock of the growers Bhatti *et al.* (2013). Presently, intercropping is gaining acceptance among small holding farmers as it provides a yield advantage over sole cropping through yield stability and helps achieving diversified domestic needs Bhatti *et al.* (2013). Multiple cropping facilitates the farmers to cultivate two or three crops in a year especially in those areas where growing season is shrinking for sequential farming due to climate change (Jabbar *et al.* 2010). Inter or relay cropping systems are more stable than sole cropping. Relay cropping has been recognized especially for smallholder farmers because of its potential to increase land use efficiency and reduce fertilizer consumption enhance crop yield and nutrient accumulation and improve biological activities Ghosh *et al.* (2006). Relay cropping is a beneficial tool that results in better utilization of residual soil moisture from previous crops and reduces cost of production per unit area with efficient use of natural resources Jabbar *et al.* (2005)

In Bangladesh small and marginal farmers constitute 79.4% of our farming community and their cultivated lands are decreasing day by day (MoA, 2022). Besides, multiple cropping may ensure proper utilization of resources towards increased production per unit area and time on a sustainable basis Ahmad *et al.* (2013). Brinjal is an important vegetable crop in Bangladesh. Onion is also an important spices crop in Bangladesh. Brinjal growers are used to grow onion as intercropping in some pocket areas of Bangladesh. Traditionally, the farmers of these areas practice the intercropping brinjal-onion with relay snake gourd. For getting higher productivity and economic return, it is in need to find out the optimum combination of brinjal-onion intercropping with relay snake gourd system. However, various studies have been conducted in the past about vegetables intercropping system but results on brinjal-onion intercropping with relay snake gourd are very scanty. Thus, this study was undertaken to find out the suitable crop combination under intercropping of brinjal + onion with relay snake gourd without trellis for increasing system productivity, profitability and maximization of land utilization.

Materials and Methods

The experiment was conducted at Regional Agricultural Research Station, Jamalpur under Agronomy Division, Bangladesh Agricultural Research Institute (BARI) during 2020-21 and 2021-22 under AEZ-9. The experimental field is situated at approximately $24^{0}55^{/}$N latitude and $89^{0}46^{/}$E longitude with the altitude of 20.16 m above the sea level. The geographical position of the area is between $24^{0}17'$ N latitude and $89^{0}90'$ E longitude. The meteorological data of the experimental site showed that the higher average temperature prevails in May to August and the lower in December and January. There is minimum precipitation in December and January. Maximum rainfall was received during the months of April to September. The meteorological data in 2020-21, monthly mean maximum 31.88^{0}C and minimum 20.11^{0}C air temperature and annual total rainfall 1556.6 mm and in 202122, monthly mean maximum 31.04^{0}C and minimum 20.80^{0}Cair temperature and annual total rainfall 1484.85 mm were prevailing in the study area (Appendix 1.)

The experiment was laid out in a randomized complete block design with five compact replications. The experiment consisted of five treatments, viz., T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd (2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd (3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake (1.75m×1.5m),T_5= Sole brinjal (100cm×60cm),T_6= Sole onion(10cm×6cm),T_7= Sole snake gourd (1m×1.5m). The unit plot size was 6.0 m × 3.0 m and spacing for brinjal was 100 cm × 60 cm. Brinjal was the main crop, onion and snake gourd were the inter and relay crops in the study. The variety BARI Begun-8, BARI Piaj-4 and BARI Chichinga-1 were used as test materials. The crop brinjal seedlings, onion seedlings and snake gourd seedlings were transplanted on 10 November 2020, 15 November 2020, 18 April 2021 and 15 November 2021, 17 November 2021 and 19 April 2022, respectively. Onion and snake gourd were sown in lines between the brinjal rows maintaining the spacing of the respective treatments. The recommended fertilizer doses @ 173-30-125-18-2 kg ha^{-1} NPKSB along with cowdung 5 t ha^{-1}, 90-40-75-25-2-1 kg ha^{-1} NPKSZnB and 100-40-60-20-2-2 kg ha^{-1} NPKSZnB along with 5 t ha $^{-1}$,respectively were applied separately in monoculture brinjal, onion and snake gourd were applied in the form of urea, triple super phosphate, muriate of potash, gypsum, Zinc sulphate and borax. In sole brinjal and intercrop all of cowdung, P, S, Zn, B and one-third of N, half of K were applied during final land preparation. Remaining N was applied in three equal splits at 15, 50 and 70 days after transplanting (DAT) and remaining K was applied in two equal splits at 15 and 50 days after transplanting. In sole onion, all of P, S, Zn and B and half of N and K were applied as basal during final land reparation. Remaining N and K were applied in two equal slits at 25 and 50 DAP for bulb production. In snake gourd, all of cowdung, P, S, Zn, B and one third of N and K were applied in pit 5-7 days prior planting and mixed thoroughly with the soil. Remaining N and K were applied during 20, 35 and 50 DAT around the plants as side dressing under moist soil condition and mixed thoroughly with the soil as soon as possible for better utilization. Mulching, weeding, irrigation and crop protection measures were taken properly for normal growth of the crops. Brinjal harvest started from 10 February 2021 and continued up to 6 April 2021and 15 February 2022 and continued up to 16 April 2022, onion harvested on 10 March 2021 and 13 March 2022, and snake gourd harvest started on 29 May 2021 and continued up to 8 August 2021and 27 May 2022 and continued up to 12 August 2022 in two consecutive years. The yield of brinjal, onion and snake gourd was calculated in tons per hectare considering the whole plot as harvest area. Ten plants of brinjal from each plot were selected randomly to collect data on yield components.

Yield of individual crop was converted into equivalent yield on the basis of the prevailing market price of individual crop following Prasad and Srivastava (1991). Brinjal equivalent yield (BEY) = Yield of intercrop brinjal + $\frac{\text{Yio}\times\text{Po}}{\text{Pb}}$ +$\frac{\text{Yisg}\times\text{Psg}}{\text{Pb}}$, Onion equivalent yield (OEY) = Yield of intercrop onion+ $\frac{\text{Yib}\times\text{Pb}}{\text{Po}}$ + $\frac{\text{Yisg}\times\text{Psg}}{\text{Po}}$ and Snake gourd equivalent yield (SgEY) = Yield of intercrop snake gourd + $\frac{\text{Yio}\times\text{Po}}{\text{Psg}}$ + $\frac{\text{Yib}\times\text{Pb}}{\text{Psg}}$ Where, Yio= Yield of intercrop onion, Po= Price of onion, Yisg= Yield of intercrop snake gourd, Psg= Price of snake gourd and Yib= Yield of intercrop brinjal and Pb= Price of brinjal

Relative yields (RY) based on grain yields were calculated according to the formula of De Wit and van den Bergh (1965) Relative Yield of Brinjal (RYB): $\frac{\text{Yib}}{\text{Ysb}}$, Relative Yield of Onion (RYO): $\frac{\text{Yio}}{\text{Yso}}$, Relative Yield of Snake gourd (RYSg):$\frac{\text{Yisg}}{\text{Yssg}}$ and Relative Yield Total (RYT): RYb + RYo + RYsg Where, Yib= Intercrop yield of brinjal, Ysb= Sole yield of brinjal, Yio= Intercrop yield of onion, Yso= Sole yield of onion, Yisg = Intercrop yield of snake gourd and Yssg = Sole yield of snake gourd.

Pooled analysis was done as there was no significant difference in yield and yield contributing characters between two years. The collected data on different parameters were statistically analyzed using analysis of variance technique with the help of computer package program STAR and the means were separated by

Least Significance Difference (LSD) test at 5% level of significance. Economic analysis was done on the basis of prevailing market price of the commodities. The inputs used included seed, fertilizer, labour and insecticides. The two years average results were analyzed for economic benefits using the methodology prescribed by CIMMYT (1988).

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross return}}{\text{Total cost}}$$

Results and discussion

Plant population of different treatments

Plant population per unit plot (18m^2) of different component crops are presented in Table 1. The plant populations in all treatments of brinjal were same (30) as because during planting the number of brinjal line per plot was six (6) and number of brinjal plants per line was five (5). Similarly, plant populations of onion were same as four hundred (400) due to number of onion line per plot forty (40) and number of onion plants per line ten (10) but snake gourd populations per plot were different as because the line spacing of was different among the treatments of brinjal + onion intercropping system with relay snake gourd.

Table 1. Plant population of component crops as influenced by intercropping onion with relay snake gourd without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Brinjal (Plant/18 m^2)	Onion (Plant/18 m^2)	Snake gourd (Plant/18 m^2
T_1	30	400	12
T_2	30	400	6
T_3	30	400	4
T_4	30	400	7
T_5	30	-	-

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd(2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm)

Effect of intercropping on yield attributes of brinjal

Yield attributes of brinjals influenced by intercropping with onion and snake gourd are presented in Table 2. The result indicated that all the yield attributes were significantly influenced due to brinjal + onion intercropping system with relay snake gourd. The tallest plant (112.93cm) was recorded from sole brinjal (100cm×60cm) treatment which was statistically at par with other treatments except brinjal paired row + 12 rows onion with relay snake gourd (1.75×1.5m) treatment. The shortest plant height (102.80 cm) was recorded from brinjal paired row+ 12 row onion + relay snake (1.75×1.5m) treatment due to maximum crop competition. The highest branchesplant^{-1} (4.53) were found from sole brinjal treatment and the lowest (4.00) was brinjal (100%) + 6 row onion + relay snake gourd (1.0m×1.5m) treatment. The highest number of brinjal plant^{-1} (28.80) was achieved from sole brinjal treatment and the lowest (20.60) was brinjal (100%) + 6 row onion+ relay snake gourd (1.0m × 1.5m) treatment. The highest single brinjal weight (95.60g) was recorded from sole brinjal treatment and the lowest was (69.01g) from brinjal (100%) + 6 row onion+ relay snake gourd (1.0m × 1.5m) treatment. The highest weight of brinjal (1.66 kgplant^{-1}) was recorded from sole brinjal treatment and the lowest weight of brinjal (0.94kgplant^{-1}) was found from brinjal (100%) + 6 row onion + relay snake gourd (1m×1.5m) treatment. Sole brinjal produced higher yield attributes compared to different intercropping systems might be due to less competition among the plants for sun light, nutrients, water and space than intercropped and relay systems. Less competition among plants leads to better growth and development of plants as well as fruits yield in monoculture. These results are in agreement with the findings of Chowdhury *et al.* (2022).

Table 2. Yield attributes of brinjal as influenced by intercropping onion with relay snake gourd without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Plant height (cm)	No. of branches Plant^{-1}	No. of brinjal Plant^{-1}	Single brinjal weight (g)	Yield of brinjal (kgplant^{-1})
T_1	110.20	4.00	20.60	69.01	0.94
T_2	111.13	4.33	23.20	80.47	1.33
T_3	109.60	4.41	25.40	82.80	1.42
T_4	102.80	4.13	22.20	77.96	1.23
T_5	112.93	4.53	28.80	95.60	1.66
LSD $_{(0.05)}$	6.17	0.87	4.98	7.55	0.08
CV (%)	3.08	3.72	6.40	4.94	3.07

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd(2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm)

Yield of components crops as influenced by inter and relay cropping systems

Two years pooled yield of brinjal, onion and snake gourd are presented in Table 3. The highest brinjal, onion and snake gourd yields were recorded from sole crops. Brinjal gave 14 to 29, onion gave 31 to 39 and snake gourd gave 25-58% lower yield in intercropped and relay crop system as compared to their corresponding monoculture presumably due to higher competition among the plants for sun light, nutrients, water and space in intercropped and relay situation than sole crop. Contrary, in the sole cropping treatment the highest yield was attributed due to the higher number of branches per plant, number of brinjal per plant, and single brinjal weight

The yields of brinjal, onion and snake gourd were significantly influenced by intercropped onion and relay snake gourd without trellis. Among the intercropping and relay combinations the higher yield of brinjal (20.05 t ha^{-1}), onion (12.86 tha^{-1}) and snake gourd yield (15.80 tha^{-1}) were recorded in T_4 treatment (Brinjal paired row+12 row onion + relay snake gourd) and the lower yield of brinjal (19.67 t ha^{-1}), onion yield (11.41 tha^{-1}) and snake gourd yield (8.92 tha^{-1}) from T_1 (Brinjal (100 %) + 6 row onion + relay snake gourd). This might be due to higher plant population in T_4 treatment. Similar results reported by Rahman *et al*. (2020) who found that higher brinjal yield was observed in relaying snake gourd .

Table 3. Yield of component crops (whole plot basis) as influenced by intercropping onion with brinjal and relay snake gourd systems without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Yield (t/ha)					
	Brinjal	% yield decrease over sole	Onion	% yield decrease over sole	Snake gourd	% yield decrease over sole
T_1	19.67	29	11.41	39	8.92	58
T_2	22.17	20	11.49	38	12.65	40
T_3	23.67	14	11.80	37	10.22	52
T_4	20.05	28	12.86	31	15.80	25
T_5	27.66	-	-	-	-	-
T_6	-	-	18.65	-	-	-
T_7	-	-	-	-	21.18	-
LSD $_{(0.05)}$	1.19	-	1.64	-	1.71	-
CV (%)	5.73	-	6.14	-	5.39	-

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd (2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm),T_6= Sole onion (10cm×6cm)and T_7= Sole snake gourd (1m×1.5m).

Cost and return analysis of brinjal intercropping onion with relay snake gourd systems

Cost and return of different brinjal intercropping systems were analyzed taking into account the prices prevailed at local market. On the basis of two years average result, all the intercrop combinations gave monetary advantages over sole crops (Table 4). The highest gross margin (Tk. 10,32,100ha^{-1}) was found in brinjal paired row +12 row onion+ relay snake gourd in brinjal, onion and snake intercropping system (T_4) which gave an additional income of Tk. 461310, 704580 and 651190 ha^{-1}over brinjal, onion and snake gourd sole cropping, respectively. Cost of production of all intercropping systems were more than sole crops because inclusion of component crops, involvement of higher seed cost as well as cost of more labour engaged in different operations. Intercropping of onion and relay snake gourd brought about an increase in return per taka investment. It was evident that intercropping was beneficial and recorded higher benefit cost ratio (BCR) than monoculture of brinjal, onion and snake gourd. Among the intercropping systems the highest BCR (5.13) was obtained from brinjal paired row + 12 row onion + relay snake gourd intercropping system which further indicated the superiority to T_4over other treatments (Table 3). These results are in agreement with the findings of Islam *et al.* (2016) who reported that monetary return, BCR as well as other intercropping determinants were also higher in Brinjal 100% + garlic 60% intercropping system than other treatments and sole cropping of brinjal.

Table 4. Cost and return analysis of brinjal onion intercropping with relay snake gourd systems without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Gross return (Tk.ha^{-1})	Total cost (Tk. ha^{-1})	Gross margin (Tk.ha^{-1})	BCR
T_1	10,57,000	2,49,560	8,07,440	4.24
T_2	12,17,750	2,49,670	9,68,080	4.86
T_3	12,65,750	2,49,920	10,15,830	5.06
T_4	12,82,000	2,49,900	10,32,100	5.13
T_5	6,91,500	1,80,710	5,70,790	3.83
T_6	4,66,250	1,38,730	3,27,520	3.36
T_7	5,29,500	1,48,590	3,80,910	3.56

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd (2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm), T_6= Sole onion (10cm×6cm) andT_7= Sole snake gourd (1m×1.5m).

Sale price/kg: Brinjal=Tk. 25.00, Onion = Tk. 30.00, Snake gourd= Tk. Tk. 25.00

Equivalent yield of component crops

Total productivity of system was expressed in brinjal, onion and snake gourd equivalent yield. Equivalent yield and relative yield of component crops are presented in Table 5. All intercropping systems gave higher brinjal, onion and snake gourd equivalent yield than that of their respective sole crop. It's indicated that higher biomass production and consequently more efficient use of land and available resources under intercropping than sole cropping. Among those, the highest brinjal, onion and snake gourd equivalent yield 51.28, 42.74 and 51.28 tha^{-1} were recorded from brinjal (100%) + 12 row onion + relay snake gourd in between two paired rows of brinjal (T_4) which covered the yield advantages of 85, 128 and 142% over their respective sole crops. Such yield advantage might be due to combined yield of component crops. Similar results were also reported by Begum et al. (2015) in chilli + garlic and chilli + onion intercropping systems.

Table 5. Equivalent yield of brinjal onion intercropping with relay snake gourd systems without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Brinjal equivalent yield (t/ha)	Onion equivalent yield (t/ha)	S. Gourd equivalent yield (t/ha)	% increase BEY over sole brinjal	% increase OEY over Sole onion	% increase SgEY over sole snake gourd
T_1	42.28	35.23	42.28	53	89	100
T_2	48.71	40.51	48.61	76	117	130
T_3	50.63	40.05	48.05	83	115	127
T_4	51.28	42.47	51.28	85	128	142
T_5	27.66	-	-	-	-	-
T_6	-	18.65	-	-	-	-
T_7	-	-	21.18	-	-	-

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd (2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm), T_6= Sole onion (10cm×6cm)and T_7= Sole snake gourd (1m×1.5m).

Partial relative yield and land equivalent ratio

The partial relative yields and land equivalent ratio of intercropped brinjal, onion and relay snake gourd are presented in Table 6. The partial relative yields of intercropped brinjal, onion and relay snake gourd varied from 0.71 to 0.86, 0.61 to

0.69 and 0.42 to 0.75, respectively. Brinjal yield was reduced from 29 to 14%, onion yield was reduced 39 to 31% and relay snake gourd yield was reduced 58 to 25%amongtheintercropping and relay system. The yield was reduced due to lower plant population. The result showed that $T_4$was well accommodative in competitiveness in brinjal + onion + relay snake gourd system (Table 5). The results are in agreement with the finding of Islam *et al.* (2016).

The values of Land Equivalent Ratio (LER) in different intercropping systems were found greater than unity indicating higher land use efficiency of intercropping systems over the respective monoculture (Table 5). Yield advantages occurred in intercropping was mainly due to development of both temporal and spatial complementarities. However, total relative yield value (2.16) was the highest in brinjal (100%) + 12 row onion + relay snake gourd(1.75m×1.5m) in between paired rows of brinjal (T_4), where brinjal, onion and snake gourdachieved 72, 69 and 75% of their sole yields, respectively indicating higher biological and economic efficiency. It also expressed that by intercropping brinjal with onion and relay snake gourd a farmer can produce 20.05, 12.86 and 15.80 t ha^{-1}brinjal, onion and snake gourd, respectively in one hectare of land instead of growing them separately as sole crop. The results are in agreement with observations made by Ali *et al.* (2016) who reported that total LER values of intercropping were higher than that of monocrop corn and soybean.

Table 6. Partial relative yields and Total relative yield of brinjal onion intercropping with relay snake gourd systems without trellis during 2021-22 and 2022-23 at RARS, Jamalpur (Pooled data)

Treatments	Partial (LER			Total (LER)
	Brinjal	Onion	S. gourd	
T_1	0.71	0.61	0.42	1.74
T_2	0.80	0.62	0.60	2.02
T_3	0.86	0.63	0.48	1.97
T_4	0.72	0.69	0.75	2.16
T_5	1.00	-	-	1.00
T_6	-	1.00	-	1.00
T_7	-	-	1.00	1.00

Note: T_1= Brinjal (100%)+ 6 row onion + relay snake gourd (1m×1.5m), T_2= Brinjal (100%)+ 6 row onion + relay snake gourd (2m×1.5m), T_3= Brinjal (100%)+ 6 row onion + relay snake gourd(3m×1.5m), T_4= Brinjal paired row+12 row onion + relay snake gourd(1.75m×1.5m)and T_5= Sole brinjal (100cm×60cm),T_6= Sole onion (10cm×6cm)and T_7= Sole snake gourd (1m×1.5m).

Conclusion

Two years average result indicated that intercropping brinjal with onion and relay snake gourd gave higher productivity as well as economic return than monoculture of the component crops. The equivalent yields, relative yields, total relative yield and gross return were found higher in brinjal (100%) + 12 rows onion + relay snake gourd (1.75m×1.5m) system. Thus, it is concluded that a planting pattern comprising on brinjal (100%) +12 rows onion + relay snake gourd(1.75m×1.5m) in between two paired rows of brinjal intercropping system could be adopted for better productivity and maximum profit. The farmers of Jamalpur regions of AEZ-9 could be suggested to cultivate brinjal intercropping with onion and relay snake gourd as an alternative of sole cropping.

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Appendix1. Monthly air temperature, relative humidity and total rainfall in the experimental area of Jamalpur, during 2020-21 to 2021-22

Month	Temperature (°C)				Average RH (%)		Total rainfall (mm)	
	Avr. Max		Avr. Min					
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
July	37.19	36.87	27.63	26.33	82.78	73.30	127.20	42.75
August	35.44	34.93	26.94	26.60	83.51	75.40	143.25	39.00
September	33.13	33.73	25.07	27.27	75.78	84.38	10.50	191.50
October	33.38	32.33	22.19	25.00	84.18	74.60	205.75	81.00
November	29.92	29.84	19.22	17.89	76.83	82.00	46.00	49.50
December	24.31	25.63	13.51	13.29	78.35	85.30	22.80	21.00
January	23.15	26.31	11.87	11.57	74.71	83.58	40.00	44.30
February	26.26	28.09	13.29	14.73	71.71	74.25	73.60	71.00
March	31.51	31.26	18.47	19.10	67.52	66.80	99.70	84.60
April	33.13	33.18	21.48	22.37	74.70	74.77	281.20	293.30
May	32.93	34.79	23.09	24.36	77.13	79.00	360.30	350.40
June	32.13	35.60	19.60	21.07	77.96	84.80	146.30	218.50
Yearly average	31.04	31.88	20.11	20.80	77.10	78.18	1556.6	1484.85

Source: Weather yard, Regional Agricultural Research Station, BARI, Jamalpur.

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DEVELOPMENT OF IN VITRO PROPAGATION PROTOCOL FOR Stevia (*Stevia rebaudiana* Bertoni)

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AND M. A. HAQUE[5*]

Abstract

Stevia rebaudiana Bertoni an anti-diabetic medicinal herb is cultivated throughout the world for economic and medicinal values. However, conventional propagation methods are inefficient due to seed dormancy and slow growth rates. In this study, *in vitro* propagation protocol has been developed through indirect organogenesis for the production of healthy plantlets. Nodal and leaf explants were sterilized and cultured on MS medium containing various concentration and combination of Plant Growth Hormone (PGRs). Shoot induction was highest (100%) with Kinetin (0.5 mg L^{-1}) while shoot proliferation (14.57 shoots/explant) was improved with Kinetin (1.0 mg L^{-1}) + 6-Benzylaminopurine (BAP) (0.2 mg L^{-1}). The highest rooting (100%) was observed in the MS medium supplemented with Indole-3-acetic acid (IAA) at 0.2 mg L^{-1} and Naphthalene Acetic Acid (NAA) at 0.5 mg L^{-1}. Hardened plantlets were successfully acclimatized to the sand and showed the maximum survival rate (87.5%) with similar morphology to the mother plants. Therefore, this study offers a valuable alternative to overcome the limitations of conventional propagation methods contributing to the commercial production of *Stevia rebaudiana* in Bangladesh and similar agro-climatic regions.

Key words: Nodal explant, Indirect organogenesis, *In vitro* propagation, *Stevia rebaudiana*

Introduction

Stevia is a non-caloric natural sweet herb originated in Paraguay. Stevia leaves accumulate bioactive compounds, Steviol glycosides (SGs) (less than 1% of each leaf), which is 250-300 times sweeter than commercial sucrose (Ashwell, 2015). In 2008, the Food and Drug Administration approved SGs as a safer and healthier sugar substitute for diabetes and obesity because they stimulate insulin secretion and reduce blood glucose levels (Marcinek and Krejpcio, 2015). The increasing trend of global diabetes and obesity also increases the global importance of natural sweeteners. For this reason, stevia has become more prevalent as a significant crop in several developed and developing countries worldwide for food and

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pharmaceutical use (Hossain *et al*. 2017). Clonal propagation was widely used commercial propagation method. Nevertheless, stevia cultivation is not profitable due to high labor costs, large input stocks, and obtaining quality planting materials are the main limitations. The micropropagation of plants by using shoot tips or axillary buds can provide genetically uniform plants. Various reports have been published on successful multiplication and *in vitro* rhizogenesis (Singh *et al*., 2017; Rasouli *et al*., 2021). Subsequently, the maximum survivability of *in vitro* regenerated stevia plantlets has been reported by many researchers (Soliman *et al*., 2014) but their success in the hardening process is low. Therefore, this study aimed to optimize the *in vitro* propagation protocol of *S. rebaudiana* to achieve the higher survival rate of acclimatized plants for large-scale propagation.

Materials and Methods

Explant preparation and culture conditions

Healthy shoots with nodal buds (5-6 cm) were collected from field-grown Stevia genotype at Bangladesh Sugarcrop Research Institute (BSRI), Ishwardi, Pabna, Bangladesh. After washing under running tap water for 15-30 minutes, explants were resized to 1.5 -2.5 cm. Then the explants were surface sterilized using 0.1% $HgCl_2$ and 1% Sodium hypochlorite and ethanol for different time duration. The explants were rinsed with sterile distilled water (SDW) and cultured on MS (Murashige and Skoog, 1962) medium supplemented with 3 % sucrose and 0.7 % agar and BAP (0.2 mg L^{-1}) and 2,4 D (1 mg L^{-1}). The medium was adjusted at 5.7 and autoclaved at 121°C for 20 min. Cultures were incubated at 25±2ºC, 55-60% humidity under florescent light (33.73 μmol $m^{-2}s^{-1}$) intensity for 16/8 hours (light/dark cycle).

Shoot induction and shoot proliferation

Surface sterilized nodal explants (0.5-1.5 cm) were cultured on MS medium containing different concentrations of BAP or Kin (0.5, 1.0, 1.5, 2, 2.5 mg L^{-1}) for shoot induction, as both BAP and Kin are crucial for cell division, shoot initiation. Multiple shoots were induced on MS medium with BAP and Kin at different concentrations (0.5, 1.0, and 1.5 mg L^{-1}).

In vitro root formation

In this stage, elongated shoots (2-5 cm in length and about 8–12 leaves) were transferred onto MS medium supplemented with different concentrations of auxin (0.5, 1.0, 1.5, 2.0, and 2.5 mg L^{-1} of IAA, Indole-3-butyric acid (IBA) and NAA each.

Acclimatization

Healthy-rooted plantlets (3 to 4 cm) with expanded leaves were transferred in the controlled environment for approximately 2-3 days for initial adaptation (Figure 3B). Afterward, the plantlets were gently removed from the culture tubes so that the roots were not damaged. Then, the plantlets were washed and dipped in 0.1% Bavistin, transplanted into plastic pots containing one of the following substrates: Garden soil, Sand, Cocopeat, Sand + Garden soil (1:1), Sand + Cocopeat (1:1), Garden soil + Cocopeat (1:1). After two weeks, polythene bag were gradually removed to acclimatize the plantlets under natural conditions.

Statistical analysis

All statistical analyses were performed with Statistix-10 and the Microsoft Excel 2010. All the experiments were set up in a completely randomized design (CRD) with four replicates with 12 explants per replication. Data represent the mean± SE (n = 4) and were analyzed with one-way ANOVA, mean values were separated by the Tukey's HSD. All statistical analyses were carried out with Statistix-10 (Trial version) and the Microsoft Office Excel 2010 program package.

Results and Discussion

Effect of cytokinins on direct organogenesis

Cytokinins are the most influential group of endogenous hormones for all plant species. In this study, the induction of healthy green shoots was observed from nodal explant after four weeks of culture. The MS medium supplemented with Kinetin at 0.5 mg L^{-1} induces the highest percent of shoots (100%) compared to the hormone free medium. (Fig. 1, Table 1). Similarly, Razak *et al.* (2014) found lower concentration of kinetin for highest number of shoot production. Shoot number is also affected by Cytokinin concentration. Kin at 1.0 mg L^{-1} produced a maximum of seven shoots from nodal explant within one week of culture. Increasing the concentration of Kin from 1.0 to 2.5 mg L^{-1} decreased the establishment percentage at a 5 % level. Among the different BAP, concentrations applied with MS medium, only BAP at 0.5 mg L^{-1} induced maximum percentages (91.6%) of shoot bud with 4.42 shoots/explant. As shown in Table 1, increasing the concentration of BAP from 0.5 to 2.5 mg L^{-1} significantly decreased the establishment rate. However, the higher concentrations of BAP caused the earlier blooming (5th day) with hyper hydrous buds. The shoot induction study showed that both cytokinin performed well and were almost equally effective. Considering the importance of shoot multiplication, it is beneficial and economical to use Kin (as lower concentration is very effective in induction of shoots and no. of shoots) in MS media for micropropagation instead of other cytokinin (Abu-Romman *et al.*, 2015).

Table 1. Effects of MS medium with cytokinins at various concentrations on cultures establishment from nodal explant of *Stevia rebaudiana*

Plant growth regulators (mg L^{-1})	Days to shoot bud initiation	Shoot induction (%)	Shoot number explant^{-1}
Control	15.25±0.27^{a}	31.24±2.08^{e}	1.05±0.17^{h}
BAP (0.2)	11.18±0.65^{b}	64.57±2.08^{c}	3.5±0.18d^{e}
BAP (0.5)	9.43±0.25^{c}	91.66±0^{a}	4.42±0.12^{c}
BAP (1.0)	8.0±0.54^{cd}	81.24±2.08^{b}	5.42±0.12^{b}
BAP (1.5)	5.42±0.14^{f}	72.91±2.08^{bc}	3.67±0.28^{d}
BAP (2.0)	5.25±0.21^{f}	64.57±2.08^{c}	2.62±0.18^{f}
BAP(2.5)	6.06±0.12^{ef}	47.91±2.08^{d}	1.67±0.18^{g}
Kin (0.2)	6.18±0.27^{ef}	97.91±2.08^{a}	3.17±0.09^{e}
Kin (0.5)	7.37±0.21^{de}	100±0^{a}	5.32±0.17^{b}
Kin (1.0)	6±0.27^{ef}	95.83±2.4^{a}	7.22±0.15^{a}
Kin (1.5)	5.43±0.21^{f}	77.08±2.08^{b}	5.55±0.12^{b}
Kin (2.0)	5.18±0.18^{f}	66.66±0^{c}	4.2±0.14^{c}
Kin (2.5)	7.18±0.12^{de}	45.83±2.4^{d}	5.2±0.14^{b}

Data represent the mean± SE (n = 12, replication = 4) after 4 weeks of culture. Mean data in each column followed by the same letter in superscript are not significantly different at $P \leq 0.05$ as determined by Tukey's HSD test.

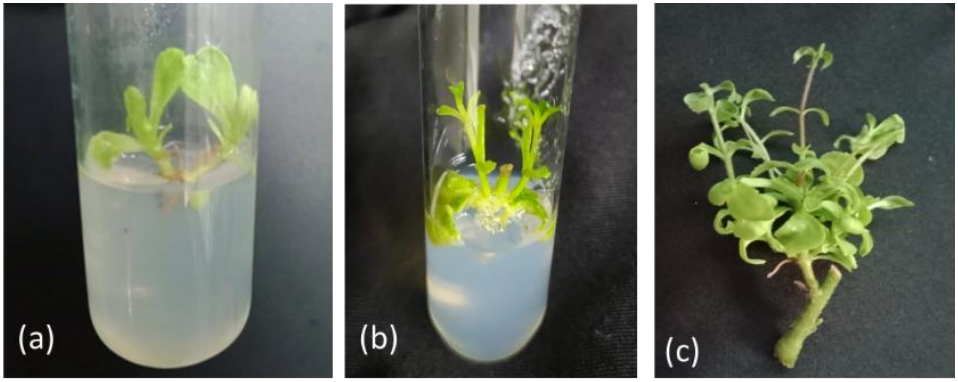

Fig. 1. Shoot induction of *S. rebaudiana* (a) BAP (2.0 mg L^{-1}); (b) Kin (0.2 mg L^{-1}); (c) Kin (0.5 mg L^{-1}).

Effects of PGRs on shoot proliferation

Following the shoot induction, 2 cm long shoots were transferred on the shoot proliferation medium. MS medium with Kin 1.0 (mg L^{-1}) and BAP (0.2 mg L^{-1}) was found to be the best for shoot proliferation (95%) with 14.57 shoots/culture. MS medium supplemented with 0.5 mg L^{-1} BAP was recorded maximum number of shoots (7.12 shoots/explant) compared to all the BAP treatments tested (Fig. 2, Table 2). The shoot proliferation frequency, number of shoot buds, and length of shoots were negatively affected by increasing the Kin and BAP concentration to 1.5 mg L^{-1}. Similar effects also observed with on MS medium supplemented with higher concentration of Kin (1.5 mg L^{-1}) compared to the other Kin treatments with maximum number of shoots (12.52 shoots/explant). However, increasing concentrations of Kin from 1.0 to 1.5 mg L^{-1} significantly increased the shoot number (Figure 2). Das *et al*. (2011) reported Kin (2.0 mg L^{-1}) resulted most effective in multiple shoot proliferation in stevia. Moreover, Razak *et al*. (2014) observed that BAP at 1.5 mg L^{-1} with Kinetin showed the maximum response for shoot proliferation. Considering the importance of shoot proliferation, it is beneficial and economical to use a combination of Kin (1.0 mg L^{-1}) and BAP (0.5 mg L^{-1}) micro propagation.

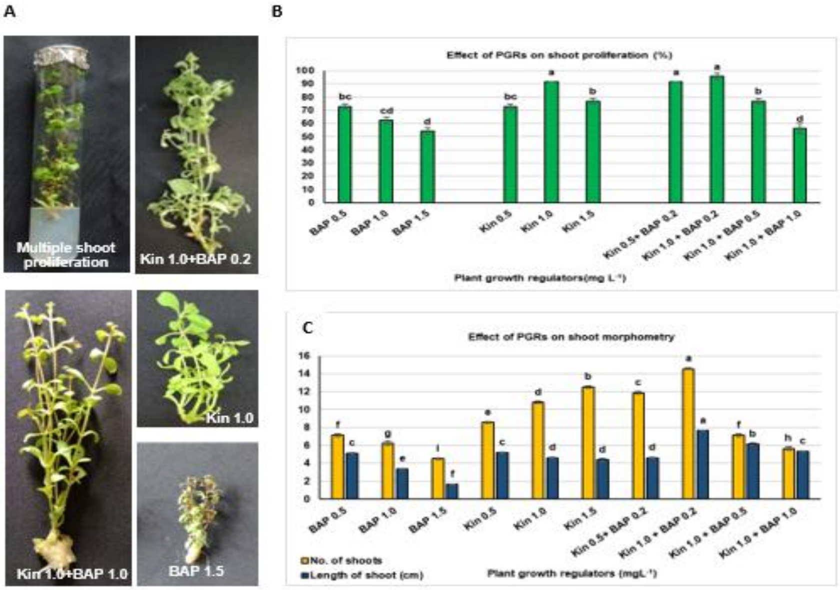

Fig. 2. Effects of growth regulators combination on shoot proliferation from micro shoots of *S. rebaudiana* (A) Morphology (B) percentage of shoot proliferation and (C) shoot morphometry from micro shoots. The photos in (A) were taken after 4 weeks of culture.

Data represent the mean± SE (n = 12, replication = 4) and mean data followed by the same letter in superscript are not significantly different at $P < 0.05$ as determined by Tukey's HSD test.

In vitro rooting

Root induction is one of the important limiting factors in plant propagation. In this study, MS-medium supplemented with 0.2 mgL^{-1} of IAA induces significantly highest percent (100%) root with maximum number of roots and root length obtained was 10.13 and 5.35cm roots/shoot, respectively compared to control (27%) (Figure 3a, Table 2). This result is in agrees with Soliman *et al.* (2014), and Yucesan *et al.* (2016), who found the highest rooting on MS medium augmented with low concentration of IAA. However, Yesmin (2019) found MS medium containing lower concentration of IBA is best for rooting. MS media fortified with intermediate concentration of IAA and IBA were found to produce more thick and long roots (IBA 1.0 mg L-1) than lower and higher concentrations (IBA 1.5 mg L^{-1}).

Table 2. Effects of auxins (IAA, IBA, NAA) on the rooting of *S. rebaudiana*

Plant growth regulators (mg L^{-1})	Days to rooting	Rooting (%)	Root number explant $^{-1}$	Root length (cm)
Control	25.12±.31^{a}	27.08±2.08^{f}	2.23±0.01^{f}	3.01±0.20^{c}
IAA (0.2)	15.25±.27^{b}	100±0.00^{a}	10.13±0.06^{a}	5.35±0.23^{a}
IAA (0.5)	11.18±.65^{cd}	81.24±2.08^{b}	8.37±0.12^{b}	3.14±0.12^{c}
IAA (1.0)	10.18±.27^{cd}	66.66±0.00^{c}	6.56±0.01^{c}	1.97±0.17^{f}
IAA (1.5)	11.56±.21^{c}	47.91±2.08^{e}	3.46±0.10^{e}	1.32±0.09^{g}
IAA (2.0)	15.18±.29^{b}	12.49±2.40^{h}	1.53±0.01^{g}	0.7±0.08^{h}
IBA (0.2)	10.18±.27^{cd}	77.08±2.08^{b}	3.66±0.07^{d}	1.87±0.09^{f}
IBA (0.5)	9.18±.12de	64.57±2.08^{c}	6.57±0.06^{c}	2.65±0.12^{d}
IBA (1.0)	8±.54^{e}	54.16±2.4d^{e}	3.66±0.07^{de}	2.37±0.18^{de}
IBA (1.5)	12.25±.25^{c}	47.91±2.08^{e}	2.24±0.01^{f}	1.15±0.25^{g}
IBA (2.0)	10.93±.59^{cd}	22.91±2.08f^{g}	0.98±0.07^{h}	0.79±0.07^{h}
NAA (0.2)	11.81±.10^{c}	81.24±2.08^{b}	3.71±0.08^{d}	2.47±0.12^{de}
NAA (0.5)	9.31±.23de	64.57±2.08^{c}	8.34±0.02^{b}	4.17±0.09^{b}
NAA (1.0)	10.93±.59^{cd}	58.33±0.00^{cd}	3.67±0.09^{d}	2.21±0.04^{ef}
NAA (1.5)	11.12±.63^{cd}	27.08±2.08^{f}	1.53±0.02^{g}	1.44±0.02^{g}
NAA (2.0)	11±.60^{cd}	14.57±2.08^{gh}	0.86±0.02^{h}	0.48±0.02^{h}

Data represent the mean± SE (n = 12, replication = 4) after 4 weeks of culture. Mean data in each column followed by the same letter in superscript are not significantly different at $P < 0.05$ as determined by Tukey's HSD test.

Although, IBA at a lower concentration (0.5 mg L^{-1}) shows an average number of shoots per explant. NAA alone (0.2 mg L^{-1}) also showed better rooting (82.3%), a maximum of 8.34 roots per shoot after 12 days of cultivation as compared to IBA augmented media. The rooting percentage decreased with increasing the concentration of all auxins. However, with the higher concentration of IBA, IAA at 2.0 mg L^{-1} and NAA (1.5 and 2.0 mg L^{-1}) were found less effective in percent root induction. But maximum shoot length with the least number of roots per plantlet was observed when the MS medium was augmented with 2.0 mg L^{-1} of IBA. From root induction study, it is observed that MS media supplemented with all three auxins at lower concentrations (individually) performed well and were almost equally effective. Therefore, considering the importance of plant survival, it is beneficial and economical to use IAA in MS media for micro propagation instead of other auxins.

Acclimatization

The acclimatization of *in vitro* regenerated plants was the most difficult and labor consuming step because the newly transplanted plantlets were highly susceptible to fungal contamination. Garden soil alone has no beneficial effects on in vitro-raised stevia plantlets due to necrosis and contamination. Higher survival values (87.5%) were recorded on the sand with the average root number (17.5), most extended root length (8.41cm), and leaves (105) per plant (Table 3, Fig. 3C). However, 43% of plantlets survived with lower root numbers on garden soil. These results agree with Sreedhar *et al*. (2008), who successfully established (more than 90%) *in vitro* stevia plantlets on the sand. The different mixtures of sand: coco peat (1:1), sand: garden soil (2:1), and garden soil: coco peat (1:1) also influenced plant height and the number of leaves. It was found that after transplanting on sand: garden soil and sand: coco peat, 75% and 65% of adapted plants survived respectively, with an average number of leaves of 80 and 52 per plant. The Rest of the substrates had inhibiting effects on growth and development, resulting in low acclimatization rates.

Fig. 3. Effect of different hardening media on plantlets survival during acclimatization of *S. rebaudiana* (A) Morphology of in vitro rooted plantlets (B) Acclimatization of plantlet in culture room; (C) Ex vitro plant on sand with greater number of leaves after successful establishment under natural field conditions.

Coco peat alone (33.3%) or mixing with the garden soil (35.5%) proved to be the least beneficial growth medium compared to sand (87%). Because, with frequent misting, water logging occurred around the plantlets, and they started to rot, leading to reduced survival. However, plant heights are significantly taller than ther plant heights. There was no detectable variation among the potted regenerants of *S. rebaudiana* plants and mother plants concerning morphological and growth characteristics. The in vitro- derived plantlets have a characteristic feature of a poorly developed epicuticular waxy layer. This leads to uncontrolled foliar water loss when the plants are taken out from the culture vessels. However, when the plants are kept at high humidity conditions, they synthesize more epicuticular wax, which enhances survival success during acclimatization. Besides, the in-vitro raised plants have poorly developed epicuticular waxes, more stomata per unit area, and raised guard cells with wide openings, which result in more transpiration losses and less survival of plantlets.

Table 3. Effects of different hardening media on the acclimatization of *S. rebaudiana*

Hardening media	Survival rate (%)	Plantlets height (cm)	Root number explant $^{-1}$	Root length (cm)	Leaf numbers
Garden soil	45.83±2.4^{c}	17.27±0.11^{c}	7.57±0.11^{c}	3.47±0.02^{f}	43.27±0.87^{d}
Sand	87.50±4.17^{a}	20.6±0.03^{b}	17.47±0.08^{a}	8.41±0.04^{a}	105.09±1.25^{a}
Cocopeat	33.33±3.40^{c}	25.5±0.06^{a}	6.37±0.18^{d}	5.63±0.06^{d}	24.58±0.87^{e}
Sand + Garden soil (1:1)	75.00±00^{ab}	14.33±0.03^{f}	13.85±0.06^{b}	6.56±0.34^{b}	80.42±5.16^{b}
Sand + Cocopeat (1:1)	64.57±2.08^{b}	16.43±0.03^{d}	6.82±0.37c^{d}	6.35±0.23^{c}	51.9±0.89^{c}
Garden soil + Cocopeat (1:1)	35.41±3.99^{c}	15.54±0.21^{e}	5.37±0.16e	3.92±0.01^{e}	47.25±1.3^{cd}

Data represent the mean± SE (n = 12, replication = 4) after six weeks of culture. Bold characters denote significant responses and values. Mean data in each column followed by the same letter in superscript are not significantly different at $P < 0.05$ as determined by Tukey's HSD test.

Conclusion

This study developed an efficient micro-propagation protocol for *Stevia rebaudiana* using tissue culture techniques. During the proliferation stage, optimal shoot growth was achieved using low concentrations of BAP (0.2 mg L^{-1}) and Kinetin (1.0 mg L^{-1}), while rooting was induced with low concentrations of IAA

(0.2 mg L^{-1}) and NAA (0.5 mg L^{-1}). Then, the regenerated plantlets were acclimatized on various hardening media and evaluated under field conditions. Quantitative evaluations confirmed that plants grown in sand showed morphological characteristics identical to the mother plant. These findings suggest that this protocol is highly suitable for the large-scale commercial propagation of stevia and efficient alternative to conventional cultivation propagation techniques.

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RESPONSE OF FOUR POTATO VARIETIES TO WATER DEFICIT STRESS UNDER FIELD CONDITION

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Abstract

An experiment was conducted at the Horticultural Research Field of Gazipur Agricultural University, Salna, Gazipur, during November 2016 to March 2017 to observe the responses of different potato varieties under different water deficit stress conditions and to find out the potential potato variety(ies) for achieving the maximum yield under water deficit stress condition. The experiment comprised four potato varieties, namely BARI Alu-7 (Diamant), BARI Alu-8 (Cardinal), BARI Alu-25 (Asterix) and BARI Alu-28 (Lady Rosetta) and three irrigations *viz*., Single irrigation at 30 days after planting (DAP) (Severe water stress), two irrigations at 30 and 45 DAP (Mild water stress) and three irrigations at 30, 45 and 60 DAP (Normal condition-no water stress). The results revealed that yield reduction under severe water stress condition was minimum in BARI Alu-25 (23.68%), followed by variety BARI Alu-28 (25.68%). The high yield maintenance ability of BARI Alu-25 and BARI Alu-28 under severe water stress was also supported by their higher stress tolerance indices of 0.82 and 0.74, respectively and their lower stress susceptibility indices of 0.58 and 0.55, respectively. BARI Alu-25 produced the highest fresh tuber yield, dry matter percentage, stress tolerance index (STI), lowest yield reduction and lowest stress susceptibility index (SSI) in well watered condition as well as the other two water deficit stress conditions.

Keywords: Potato, water deficit stress, dry matter, tuber yield, stress susceptible index, stress tolerance index.

Introduction

Potato (*Solanum tuberosum* L.), a member of Solanaceae family, is popularly known as ‘Alu’ in Bangladesh. It is the second largest food crop in Bangladesh next to rice and has recently occupied an important place in the list of major food and cash crops of Bangladesh (Ali and Haque, 2011). In the year 2022-23, total annual potato production was 10.431 million tons from an area of 0.455 million hectares and average yield was 22.90 t/ha (Anon., 2024). The area and production of potatoes are increasing day by day due to its higher demand and profitability. Potato is grown more or less in all districts of Bangladesh but better in the districts of Munshiganj, Bogra, Rangpur, Dinajpur and some parts of greater Cumilla (Anon., 2014). In the last few decades, several dozens of high yielding varieties (HYV) of potato were

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brought to Bangladesh and tried experimentally under local conditions before they were recommended for general cultivation (Khalil *et al*., 2013). The yield range of these released potato varieties is 20-40 t/ha (Azad *et al*., 2020).

Drought is commonly defined as a period without significant rainfall. Water deficit is a global issue that needs to be taken into consideration to ensure survival of agricultural crops and sustainable food production (Jaleel *et al*., 2009). Potato is a drought-sensitive crop and the detrimental effects of drought on potato tuber yield and other related traits are well documented (Hassanpanah, 2010). Water deficit (drought) is responsible for reduction of tuber yield, plant height, ground coverage and tuber number (Hassanpanah, 2010). Lahlou *et al*. (2003) and Hassanpanah (2010) reported the genotype-dependent differences of tuber yield under water deficit stress. Aliche *et al*. (2018) and Hill *et al*. (2021) reported that water restriction reduced leaf growth as well as having negative effects on growth, tuber formation, and tuber enlargement under drought stress. In Bangladesh, monsoon rains provide about 80% of annual rainfall, when this is reduced, drought becomes a significant problem. Every year Bangladesh experiences a dry period of seven months from November to May when rainfall is normally low. Though TCRC of BARI has been released more than 100 varieties of potato, most of the varieties did not get popularity due to several reasons among which abiotic stresses such as water deficit (drought). Performance of BARI potato varieties in the changed climate like water deficit stress needs to be studied to find out the adaptable varieties under water stress (drought) condition. Information regarding this aspect is scarce in Bangladesh. Considering the above facts in view the present study was conducted to study the responses of different potato varieties under water stress condition and to find out the suitable variety (ies) which can give high yield under this moisture stress condition.

Materials and Methods

The experiment was conducted at the Horticultural Research Farm of Gazipur Agricultural University (GAU). The area belonged to the Agro-Ecological Zone 28 (AEZ 28) i.e. the Madhupur tract which lies between 24^0 05' N latitude and $90^0$25' E longitude with an elevation of about 8.5 m above sea level. Weather data of GAU during the experimental period (2016-17) are presented in Fig. 1. The initial soil (0-30 cm depth) sample of experimental plot was analyzed as per standard methods (Table 1).During the cropping season (November-March), the maximum temperature ranged was 24.63-33.16 ºC while the minimum temperature range was 11.53-20.93 ºC and the average temperature range was 18.08-23.04 ºC (Fig.1). The average relative humidity (RH) percentage was 78.45-89.41% and total rainfall was 99.99 mm during the cropping season.

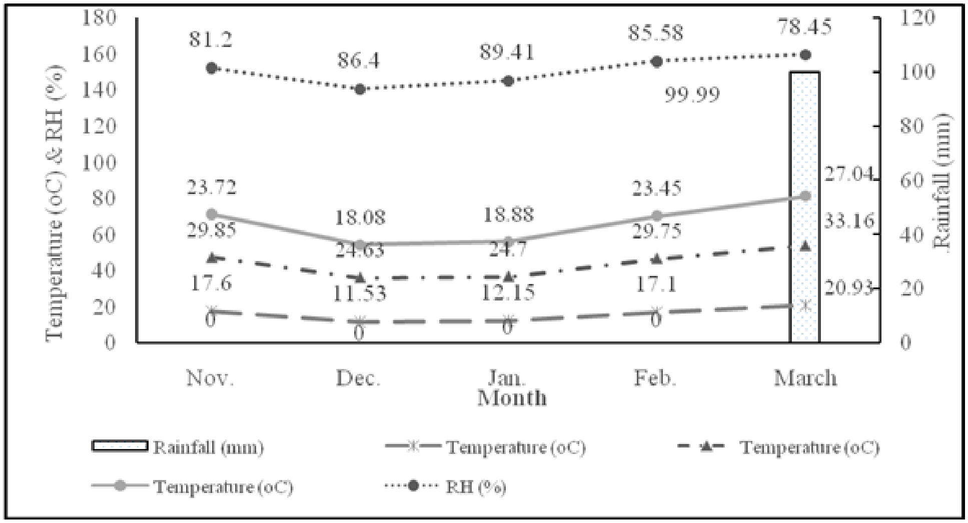

Fig. 1. Weather data (temperature, rainfall and relative humidity (RH)) during experimentation period in 2016-17.

Table 1. The initial physical and chemical properties of soil in the experimental field

Soil properties	Value	Remarks
Sand	21	-
Silt	42	-
Clay	37	-
Textural class	clay loam	-
Particle density (g cm^{-3})	2.61	-
Soil moisture at Field Capacity	28.5-29%	
Bulk density (g cm^{-3})	1.32	
Soil pH	6.20	Slightly acidic soil
Total nitrogen (%)	0.06	<0.12 (critical level), very low
Organic carbon (%)	0.72	low
Organic matter (%)	1.24	low
Available P (µg/g))	21.07	>7.0 (critical level), high
Available S (µg/g)	11.02	>10.0 (critical level), low
Available B (µg/g)	0.14	<0.2 (critical level), low
K (meq 100^{-1} g soil)	0.25	>0.12 (critical level), medium

The experiment was laid out in the field following Strip Plot Design with three replications. The experiment consisted of four potato varieties, namely V_1 = BARI Alu-7 (Diamant), V_2 = BARI Alu-8 (Cardinal), V_3 = BARI Alu-25 (Asterix) and V_4 = BARI Alu-28 (Lady Rosetta) that were allocated in horizontal plot and three irrigations viz. I_1= Single irrigation at 30 DAP (Severe stress), I_2 = 2 Irrigation at

30 and 45 DAP (Mild stress) and I3= Three Irrigation at 30, 45 and 60 DAP (Normal irrigation) that were allocated in vertical plots. The field was prepared thoroughly by plowing with power tiller followed by laddering to obtain a good tilt. The weeds and stubbles were removed from the field and bigger clods were broken into small pieces. The soil particles were pulverized and the land was leveled uniformly for the experimentation. There were five rows in each plot at 60 cm distance and twelve plants in each row at 25 cm distance. Total area of each plot was 9.0 m^2 (3.0 m × 3.0 m). Tubers of different varieties were kept in a well-ventilated room and allowed to sprouting in diffused light for obtaining healthy sprout prior to planting. Tubers of different varieties were kept in a well-ventilated room and allowed to sprouting in diffused light for obtaining healthy sprout prior to planting. Sprouted seed tubers were planted on 20 November, 2016. Sprouted whole tubers were planted following ridge method. Ridge was made by earthing up of side soils**.** Plant nutrients (N-P-K-S-Zn-B) were applied @ 150-44-130-22-3-1 kg/ha in the form of urea, TSP, Muriate of Potash, Gypsum, Zinc oxide and Boric acid, respectively. Cowdung was applied @ 10 t/ha during final land preparation. Full dose of P, S, Zn, B, and half of N were applied in furrows at the time of planting and then mixed with soil so that the tubers do not come in contact with fertilizers. The remaining half of N was applied as top dress at 35 days after planting (DAP).

Intercultural operations such as weeding, earthing up were done manually. After spading the soil between the rows, weeds were removed. Earthing up was done two times during growing period. First earthing up was done at 35 DAP when the plants attained a height of 15-20 cm from the ground, the second one was done after 20 days of first earthing up. Before first earthing up, the remaining half N was applied. Furadan 5G @ 10 kg/ha was applied during the final land preparation to control ant, mite, cutworm, aphid and other soil borne insects. Malathion (0.2%) was sprayed to the crops in two installments at 45 and 60 DAP to control insects. The crops were sprayed with Dithane-M 45 (a.i. Mancojeb) (0.2%) and Ridomyl Gold (a.i. Mancozeb + Metaloxyl) (0.2%) alternatively five times at 30, 40, 50, 65 and 75 DAP to prevent late blight infection and other diseases of potato. Haulm pulling was done before seven days of harvest. Hardening of tuber and setting up of skins were allowed for 8 days under the soil and there after tubers were harvested on 23 February, 2017. Tubers were collected carefully with the help of spade without any injury. Data were recorded on plant height (cm), number of stems/hills, foliage coverage (%), plant vigour, tuber dry matter (%), tuber fresh weight/plant, tuber fresh yield/ha, number of tubers/plants, individual tuber weight (g), Stress susceptibility index (SSI) and Stress tolerance index (STI). Foliage coverage (%) was recorded at 45 and 60 DAP with a 1 m x 1 m wooden frame having 100 gaps (10 cm x 10 cm). By placing the quadrant on the foliage of the crops and counting the blank gaps and then foliage coverage (%) were estimated by subtracting the blank gap value from 100 and expressed in percentage. The plant vigour was recorded on the basis of phenotypic expression of plants on eye estimating using arbitrary CIP 1-9 scale, where, 1=poor, 9=vigorous (Moonsat, 2014). Tuber dry matter (%) was determined by drying the tuber slices at 70 ˚C for 72 hours in drying oven according to the method of Dogras *et al.* (1991).

Stress susceptibility index (SSI) was calculated according to the formula given below (Fischer and Maurer, 1978):

Stress susceptibility index (SSI) = $(1 - \frac{Y_{si}}{Y_{pi}})/SI$; (Fischer and Maurer, 1978)

Where, Y_{Si} and Y_{Pi} = yield of cultivar under stress and normal conditions, respectively and $(SI = \frac{Y_{si}}{Y_{pi}})$

Stress tolerance index (STI) was calculated according to the formulae given below (Fernandez, 1992):

Stress tolerance index (STI) = $\frac{Y_{si} \times Y_{SI}}{(Y_{mp})2}$

Where, Y_{Si} and Y_{Pi} = yields of cultivar under stress and normal condition, respectively. Y_{mp} = average yield of all varieties under normal condition.

The water amount used was regularly calculated according to the collected evaporation of a Class A Basin using the equation: IW/CPE = 0.8 where IW=the amount of irrigation water (mm) and CPE=the collected evaporation calculated from evaporation pan (mm). Application of measured amount of irrigation water (IW): A calibrated watering container of 100 liters volume was used to apply measured amount of irrigation water. Amount of precipitation was measured by a udometer and daily evaporation by a Class A evaporation pan. For monitoring soil moisture at a regular interval to find out the irrigation requirement and irrigation timing Electronic 4in1 Soil Survey Instrument was used. The collected data on various parameters were statistically analyzed using the Statistix 10 software program. Mean values were compared using the least significant difference (LSD) test at the 1% or 5% level of probability.

Results and Discussion

The results obtained from the experiment are presented and discussed character wise under separate headings in this chapter. Plant height, number of stems/hill, foliage cover and plant vigour were significantly influenced by various potato varieties and water stress treatments (Tables 2, 3 and 4)

Plant height (cm) at 60 days after planting

The longest plant (60.43 cm) was obtained from V_3 which was statistically similar to V_4 (51.53 cm). This corroborates the results of Amanullah *et al.* (2010) who recorded similar increasing pattern in different potato varieties viz. Binella, Cardinal, Chamak and Heera. The influence of different levels of water stress treatments (levels of irrigations) on plant height was found significant at 60 DAP. The tallest plant (61.58 cm) was found in I_3 (no stress condition), while, the shortest plant (40.11cm) was found in I_1 (severe water stress) at 60 DAP. At 60 DAP, in severe water deficit stress (I_1) condition, the variety V_3 gave the maximum plant height (43.81 cm) which was statistically similar to V_4 and V_1 and the variety V_2 recorded the lowest plant height. In well watered condition (I_4), the variety V_4 produced the highest plant height (74.67 cm) followed by V_3 (65.33 cm) and V_1 (60.78 cm), and the V_2 gave the lowest plant height. Across varieties, plant height was decreased significantly with an increase in the water deficit. Water stress is known to suppress cell expansion and cell growth due to low turgour pressure. Our results confirm the findings of Jaleel *et al.* (2009).

Number of stems per hill at 60 days after planting

The maximum number of stems (7.08) per hill at 60 DAP was found in V_4, which was statistically similar to V_2. The larger seed tubers showed the trend to produce a greater number of sprouts than the smaller seed tubers correspondingly gave the greater number of stems per hill. The highest number of stems (7.24) per hill at 60 DAP was found in I_3 which was statistically dissimilar with other treatments. At 60 DAP the maximum number of stems/hill was recorded from V_4 (8.17/hill) which was identical with V_3 (7.60) and then followed by V_2 (6.63/hill) and V_1 (6.27/hill) with no significant difference between V_1 and V_2 at well watered condition (3). At mild water stress condition (I_2) the variety V_4 gave the highest number of stems (7.23/hill) which was statistically similar to the rest all three varieties (V_1, V_2 and V_3), whereas at severe water stress condition (I_1), the variety V_4 produced the maximum number of stems (5.83/hill) being identical with V_3 and V_1, and the variety V_2 gave the lowest number of stems/hills. Similar findings showing the effects of water deficit stress on number of stems per hill were also reported earlier by Deblode and Ladent (2001).

Foliage coverage (%) at 60 days after planting

The best foliage coverage 93.11% at 60 days after planting (DAP was found in both V_4 and V_3 followed by V_2 (74.11%) and V_1 (72.78%) with no significant difference between them. This deviation from our findings might be due to differences in climatic conditions. Foliage coverage is an important factor for a variety as it is directly related to the photosynthetic area. The highest coverage at earlier stage may ensure early bulking. Better foliage coverage resulted in increased photosynthesis rate and high total tuber yield (Saika and Deka, 2006).

The best foliage coverage 89.00% at 60 DAP was found in I_3 followed by I_2 (82.92%) and the lowest foliage coverage 76.42% was found in I_1 at 60 DAP. At 60 DAP, when well water condition was fulfilled, the topmost foliage coverage (97.67%) was recorded from V_4 which was statistically similar to V_3 (95.00%) and the lowest foliage coverage (65.00%) was obtained from V_1 which was statistically similar to V_2. At severe water deficit stress condition (60 DAP), the V_4 gave the highest foliage coverage (88.33%) followed by V_3 (86.67%). Fleisher *et al* (2008) reported that water deficit stress affected potato canopy architecture by decreasing leaf size and leaf expansion rate while limiting formation of new leaves and increasing the rate of senescence.

Plant vigor at 60 days after planting

The highest plant vigor (9.07) was observed in V_4 which was statistically similar to V_3 (8.77) and the lowest (6.04) plant vigor was observed in $V_{1.}$ The best plant vigor (8.65) was found in I_3 which was statistically dissimilar with other treatments. At 60 DAP, the highest plant vigor (9.77) was found in V_4 which was identical with V_3 (9.70) and the minimum plant vigour was recorded in V1 at well watered condition (I_3). At 60 DAP, in severe water stress condition, the variety V_4 recorded the maximum plant vigour (8.27) which was closely followed by V_3 (7.63) and the variety V_1 had the lowest plant vigour (5.33) which was statistically similar to V_2 (7.13)..The result indicated that the plant vigour of potato was influenced by the moisture present in the soil. Plant vigor also depends on the seed quality, seed size and potentiality of the genotypes, infection of virus, soil born and seed borne diseases.

Table 2. Main effect of variety on plant height, number of stems per hill, foliage coverage and plant vigor of potato at 60 DAP

Variety	Plant height (cm)	Stems/hill (no)	Foliage coverage (%)	Plant vigor
V_1	49.01	5.82	72.78	6.044
V_2	41.65	5.70	74.11	6.97
V_3	60.43	6.62	91.11	8.77
V_4	51.53	7.08	93.11	9.07
LSD	6.43	0.93	4.53	0.54
CV (%)	12.62	12.85	4.74	6.97

V_1= BARI Alu-7 (Diamant), V_2= BARI Alu-8 (Cardinal), V_3= BARI Alu-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta).

Table 3. Main effect of irrigation on plant height, number of stems per hill, foliage coverage and plant vigor of potato at 60 DAP

Variety	Plant height (cm)	No. of Stems/hill	Foliage coverage (%)	Plant vigor
I_1	40.11	5.12	76.42	6.81
I_2	50.28	6.56	82.92	7.98
I_3	61.58	7.24	89.00	8.65
LSD	6.93	0.34	3.81	0.63
CV (%)	11.98	4.74	4.06	7.07

I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two irrigations at 30 and 45 DAP (Mild stress) and I_3= Three irrigations at 30, 45 and 60 DAP (Normal Condition-no water stress)

Table 4. Interaction effect of variety and irrigation on plant height, number of stems per hill, foliage coverage and plant vigor of potato at 60 DAP

Variety x Irrigation	Plant height (cm)	No. of Stems/hill	Foliage coverage (%)	Plant vigor
$V_1 I_1$	38.00	4.70	65.00	5.33
$V_1 I_2$	48.23	6.20	71.67	6.87
$V_1 I_3$	60.78	6.57	81.67	7.13
$V_2 I_1$	35.57	4.17	65.67	6.00
$V_2 I_2$	39.85	6.30c	75.00	6.90
$V_2 I_3$	49.53	6.63	81.67	8.00
$V_3 I_1$	43.81	5.80	86.67	7.63
$V_3 I_2$	59.52	6.47	91.67	8.97
$V_3 I_3$	65.33	7.60	95.00	9.70
$V_4 I_1$	43.05	5.83	88.33	8.27
$V_4 I_2$	50.00	7.23	93.33	9.17
$V_4 I_3$	74.67	8.17	97.67	9.77
LSD	10.50	1.17	6.52	0.93
CV (%)	4.73	8.48	2.93	3.33

V_1= BARI Alu-7 (Diamant), V_2= BARI Alu-8 (Cardinal), V_3= BARI Alu-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta).

I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two irrigations at 30 and 45 DAP (Mild stress) and I_3= Three irrigations at 30, 45 and 60 DAP (Normal Condition-no water stress).

Variation in number of tubers per plant, tuber fresh weight (g)/plant, individual tuber weight (g), tuber fresh yield (t/ha) and Tuber dry matter percentage at 95 days after planting was found significant (Table 5, 6 and 7). The maximum number of tubers/plant (10.78) was found in V_4 which was statistically similar to V_3 (9.61) and the minimum (8.51) was found in V_2 being identical with V_1 (8.53). Variation in number of tubers/plants was also found significant due to the influence of irrigation at 95 DAP. The highest number of tubers/plant (10.88) at 95 DAP was found in I_3 and the lowest tuber number/plant (8.10) was found in I_1. From the above results it is observed that a gradual increase in tuber number/plant was found with the corresponding increase in water supply in all the varieties.

At 95 DAP, in well watered condition, the maximum tuber number/plant (12.42) was found in V_4 followed by V_2 (10.58) which was statistically similar to V_3 (10.47) and V_1 (10.06) (Table 8). At 95 DAP, in severe water deficit water stress condition, the variety V_4 gave the maximum tuber number per plant (9.60), which was statistically similar to V_3 (8.90). From the above results it was observed that water deficit stress reduced the tuber number/plant of potato variety at 95 DAP. Similar results were reported by (Deblonde and Ladent, 2001).

Tuber fresh weight/plant (g) at 95 days after planting

The maximum (407.57g) tuber fresh weight/plant at 95 DAP was found in V_4 which was statistically similar to V_3 (382.40 g) and the minimum tuber fresh weight (291.65g/plant) was found in V_2 being identical with V_1 (302.08 g/plant. The maximum tuber fresh weight (440.01g/plant) at 95 DAP was found in I_3 followed by I_2 (337.25 g/plant) and the minimum tuber fresh weight (260.51g/plant) was found in I_1 (260.15 g/plant). At 95 DAP, in well watered condition, the maximum tuber fresh weight (461.17g/plant) was found in V_4 which was statistically similar to other three varieties (V_3, V_2 and V_1). At 95 DAP, in severe water deficit stress condition, the highest tuber fresh weight (342.84 g/plant) was obtained from V4 closely followed by V_3 (331.50) and the lowest tuber fresh weight was found in V_2 (171.23 g/plant) being identical with V_1 (196.47 g/plant). From the above results it was observed that water deficit stress reduced the tuber fresh yield/plant at 95 DAP in potato variety studied. Lahlou *et al.* (2003) reported that yields are frequently constrained by water deficit (drought) stress because drought stress affects the development and growth of shoots, roots and tubers.

Tuber fresh yield at 95 days after planting

The maximum tuber fresh yield at 95 DAP was found in V_4 (27.15 t/ha) which was statistically similar to V_3 (25.47 t/ha). The maximum tuber fresh yield at 95 DAP was found in I_3 (29.31 t/ha) which was identical with I2 (22.62 t/ha) and the minimum tuber fresh yield at 95 DAP was recorded in I_1 (17.35 t/ha).

At 95 DAP, in well watered condition, the highest tuber fresh yield was found in V_4 ((30.72 t/ha) which was statistically similar with V_3, V_1 and V_2. In severe water deficit water stress condition, maximum tuber fresh was obtained from V_4 (22.83 t/ha) closely followed by V_3 (22.08 t/ha) and the minimum fresh yield was recorded in V_2 (11.40 t/ha) being identical with V_1 (13.08 t/ha). The findings are in agreement with Deblonde and Ladent (2001) and Hassanpanah (2010) who reported that drought treatment adversely affected tuber yield.

Individual tuber weight at 95 days after planting

Individual tuber weight (g) was significantly influenced by variety at 95 days after planting (DAP). The maximum individual tuber weight (39.79 gm) was found in V_3 closely followed by V_4 (37.76 g) and V_1 (34.60 g). There was no significant difference found among V_4, V_2 and V_I in respect of individual tuber weight. The highest individual tuber weight was found in I_4 (40.64 g) closely followed by I_2 (36.82 g) and the least individual tuber weight was found in I_1 (31.49.g). At 95 DAP, in well watered condition, all the four varieties gave the identical individual tuber fresh weight where the maximum individual tuber weight was found in V_1 (42.27 g) and the minimum individual tuber weight was noticed in V_2 (25.00 g) (Table 8). Steckel and Gray (1979) reported that drought-tolerant potato cultivars produced fewer but larger tubers (>40 mm in length), making the yield more marketable than drought-sensitive cultivars.

Tuber dry matter at 95 days after planting

Across varieties, the tuber dry matter content increased as the water deficit stress increased. The highest tuber dry matter at 95 DAP was found in V_3 (22.80%) which was statistically different from other three varieties. The maximum tuber dry matter was found in I_1 (22.77%) which was statistically different from other irrigation treatments. The minimum tuber dry matter at 95 DAP was found in I_3 ((20.32%).

At 95 DAP, in normal condition, the maximum tuber dry matter was found in V_3 (21.37%) which was statistically different from other treatment combinations (Table 7), and the lowest tuber dry matter (19.24%) was found in V_2 (19.24%) which was statistically similar to V_1 (19.71%) and also no significant difference was found between V_4 and V_1 with regard to tuber dry matter content. At 95 DAP, in mild water deficit stress condition, At 95 DAP, in mild water deficit stress, the maximum tuber dry matter content was recorded from V_3 (22.36%) which was statistically similar to V_4 (21.37%) and the minimum tuber dry matter content was found from V_2 (19.99%). In severe water stress condition, the highest tuber dry matter content was found in V_3 (24.38%) followed by V_4 (23.21%) and the lowest dry matter content was recorded in V_2 (21.55%) which was identical with V1 (21.92%). Under water deficit stress condition, the plant might have used the water from the tuber that might increase dry matter content in potato tuber. These findings are in agreement with Levy (1983) who reported that tubers from water stressed plants had higher contents of total sugars and dry matter than well-watered plants. Steckel and Gray (1979) found similar findings that the dry matter content of potato tubers grown under low soil moisture was much higher than in tubers from well-watered plants. Due to the higher moisture content of the tubers and subsequently the significant decrease in the dry matter during drought exposure, the dry matter percentage of potato tubers decreased (Widuri *et al.,* 2020). However, dry matter content significantly increased in BARI Alu-25 (V_3) followed by BARI ALu-28 (V_4) when compared to BARI Alu-8 (V_2) and BARI ALu-7 (V_1).

Table 5. Main effect of varieties on number of tubers/plants, tuber fresh weight /plant, tuber fresh yield, individual tuber weight and tuber dry matter of potato at 95 DAP

Variety	Tubers/plant (no)	Tuber fresh weight/plant (g)	Individual tuber weight (g)	Fresh tuber yield (t/ha)	Tuber dry matter (%)
V_1	8.53	302.08	34.60	20.12	20.78
V_2	8.51	291.65	33.12	19.42	20.21
V_3	9.61a	382.40	39.79	25.47	22.80
V_4	10.78	407.57	37.76	27.15	21.74
LSD	1.21	44.15	5.51	2.94	0.92
Lev. of sig.	**	**	*	**	**
CV (%)	11.22	11.06	13.15	11.07	3.74

V_1= BARI ALU-7 (Diamant), V_2= ARI ALU-8 (Cardinal), V_3= BARI ALU-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta); Lev. of sig. = Level of Significance

Table 6. Main effect of irrigations on number of tubers/plant, tuber fresh weight/plant, tuber fresh yield, individual tuber weight and tuber dry matter of potato at 95 DAP

Irrigation	Tubers/plant (no)	Tuber fresh weight/plant (g)	Individual tuber weight (g)	Fresh tuber yield (t/ha)	Tuber dry matter (%)
I_1	8.10	260.51	31.49	17.35	22.77
I_2	9.10	337.25	36.82	22.62	21.11
I_3	10.88	440.01	40.64	29.31	20.32
LSD	0.70	50.44	4.18	3.36	0.54
CV (%)	6.63	12.86	10.16	12.86	2.23

**= Significant at 1% level of probability; *= Significant at 5% level of probability.

I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two Irrigations at 30 and 45 DAP (Mild stress) and I_3= Three Irrigations at 30, 45 and 60 DAP (Normal); DAP = Days after planting; Lev. of sig. = Level of significance.

Table 7. Interaction effect of variety and irrigation on number of tubers/plants, tuber fresh weight/plant, tuber fresh yield, single tuber weight and tuber dry matter of potato at 95 DAP

Variety X Irrigation	Tubers/plant (no)	Tuber fresh weight/plant (g)	Individual tuber weight (g)	Fresh tuber yield (t/ha)	Tuber dry matter (%)
$V_1 I_1$	7.02	196.47	27.86	13.08	21.92
$V_1 I_2$	8.53	286.09	33.67	19.05	20.71
$V_1 I_3$	10.06	423.68	42.27	28.22	19.71
$V_2 I_1$	6.86	171.23	25.00	11.40	21.55
$V_2 I_2$	8.08	262.80	32.65	17.50	19.99
$V_2 I_3$	10.58	440.92	41.71	29.37	19.24
$V_3 I_1$	8.90	331.50	37.44	22.08	24.38
$V_3 I_2$	9.47	381.43	40.38	25.41	22.36
$V_3 I_3$	10.47	434.28	41.54	28.93	21.67
$V_4 I_1$	9.60	342.84	35.67	22.83	23.21
$V_4 I_2$	10.33	418.71	40.56	27.89	21.37
$V_4 I_3$	12.42	461.17	37.04	30.72	20.64
LSD	1.53	74.69	7.67	4.97	1.12
CV (%)	5.77	8.48	8.13	8.48	1.44

V_1= BARI Alu-7 (Diamant), V_2= ARI Alu-8 (Cardinal), V_3= BARI Alu-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta)

I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two Irrigations at 30 and 45 DAP (Mild stress) and I_3= Three Irrigations at 30, 45 and 60 DAP (Normal); DAP = Days after planting.

Stress susceptibility index (SSI) and Stress tolerance index (STI)

Stress indices were used to screen and identify the stress tolerant genotypes. In the present study, the maximum SSI (150) was recorded in the variety BARI Alu-8 (V_2) which was closely followed by the variety BARI Alu-7 (V_1) (1.32) under severe water deficit stress condition (I_1) (Table 8). The lowest value of SSI was found in BARI Alu-25 (0.58) which was statistically similar to BARI Alu-28 (V_4). The STI value was found maximum (0.82) in the variety BARI Alu-28 (V_4) which was closely followed by the variety BARI Alu-25 (V_3) (0.74) under severe water deficit stress condition (Table 8). Under mild stress condition (I_2) the highest SSI value was recorded in the variety BARI Alu-8 (V_2) (1.73) which was closely followed by the variety BARI Alu-7 (V_1) (1.39) and the lowest SSI value was found in the variety BARI Alu-28 (V_4) (0.39) which was statistically similar to

BARI Alu-25 (V_3) (0.52). Under mild water deficit stress condition (I_2), the maximum STI value was found in BARI Alu-28 (V_4) (1.00) which was identical with BARI Alu-25 (V_3) (0.86) and the lowest STI value was recorded in BARI Alu-8 (V_2) (0.60) closely followed by BARI Alu-7 (V_1). Differences in potato varieties for SSI and STI indices due to water deficit stress were earlier reported by several workers in different crops (Schafleitner *et al*., 2007 and Hassanpanah, 2010). Overall, BARI Alu-25 and BARI Alu-28 were identified as promising varieties for water stress tolerance based on their high stress tolerance index and low stress susceptibility index. Fischer and Maurer (1978) concluded that selection of stress tolerant genotypes should be based on stress susceptibility index (SSI). Deshmukh *et al.* (2004) reported that stress-resistant genotypes should have high stress tolerance index (STI) and minimum stress susceptibility index (SSI).

Yield reduction

The minimum yield reduction under severe water deficit condition (I_1) was recorded in the variety BARI Alu-25 (V_3) (23.68%), followed by the variety BARI Alu-28 (V_4) (25.68%) and the highest yield reduction was noticed in the variety BARI Alu-8 (V_2) (61.18%) followed by variety BARI Alu-7 (V_1) (53.65%) (Table 9). Under mild water stress condition (I_2), the lowest yield reduction was found in BARI Alu-28 (V_4 (9.21%) followed by BARI Alu-25 (V_3) (12.17%) and the highest yield reduction was obtained from BARI Alu-8 (V_2) (40.42%) followed by BARI Alu-7 (V_1) (32.49%). Lower yield reduction indirectly reflected the drought tolerance in varieties V_3 and V_4. Tuber yield reduction due to water stress has been reported in potato by many researchers (Tourneux *et al*., 2003; Schafleitner *et al*., 2007).

Table 8. Stress susceptibility index and stress tolerance index of potato varieties under moderate and severe water deficit

Variety	Stress susceptibility index (SSI)		Stress tolerance index (STI)	
	Severe water stress (I_1)	Mild water stress (I_2)	Severe water stress (I_1)	Mild water stress (I_2)
V_1	1.32	1.39	0.43	0.63
V_2	1.50	1.73	0.39	0.60
V_3	0.58	0.52	0.74	0.86
V_4	0.63	0.39	0.82	1.00
LSD	0.61	0.65	0.17	0.20
CV (%)	30.83	33.23	14.31	13.14

V_1= BARI Alu-7 (Diamant), V_2= ARI Alu-8 (Cardinal), V_3= BARI Alu-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta); I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two Irrigations at 30 and 45 DAP (Mild stress) and I_3= Three Irrigations at 30, 45 and 60 DAP (Normal); DAP = Days after planting.

Table 9. Tuber fresh yield reduction percentage in severe and mild water deficit condition

Variety	Tuber fresh yield (t/ha) reduction (%) at 95 DAP	
	Severe water stress (I_1)	Mild water stress (I_2)
V_1	53.65	32.49
V_2	61.18	40.42
V_3	23.68	12.17
V_4	25.68	9.21
Mean	41.05	23.57

V_1= BARI ALU-7 (Diamant), V_2= ARI ALU-8 (Cardinal), V_3= BARI ALU-25 (Asterix) and V_4= BARI Alu-28 (Lady Rosetta); I_1= Single irrigation at 30 DAP (Severe stress), I_2 = Two Irrigations at 30 and 45 DAP (Mild stress) and I_3= Three Irrigations at 30, 45 and 60 DAP (Normal); DAP = Days after planting.

Conclusion

The results of the experiment revealed that almost all the physio-morphological and yield contributing characters were significantly influenced by variety as well as water deficit stress condition independently and their combinations. Reduction of fresh tuber yield, individual tuber weight and tuber number/plant at 95 days after planting were considerably higher in well watered condition than those in water deficit stress conditions. But higher tuber fresh weight/plant and tuber fresh yield) were produced by BARI Alu-25 (Asterix) followed by BARI Alu-28 (Lady Rosetta) in both severe and mild water deficit stress conditions as well as well watered condition. BARI Alu-25 (Asterix) showed the lowest stress susceptibility index (SSI) and the highest stress tolerance index (STI) followed by BARI ALu-28 (Lady Rossetta). Among the varieties, in terms of water use efficiency in severe and mild water deficit condition, the best performance was recorded in BARI Alu-28 followed by BARI Alu-25. Therefore, among the varieties, BARI Alu-25 (Asterix) and BARI Alu-28 (Lady Rosetta) may be considered for water deficit stress tolerant varieties as these showed better stability in yield and yield contributing characters under water deficit stress conditions.

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COMBINED EFFECT OF NAA AND BAP ON PROCOCORM LIKE BODIES (PLBs) DERIVED PLANTLETS PRODUCTION FOR COMMERCIAL PROPAGATION OF *DENDROBIUM SONIA* ORCHID

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Abstract

The experiment was conducted to find out the optimum concentration and combination of plant growth regulators (PGRs) and their effects on *in vitro* growth and development of *Dendrobium Sonia* orchid. The experiment was caried out at the USDA Biotechnology Laboratory, Department of Biotechnology, Bangladesh Agricultural University, Mymensingh during the period from February 2009 to May 2010. The experiment was laid out in Completely Randomized Design (CRD) with five replications. Protocorm-like bodies (PLBs) were inoculated as explants on half MS medium supplemented with four levels (0.0, 0.5, 1.0, 2.0 and 4.0 mgL^{-1}) of Naphthalene acetic acid (NAA) and 6-Benzylaminopurine (BAP) independently to proliferate and multiply the PLBs. Then, these multiplied PLBs were cultured on different concentrations and combinations of NAA (0.0, 0.5, 1.0, 2.0 and 4.0 mgL^{-1}) and BAP (0.0, 0.5, 1.0, 2.0 and 4.0 mgL^{-1}) for the growth and development of *Dendrobium Sonia* plantlets. The maximum fresh weight of PLBs (3.5 g), the highest percentage of regenerated plantlets (95%) was obtained from the combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP. At the same time, maximum number of shoots (6.40) as well as length of shoot (4.82 cm) and fresh weight of single shoot (0.414 g) was also achieved at this combination. Similarly, the highest number of leaves (6.00), longest leaf (2.36 cm) and width of leaf (0.78 cm) was observed from 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP. Moreover, the treatment combination, 0.5 mgL^{-1} each of NAA + BAP was found to be the best for producing maximum number of roots (6.40), length (2.82 cm) and fresh weight of roots (0.141 g). In contrast, higher concentration of 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP combinations showed poor results for all parameters.

Keywords: *Dendrobium Sonia*, Plantlets, NAA, BAP, Orchid.

Introduction

Orchids constitute one of the most economically important groups of ornamental plants worldwide and are extensively cultivated as both cut flowers and potted plants, contributing approximately 8% of the global floriculture trade. Their exceptional commercial value is attributed to remarkable floral diversity in terms of color, size, shape, and form, as well as their long-lasting blooms, which make

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them highly desirable in domestic and international markets (Tokuhara and Mii, 2001). In addition to their ornamental appeal, orchids possess multifaceted uses, including applications in perfumery, traditional medicine, adhesives, and food and beverage flavoring, further enhancing their economic significance (Goh *et al.,* 1992). Bangladesh possesses favorable climatic conditions for orchid growth throughout the year, offering substantial potential for orchid cultivation and commercialization. However, despite suitable environmental conditions, the orchid industry in Bangladesh remains at an early developmental stage compared to other orchid-producing countries. Globally, commercial orchid cultivation for both plant sale and cut flower production has expanded into a major industry, generating millions of dollars annually (Singh, 1998). Among orchids, *Dendrobium* is the most popular orchid, with amazing variants like Emma white that are praised for their purity of blossoms and long shelf life (Vendrame, 2008). In Bangladesh as well, *Dendrobium* is one of the most popular orchid genera due to its rapid growth, aesthetic appeal, and long-lasting flower spikes (Talukder *et al.,* 2002). In the Asian floriculture market, *Dendrobium* hybrids dominate the cut flower trade. For instance, Thailand exports *Dendrobium* flowers worth over 12 million US dollars annually to European markets (Rao, 1977). *Dendrobium*, though widely cultivated, includes several species that are considered rare or endangered in their native environments (Chen *et al.,* 2014; Ye *et al.,* 2016). Conventional methods of orchid propagation, particularly vegetative propagation, are extremely slow and inefficient, producing only 2-4 plants per year (Nasiruddin *et al.,* 2003), which is inadequate to meet commercial demand or conservation needs. Micropropagation through tissue culture has emerged as a highly effective alternative for the mass propagation of orchids, especially those with slow sexual reproduction and high genetic heterozygosity (Kanjilal *et al.,* 1999). Successful *in vitro* regeneration of *Dendrobium* orchids largely depends on the appropriate combination of plant growth regulators (PGRs) in the culture medium (Aktar *et al.,* 2008). Previous studies have demonstrated that cytokinins such as BAP play a crucial role in protocorm-like body (PLB) induction and shoot regeneration, while auxins like NAA enhance PLB growth and root formation (Fujii *et al.,* 1999; Martin and Madassery, 2006). However, the response to PGRs varies significantly among species and hybrids, making it essential to optimize hormone concentrations empirically for each genotype (Tokuhara and Mii, 1993; Teixeira da Silva, 2013). Recent findings have shown that an optimized combination of BAP and NAA significantly enhances shoot regeneration, while higher auxin concentrations favor effective root development in *Dendrobium* orchids (Hossen *et al*., 2021). Considering the aforesaid factors, the present study was conducted to establish an efficient *in vitro* propagation protocol by standardizing the optimal concentrations of BAP and NAA for enhanced shoot regeneration and high-frequency plantlet production through PLB multiplication in *Dendrobium Sonia* orchid.

Materials and Methods

The experiment was carried out at the USDA Biotechnology Laboratory, Department of Biotechnology, Bangladesh Agricultural University, Mymensingh durin February 2009 to May 2010, to investigate the effect of NAA and BAP on Protocorm Like Bodies (PLBs), shoot regeneration and multiplication and rooting of *Dendrobium sonia* orchid. In this experiment, *in vitro* multiplied shoots were cultured on ½ MS medium (Murasihge and Skoog, 1962) supplemented with different combinations of NAA (0.0, 0.5, 1.0, 2.0 and 4.0 mg L^{-1}) and BAP (0.0, 0.5, 1.0, 2.0 and 4.0 mgL^{-1}). The medium was supplemented with 3% sucrose as carbon source and solidified with 0.3% gelrite. The pH of the medium was adjusted to 5.8 before autoclaving. PLBs of *Dendrobium Sonia* orchids were used as explants. These PLBs were initiated earlier and maintained in the Tissue Culture Laboratory of the Department of Biotechnology. One-month-old *in vitro* grown PLBs were used as explants. PLBs were cultured on ½ MS medium supplemented with different concentrations of BAP and NAA individually for 60 days to investigate their effects on the proliferation and multiplication of PLBs. In each vial, four uniform PLBs were cultured. Gelrite was dissolved by boiling the mixture and about 20 ml medium was dispensed into each vial. The culture vials containing 20 ml media were autoclaved at $121^{O}C$ for 20 min at 1.16 Kg cm^{-2} pressure. The culture vials were maintained in a growth chamber at $25\pm1^{O}C$ under 16 hours photoperiod, illuminated with fluorescent tubes of 50 µmol $m^{-2}s^{-2}$. Data were collected at 60 days after culture for the following parameters: fresh weight of PLBs, percentage of PLBs, number of multiple shoots per explants, length of shoot, weight of shoot, number of leaves per plantlet, length and width of leaves, number and fresh weight of roots, length of roots. The experiment was laid out in Completely Randomized Design (CRD) with five replications. The analysis of variance was performed, and means were compared using Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984). Well rooted shoots were removed from culture vials, thoroughly washed with running tap water to remove residual medium and transferred to earthen pots containing a mixture of coconut husk. The pots were then kept in a shade house and irrigated with mist.

Results and Discussion

In vitro regeneration of plantlets offers a feasible propagation method for orchid and can be utilized for year-round and rapid propagation of orchid plants. The subsequent growth and effective shoot and root development on suitable medium, acclimatization and plantlet establishment in pot play a vital role in orchid production. The results obtained from the experiments are presented and discussed in the following Table 1 and Fig.1 & 2.

In the present study, early *in vitro* grown Protocorm Like Bodies (PLBs) and PLBs derived plantlets of *Dendrobium Sonia* were cultured on ½ MS medium supplemented with different combinations of NAA and BAP as well as data were collected after 60 days of culture. The highest fresh weight of PLBs (3.5 g) was obtained for the combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP followed by 0.0 mgL^{-1} NAA + 0.5 mgL^{-1} BAP and whereas the lowest fresh weight of PLBs (0.1 g) found on 4.0 mgL^{-1} NAA + 0.0 mgL^{-1} BAP (Fig. 1 & Plate. a). So, it is assumed that plant growth regulators play a vital role in PLBs growth. A low concentration of auxin and cytokinin had an influence on the PLBs in this study. The effects of auxin and cytokinin on *in vitro* induction, proliferation, and regeneration of PLBs of orchids are reported by several researchers (Niknejad *et al.,* 2011; Mondal *et al.,* 2013; Chew *et al.,* 2018; Chookoh *et al.,* 2019). The finding of the present study was agreed with the findings of Khatun *et al.,* (2010). They found the highest PLBs proliferation in the medium combination of 1.0 mgL^{-1} NAA and 1.0 mgL^{-1} BAP for *Dendrobium* hybrid. Similarly, the maximum percentage of plantlets (95.00%) was observed at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP, while the least percentage (4%) was found at 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP (Fig. 2 & Plate. b). It is observed that the growth of PLBs was severely reduced when the concentration increased further. The efficacy of multiple shoot formation with the combinations of BAP and NAA (Table 1 & Plate. a-e). After 60 days of culture PLBs regenerated plantlets produced multiple shoots which varied from 1.00 to 6.4 shoots per plant (Table 1& Plate. b). The highest number of multiple shoots (6.4) was observed for the combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP (Table 1& Plate. c), whereas the lowest number of multiple shoots found from control treatment after 60 days of culture. This result was supported by Polonca *et al.,* (2004) who showed the same was amount of BAP and NAA containing medium performed best for shoot multiplication. Moreover, the longest shoot length (4.82 cm) was also observed in 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP whereas the shortest (1.67 cm) was observed at 4.0 mgL^{-1} NAA + 0.0 mgL^{-1} BAP (Table 1 & Plate. d, e). Results are in agreement with the findings of Khatun *et al.* (2008) who reported that lower concentration of auxin and cytokinin favoured the enhancement of plantlet growth. Similarly, Prasad *et al.,* (2001) and Khatun *et al.* (2010) found that the highest mean shoot height was obtained from 1.0 mgL^{-1} each of BAP + NAA on MS medium.

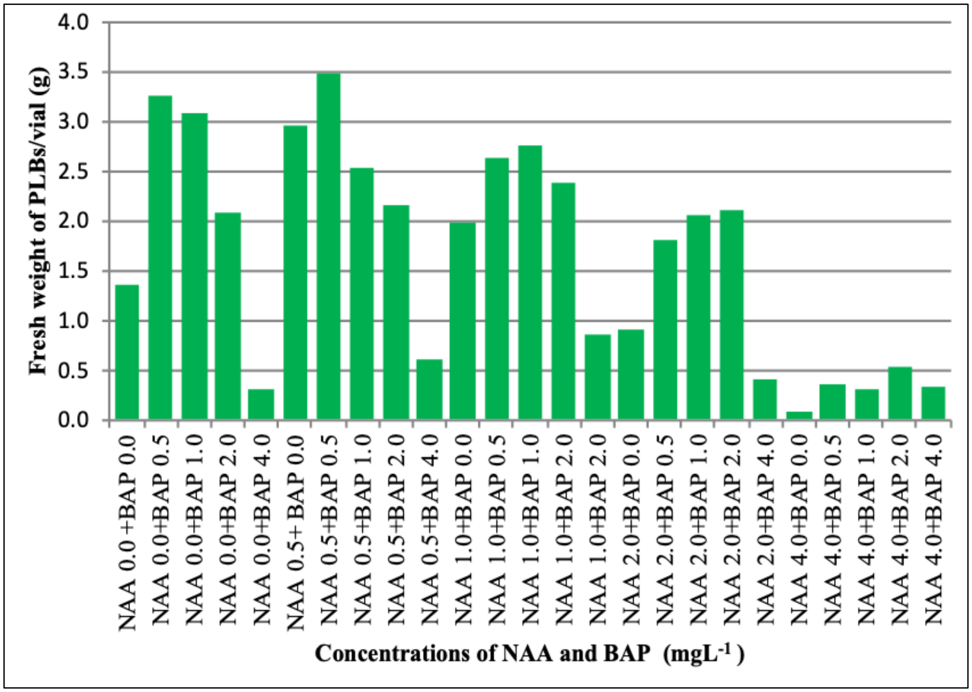

Fig. 1. Combined effect of different levels of NAA and BAP on *in vitro* fresh weight of PLBs per vial after 60 days of culture.

The number, length and width of leaves per plantlet were significantly influenced by the combined effect of NAA and BAP. The highest number of leaves (6.0) was obtained from 0.5 mgL^{-1} each of NAA + BAP (Table 1 & Plate. d, e), while, the minimum number (1.0) was recorded at 4.0 mgL^{-1} each of NAA + BAP. These findings are in agreement with the findings of Prasad *et al.* (2001). Furthermore, the largest leaf (2.36 cm) was found in the medium containing 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP whereas shortest (0.74 cm) leaf was observed from the medium containing 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP (Table 1 & Plate. d, e). According to Khatun *et al.* (2010) the highest leaf length was obtained from 1.0 mgL^{-1} of each NAA + BAP. In addition, the highest width (0.78 cm) of leaf was found from the combined use of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP (Table 1 & Plate. 3. d, e).

The lowest width (0.28 cm) of leaf was recorded from 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP after 60 days of culture. The combined application of NAA and BAP significantly influenced the number, length, and weight of roots. After 60 days of culture, the maximum number of roots (6.40) was obtained from the medium containing 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP whereas the minimum number of roots (2.00) were found from the each 4.0 mgL^{-1} NAA + BAP (Table 1 & Plate. e). These results were supported by Nayak *et al.,* (1998) who observed that NAA and

BAP combination induced rooting in regenerated shoots thereby producing complete plantlets. Similarly, Vij and Kaur (1998) found a positive effect of NAA and BAP to promote rooting in multiplied shoots. After 60 days of culture, the longest root (2.82 cm) was obtained from the medium containing a combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP, while the shortest root (0.88 cm) was obtained from 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP (able 1 & Fig. 3. e). The present result is supported by Khatun *et al.* (2010) who reported that the maximum root length was obtained from 1.0 mgL^{-1} NAA + 1.0 mgL^{-1} BAP.

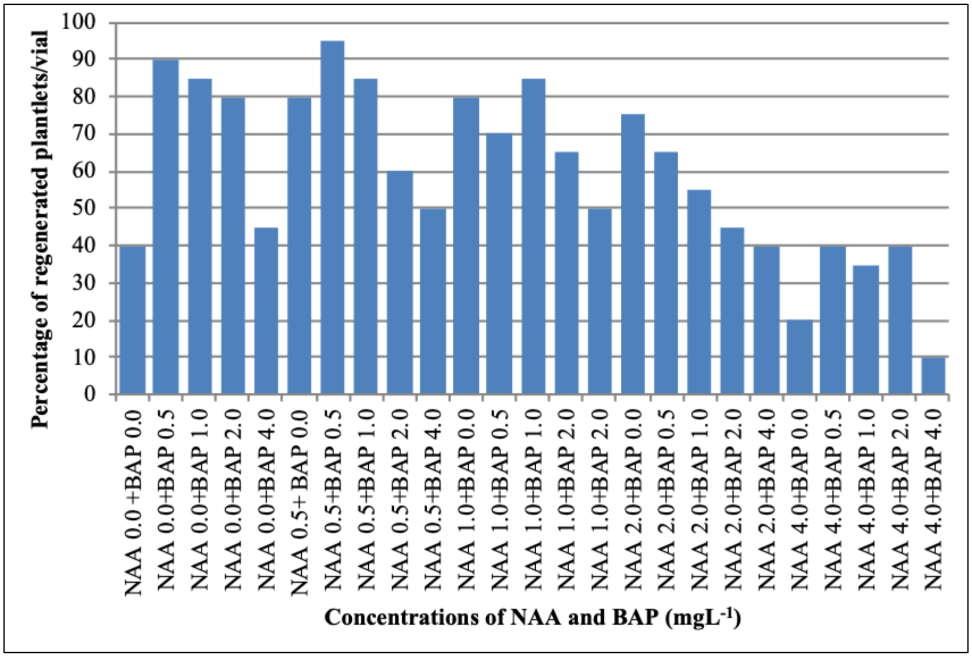

Fig. 2. Combined effect of different levels of NAA and BAP on *in vitro* percentage of PLBs regenerated plantlets after 60 days of culture.

The highest fresh weight of roots (0.141 g) was recorded at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP while the lowest (0.067 g) was from 4.0 mgL^{-1} NAA + 4.0 mgL^{-1} BAP after 60 days of culture (Table 1). This result supported by Khatun *et al.,* (2005) who showed that 0.5 mgL^{-1} each of BAP and NAA performed better growth and development of *Dendrobium Sonia* orchid root.

The result of this study supports the establishment of a protocol for *in vitro* mass propagation of *Dendrobium Sonia*. In the combined effect of NAA and BAP into ½ MS medium, the highest number of shoot and their length and weight of shoot were obtained at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP. Similarly, the maximum number of leaves, width and length of leaf was also found at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP after 60 days of culture. Moreover, half the strength of MS medium containing a

Table 1. Combined effect of different levels of NAA and BAP on growth and development of plantlets after 60 days after of culture

Treatments		No. of shoots	Length of shoot (cm)	Fresh wt. of single shoot (g)	No. of Leaves	Length of leaf (cm)	Width of leaf (cm)	No. of roots	Length of root (cm)	Fresh wt. of roots (g)
NAA (mgL^{-1})	BAP (mgL^{-1})									
0.0	0.0	3.20 efg	2.48 b-f	0.064 b	4.00 a-e	1.36 c-i	0.48 g-k	3.00 fgh	1.10 c-f	0.115 a-e
	0.5	5.20 ab	4.04 ab	0.296 a	4.90 a	2.10 ab	0.66 a-f	5.00 a-d	1.52 a-d	0.14 ab
	1.0	4.60 abc	3.99 ab	0.200 ab	4.80 ab	1.88 a-d	0.72 a-d	5.20 a-d	1.62 ab	0.12 a-d
	2.0	4.20 bce	3.39 a-e	0.164 ab	4.20 a-d	1.66 bg	0.58 c-i	4.20 b-f	1.44 a-e	0.111 a-e
	4.0	2.80 fgh	1.76 ef	0.056 b	2.60 def	0.84 hi	0.42 i-k	3.20 e-h	1.00 ef	0.091 b-e
0.5	0.0	3.40 d-g	2.66 b-f	0.138 ab	3.60 a-f	1.42 b-i	0.56 d-j	5.00 a-d	1.86 a-d	0.115 a-e
	0.5	6.40 a	4.82 a	0.414 a	6.00 a	2.36 a	0.78 a	6.40 a	2.82 a	0.141 a
	1.0	5.00 abc	3.60 abc	0.391 a	4.40 abc	1.94 abc	0.64 a-g	5.40 a-d	2.62 ab	0.128 abc
	2.0	4.60 abc	3.30 a-f	0.345 a	4.40 abc	1.68 b-g	0.58 c-i	4.80 a-e	1.96 abc	0.11 a-e
	4.0	2.80 fgh	2.08 c-f	0.115 ab	3.60 a-f	1.16 e-i	0.46 h-	3.20 f-h	1.40 a-e	0.08 cde
1.0	0.0	1.80 hij	3.10 b-f	0.081 b	4.80 ab	1.52 b-h	0.70 a-d	5.80 ab	2.42 ab	0.125 abc
	0.5	5.30 ab	3.58 a-d	0.395 a	4.20 a-d	1.74 a-f	0.74 abc	5.80 ab	2.88 a	0.136 ab
	1.0	4.40 a-d	4.11 ab	0.405 a	4.20 a-d	1.80 a-e	0.76 ab	5.40 a-d	2.76 a	0.125 abc
	2.0	4.00 cde	3.31 af	0.126 ab	3.80 a-e	1.42 c-i	0.68 a-e	5.60 abc	2.60 ab	0.111 a-e
	4.0	2.40 ghi	2.01 c-f	0.079 b	4.00 a-e	0.96 hi	0.68 a-e	3.20 e-h	1.73 a-f	0.083 cde
2.0	0.0	1.10 jk	2.50 b-f	0.12 b	3.80 a-e	1.06 f-i	0.52 f-k	3.20 e-h	2.00 abc	0.121 abc
	0.5	3.80 c-f	3.03 b-f	0.085 b	3.60 a-f	1.24 di	0.60 b-h	4.00 c-g	2.56 ab	0.135 ab
	1.0	3.40 d-g	2.70 b-f	0.082 b	3.20 b-f	1.18 e-i	0.56 d-j	4.60 b-f	2.32 ab	0.12 a-d
	2.0	3.20 efg	2.52 b-f	0.082 b	4.00 a-e	1.04 ghi	0.50 f-k	3.20 e-h	1.98 abc	0.10 a-e
	4.0	2.00 hij	1.91 def	0.071 b	3.00 c-f	0.94 hi	0.40 jkl	3.00 fgh	1.64 a-c	0.071 de
4.0	0.0	1.00 k	1.67 f	0.046 b	2.80 c-f	0.88 hi	0.40 jkl	2.40 gh	1.00 ef	0.10 a-e
	0.5	2.60 ghi	2.71 b-f	0.056 b	2.40 efg	1.08 f-i	0.42 i-l	3.20 e-h	1.26 b-f	0.125 abc
	1.0	2.40 ghi	2.21 c-f	0.051 b	2.80 c-f	0.92 hi	0.42 i-l	3.80 d-g	1.36 a-f	0.121 abc
	2.0	1.60 ijk	2.08 c-f	0.05 b	2.00 fg	0.90 hi	0.38 kl	3.80 d-g	1.24 b-f	0.113 a-e
	4.0	1.20 jk	2.47 b-f	0.049 b	1.00 g	0.74 i	0.28 l	2.00 h	0.88 f	0.067 e
CV (%)		23.21	3.74	8.40	24.88	9.14	13.54	20.82	7.29	1.94

In a column, mean values followed by a common letter are not significantly different at the 5 % level as per DMRT.

combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP showed also maximum number of roots, the longest root and fresh weight of root. Similarly, the highest weight of PLBs was found at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP. The maximum percentage of plantlets production was observed at 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP. Considering the above results, ½ MS medium supplemented with the combination of 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP could be recommended for commercially large scale of PLBs production, percentage of plantlet regeneration, growth and development of plantlets and root formation of *Dendrobium Sonia* orchid which may be applicable for other *Dendrobium* species. In contrast, the highest concentration of NAA and BAP did not show any advantage.

Finally, the plantlets were taken out from the culture vials carefully and washed under running tap water to remove medium from the basal part of plantlets (Plate. f). Then the basal part of plantlets was wrapped with coconut fiber and set into small earthen pots (Plate. g). The plantlets were kept in the hardening room under shade and supplied water twice daily as mist and gradually exposed to natural light (Plate. g).

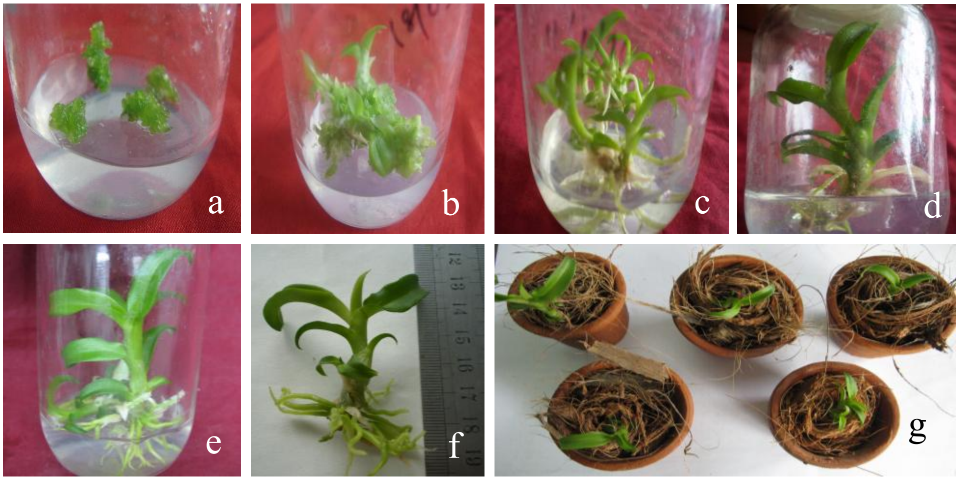

Plate (a-g): Combined effect of NAA and BAP on *Dendrobium Sonia in vitro.*

a. Multiplication of PLBs and development of PLBs. b. Shoot initiation from PLBs. c. Maximum number of shoots proliferation. d. Maximum length of shoot and number of leaf development. e. Maximum number of roots initiation and development. f. Well-rooted plantlet was removed from the culture vial prepared for acclimatization. g. Hardening of *in vitro* raised well-rooted healthy plantlets were transplanted to earthen pots filled with small pieces of coconut husks.

Conclusion

The study demonstrated that the combined application of 0.5 mgL^{-1} NAA and 0.5 mgL^{-1} BAP in ½ MS medium was the most effective for PLBs proliferation, shoot regeneration, leaf development, and root formation in *Dendrobium Sonia*. This optimized protocol ensures high plantlet regeneration (up to 95%) and superior growth performance, making it suitable for large-scale commercial propagation of this orchid. Conversely, higher concentrations of NAA and BAP negatively affected plant growth. Therefore, the standardized medium with 0.5 mgL^{-1} NAA + 0.5 mgL^{-1} BAP may serve as a reliable protocol for efficient orchid micropropagation.

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INFLUENCE OF DIFFERENT SUPPORT SYSTEMS ON VEGETATIVE GROWTH, YIELD ATTRIBUTES AND YIELD OF BLACK PEPPER (*PIPER NIGRUM)*

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AND M. H. M. B. BHUYAN[5*]

Abstract

The experiment was conducted to investigate the effect of various biotic (living trees) and abiotic (non-living RCC pole) support systems on vegetative growth, yield attributes, and berry yield of black pepper (*Piper nigrum* L.) in a long-term field trial conducted from 2014 to 2021 at the Spices Research Sub-station, Bangladesh Agricultural Research Institute (BARI), Jaintiapur, Sylhet. The variety 'Jaintia Golmorich-1' was used in the experiment. The treatment comprised eight different supports *viz.,* Jhika tree (*Lannea coromandelica*), Mandar tree (*Erythrina variegata*), Mango tree (*Mangifera indica*), Jackfruit tree (*Artocarpus heterophyllus*), Wild Jamun tree (*Syzygium cumini*), Carambola tree (*Averrhoa carambola*), Areca nut tree (*Areca catechu*) and RCC pole. The experiment was laid out in a randomized complete block design with three replications. The results based on three years' (2019, 2020 and 2021) average data revealed that the maximum number of productive plagiotropes was found under Wild Jamun and Jackfruit tree, respectively. The highest pooled value of spikes per 0.25 m^2 was recorded in Wild Jamun tree (30.93), while spike length was highest from the vines trailed on Jackfruit tree (12.52 cm). Maximum spike weight (17.56 g) was found from Mango tree, whereas the highest number of berries per spike was observed in the vines trailed on Wild jamun (82.53). The longest maturity duration was observed in Mango support (232.11 days), while RCC pole support showed the shortest (194.46 days). Wild Jamun produced the highest fresh yield (15.98 kg) followed by Jackfruit tree (15.88 kg) but the lowest fresh yield was obtained from the vines supported on Mandar tree (3.04 kg) being statistically similar to Jhika tree (3.09 kg) and RCC pole (3.11 kg). The highest dry yield over three years was found in the vines trailed on Jackfruit tree (5.52 kg) closely followed by Wild jamun tree (5.49 kg) but the lowest pooled mean was recorded from Mandar. The highest dry matter percent were observed under Jackfruit tree (35.36%) followed by Areca nut tree (35.19%), Mango tree (35.05%) and RCC pole (34.55%). The experimental results suggested the uses of Jackfruit and Wild Jamun tree as the best living standards providing structural support and favorable microclimatic, also enhanced reproductive efficiency.

Keywords: Black pepper, *Piper nigram*, living and non-living supports, spike traits, berry yield, Sylhet- hill region.

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Introduction

Black pepper (*Piper nigrum* L.), a valuable spice of the family Piperaceae, is popularly known as 'Golmorich' in Bangladesh. It is often called the "King of Spices," which is one of the oldest and most widely traded spices globally (Mathew *et al.*, 2001; Srinivasan, 2007). Its economic significance is underscored by its widespread use in culinary purpose, traditional medicine and the global spice trade (Devasahayam *et al.,* 2010; Verma, 2018). The global production of black pepper was approximately 525,000 metric tons with Vietnam, Brazil, India and Indonesia contributing over 85% of this volume (FAO, 2022). Despite its tropical origin and relatively simple agronomic requirements, black pepper cultivation poses unique challenges particularly in terms of vertical support as this crop is a perennial climbing vine.

Supports structure are essential for the successful growth and productivity of black pepper vines (Chalermchon *et al.*, 2017). These structures enable the plant to receive adequate sunlight, ventilation, and protect the plant from soil-borne diseases. Traditionally, biotic supports i.e., living trees, have been the predominant choice in many parts of South and Southeast Asia. However, with the intensification of pepper cultivation and a shift towards commercial monocultures, abiotic supports such as concrete, wooden and bamboo poles have gained popularity (George, 1981; Purseglove *et al.*, 1981; Ravindran, 2000; Thangselvabal *et al.*, 2008). Biotic supports such as *Gliricidia sepium*, *Erythrina indica*, and *Albizia lebbeck* offer several advantages, including ecological services like nitrogen fixation, organic matter contribution through leaf litter, and enhancement of biodiversity (Thomas *et al.*, 2008). Conversely, abiotic supports-particularly, concrete poles offer uniformity, structural durability and reduced susceptibility to pests and diseases that can affect host trees. In countries like Vietnam and Brazil concrete supports have facilitated high-density planting and mechanized operations (Menon *et al.*, 1982; Kurien *et al.*, 1985; Reddy *et al.*, 1992; FAO, 2020). Both support systems present a trade-off between ecological sustainability and commercial efficiency. Biotic supports are more environmentally sustainable and inexpensive in the long term but require careful management to prevent nutrient competition and shading (Sivaraman *et al.,* 1999). Additionally, host trees may harbor pests or fungal pathogens that can affect pepper vines (Anandaraj and Sarma, 2003). As many as 31 tree species were found to be serving as good biotic standards (Salam *et al.,* 1991), among them, *Erythrina indica, Erythrina lithosperma, Garuga pinnata*, *Gliricidia sepium*, *Gliricidia maculata, Ailanthus malabarica, Areca catechu,* mango and jackfruit are the popular living supports (Dinesh *et al.*,

2005) for peppers. While, abiotic supports remain free from biological interference as it is resource-intensive and requires higher investment. In warmer regions, concrete poles may also alter the microclimate around vines, potentially stressing the plants during extreme temperatures (Thomas *et al.*, 2008). Despite the widespread use of both systems, empirical studies that evaluate their relative performance-especially in terms of growth parameters, yield, cost-effectiveness, and ecological footprint are limited. This knowledge gap is particularly pronounced in regions where commercial black pepper cultivation is relatively new, such as Bangladesh.

In Bangladesh, black pepper is an emerging crop with considerable potential for commercial cultivation (Ahmed *et al.*, 2010) in north-eastern Sylhet region, south-eastern Chattogram Hill Tracts and some other parts of north-west region. The Bangladesh Agricultural Research Institute (BARI) introduced black pepper as a high-value spice crop in the country aiming to diversify the rural economy, reduce dependency on import and promoting sustainable agriculture in hilly areas (Rahman *et al.*, 2020). The only cultivar currently recommended by BARI is ‘Jaintia Golmorich-1.’However, cultivation practices including the ideal support system for this cultivar under Bangladesh conditions are still to be optimized. Although the findings regarding support systems for successful cultivation of black pepper is available in Southeast Asia, Bangladesh lacks region-specific, comparative agronomic studies on support systems. The findings developed in foreign countries like Vietnam and India are not feasible in our country owing to the variation of socio-economic conditions, landholding patterns and ecological variables. For instance, concrete poles may be cost-effective for large commercial farms but smallholder farmers in Bangladesh may find them financially burdensome without government or institutional support. Biotic supports may provide natural shade and reduce the risk of sun scorch during dry seasons but may also increase fungal disease incidence during prolonged wet periods; while, abiotic supports may facilitate better disease control through improved ventilation but could increase vine exposure to heat and light stress (Purseglove *et al.*, 1981; Anandaraj and Sarma, 2003; Thomas *et al.*, 2008). Therefore, it needs to know the impact of biotic and abiotic supports in black pepper cultivation, especially in the specific context of Bangladesh for developing scalable, farmers-friendly cultivation models. Keeping the above facts in mind, the experiment was carried out to evaluate the influence of biotic and abiotic support systems on vegetative growth, yield attributes and berry yield of black pepper cv. ‘Jaintia Golmorich-1’ under AEZ 22 of Bangladesh.

Materials and Methods

Study Location

The field experiment was conducted at the Spices Research Sub-station, Citrus Research Station (CRS), Bangladesh Agricultural Research Institute (BARI), located at Jaintiapur upazila, of Sylhet District (25.13562° N latitude, 92.13217° E longitude and 34 m altitude). This region lies within the Agro Ecological Zone-22 (Northern and Eastern Piedmont Plains) of Bangladesh and is characterized by small hillocks in the midst of plain lands.

The experimental location experiences a tropical monsoon climate characterized by high humidity, warm temperatures and heavy rainfall. The average annual rainfall ranges from 4,000 to 5000 mm with the majority occurring during the monsoon season (May to September). This includes heavy showers and thunderstorms. While the monsoon season is prominent, there's a shorter dry season typically from November to February with cold and relatively clear weather.

The crop can tolerate a maximum temperature of 40 °C and a minimum temperature of 10°C (Nair *et al.*, 2021). The mean annual temperature fluctuates between 9°C and 32°C and the area typically experiences high humidity (above 70%) year-round making it suitable for black pepper cultivation (Bhuyan *et al.*, 2015). The experimental location is characterized by undulating terrain with well-drained hill soils. The soil is typically sandy loam to silty loam, acidic in reaction and moderately fertile. The soils are strongly acidic with some areas exhibiting extremely acidic conditions (pH < 4.5). Soil pH is a key soil property that determines acidity or alkalinity and influences nutrient availability and crop growth (O'Kennedy, 2022). The variation in soil types and acidity levels can affect crop growth and agricultural practices.

Experimental design and treatments

The experiment was laid out in a randomized complete block design with eight treatments and three replications from 2014 to 2021. Each experimental unit consisted of one standard or support with four black pepper saplings per standards, resulting in a total of 24 black pepper vines). The treatments comprised seven plant species as living (biotic) support and RCC pole as one abiotic support *viz.*, T_1= Jhika tree, T_2= Mandar tree, T_3= Mango tree, T_4= Jackfruit tree, T_5= Wild Jamun tree, T_6= Carambola tree, T_7= Areca nut tree and T_8= RCC (Reinforced Cement Concrete) pole.

Brief description of the biotic and abiotic supports

In this study, seven biotic (living) support species and one abiotic (non-living) support as RCC pole were used. Their brief discussion is furnished below:

Jhika tree (*Lannea coromandelica* (Houtt.) Merr.), a medium to large deciduous tree grows to a height of 10–15 meters with a straight, moderately thick trunk and a rounded spreading crown. The tree exhibits moderate growth and a light to medium canopy density allowing sufficient sunlight penetration for photosynthesis while providing necessary structural support (Orwa *et al.*, 2009). This tree is tolerant to drought conditions; periodic pruning and its deciduous nature ensures reduced shading during the winter months. Additionally, the tree does not strongly compete with shallow-rooted pepper vines for nutrients and water (Sarkar and Bandyopadhyay, 2013).

Mandar tree (*Erythrina variegata* L.), a nitrogen-fixing, deciduous tree is commonly used as a live support in traditional pepper gardens in India and Sri Lanka. It grows rapidly up to 15 m with a straight trunk and minimal lateral branches. Its coarse bark offers excellent anchorage for pepper roots and its light canopy ensures minimal shading, which is essential for balanced photosynthesis and reproductive development in pepper vines (Ravindran, 2000; Zachariah *et al.*, 2004).

Mango tree (*Mangifera indica* L.), is widely grown in the Sylhet region. Although it offers strong structural support due to its robust trunk, its dense spreading canopy can restrict light penetration and air circulation, potentially hampering spike development and fruit set in pepper. Regular pruning is necessary to make mango trees suitable as pepper standards (Nair, 2011).

Jackfruit tree (*Artocarpus heterophyllus* Lam.) is another common support option in Bangladesh. It features a thick trunk and moderate canopy growing 10–15 m tall. It is valued for dual-purpose cultivation—support and fruit yield. However, its broad leaves can create shade stress to the pepper vines if not managed appropriately. Its deep root system ensures limited competition with the shallow-rooted pepper vine (Singh *et al.*, 2006).

Wild Jamun tree (*Syzygium cumini* L) is well adapted to tropical conditions having straight trunk and upright growth that make it physically suitable for pepper vine support. However, its dense canopy requires frequent thinning to maintain optimal light availability for the vine (Ahmed *et al.*, 2010).

Carambola tree (*Averrhoa carambola* L.) is a small size tree (6–8 m) having thin branches and light canopy which offer favorable light conditions during the early stages of vine growth. However, its delicate branching structure and limited height make it less suitable for long-term pepper cultivation unless properly trained and pruned (Ravindran, 2000).

Areca nut tree (*Areca catechu* L.) is a tall, slender palm with its upright growth habit and single smooth trunk make it a common support species for black pepper, especially in Kerala and other parts of South Asia. Its minimal canopy promotes excellent light conditions for pepper (Nair, 2011; Zachariah *et al.*, 2004).

RCC (Reinforced Cement Concrete) pole is a non-living structural support for black pepper vine. RCC poles are durable and uniform in height (15 × 15 cm rectangular shape typically 2.5 m) but they do not contribute to the microclimate regulation, soil enrichment or biodiversity as found in living supports. They are commonly used in modern commercial pepper plantations (Singh *et al.*, 2006; Ahmed *et al.*, 2010).

Crop Establishment and Management

Each support type was planted maintaining 4×4 m spacing on May 2014 and established, where the pepper vines saplings raised from two node cuttings were transplanted on May 2017. The biotic supports were regularly managed with fertilizer, irrigation, pruning and maintained to facilitate vertical vine growth and to reduce excessive shading. The RCC poles of 2.5 m in height were embedded 0.5 m into the soil for structural stability. Prior to planting, the land was cleared, tilled and leveled to ensure uniformity. Four circular pits (45 × 45 × 45 cm) were prepared by digging the soil at the base of each support. The pits were filled with a mixture of topsoil and 5 kg decomposed cowdung, 25 g P and, 100 g dolomite, 20 g S, 1 g B and 1 g Zn during March before rainy season. Four well-rooted black pepper saplings (cv. 'Jaintia Golmorich-1') were transplanted at the base of each support on May 2017. Each sapling was top-dressed with 50 g N and 25 g K in June during rainy season and again was fertilized with 5 kg decomposed cowdung, 25 g N and 25 g K during September after rainy season (Bhuyan *et al.*, 2015). Regular cultural practices were followed included weeding, training of vines along the supports using ropes and pruning of biotic supports to maintain light and airflow. In the following years each vine was administrated with organic and inorganic fertilizers as per BARI recommendations (decomposed cow dung @ 5 kg, P @ 25 g and, dolomite @ 100 g, S @ 20 g, B @ 1 g and Zn@ 1 g. in March–before rainy season, N @ 50 g and K @ 25 g top dressing in June–during rainy season and decomposed cow dung @ 5 kg, N @ 25 g and K @ 25 g during September–after rainy season). Irrigation was applied to the vines during dry spells using a hose pipe system and proper drainage system was maintained to prevent water-logging during the monsoon. A thick (5 cm) organic mulch layer (dry grasses, and leaf litter) was applied around each vine and also around the base of the support trees to conserve soil moisture and to manage soil temperature during winter, as well as to suppress weeds. The vines were infested with several insects and diseases and they were managed with insecticides (Imitaf 20 SL [imidachloprid]) and fungicides (Indofil M-45 [Mancozeb]) based on visual monitoring. Sanitation was strictly followed to minimize the incidence of fungal diseases like foot rot or quick wilt (*Phytophthora capsici*). After two years of plantation, the pepper vines flowered in May 2019 and berries matured in December 2019. Pepper spikes were harvested at physiological maturity, indicated by a color change of the bottom berries from green to yellow or red. Harvesting was done manually and the berries were separated, boiled in hot water (100°C) and oven-dried for 5–7 days (when moisture reached to 10-12%), and stored in moisture-proof containers for further data collection.

Data Collection

Data collection was started after flowering and fruiting of pepper vines. Observations were recorded across three consecutive years 2019, 2020 and 2021. Measurements were recorded during the same phenological stage (active growth and reproductive phases) each year. Data integrity was ensured by standardizing the sampling procedures and calibrating instruments regularly. Data were recorded from all 24 plots (4 vines under one support as 1 plot × 8 treatments × 3 replications). When necessary, sampling was done within a standardized 0.25 m^2 area around each vine. The parameters were grouped into three major categories: vegetative growth traits, reproductive traits and yield traits, which were as follows:

Vegetative growth parameters

Among the vegetative growth parameters vine height (m), vine spreading—E-W and N-S (cm), number of plagiotropes (fruiting vines) per 0.25 m^2, length of individual plagiotropes (cm), number of leaves $lateral^{-1}$ (plagiotrope), average leaf area $lateral^{-1}$ (cm^2) and thickness (diameter) of internode (cm) were recorded.

Reproductive parameters

Among the reproductive parameters number of spikes per 0.25 m^2, individual spike length (cm), individual spike weight (g), number of berries $spike^{-1}$, spike compactness (number of berries cm^{-1} and duration of spike maturity (days) was recorded.

Berry yield and yield attributes

Fresh weight of 100 well-developed berries (g), dry weight of 100 well developed berries (g), volume of 100 berries (cm^3), fresh yield vine^{-1} (kg), dry yield vine^{-1} (kg) and dry matter content (%) in berries were recorded.

Statistical Analysis

All recorded data were analyzed with the help of R 4.2.0 program and mean separation was done by Least Significant Difference (LSD) test at the 5% level of significance ($p \leq 0.05$).

Results and Discussion

Effect of biotic and abiotic supports on vegetative growth parameters

Vine height: The vine height of black pepper ('Jaintia Golmorich-1') was significantly influenced by different biotic and abiotic supports used over the three years of study (2019–2021) (Table 1). Among the treatments, Mango support exhibited the highest vine length across two years (6.50 m in 2020 and 7.14 m in 2021) with pooled data over three years showing a mean of 6.55 m, which was closely followed by Wild Jamun (6.49 m). The maximum vine length in 2019 was obtained from Wild Jamun support (6.12 m) followed by mango support (6.02 m). The pooled means given by mango and wild jamun supports was followed by Jack fruit support (5.63 m). In contrast, the lowest vine length was recorded across the three years with a pooled mean of 2.33 m in Jhika support. RCC pole support gave better result (2.68 m) than Cambola (2.54) and Mandar (2.57) supports across all the years. Areca nut support performed better than others except Mango, Jackfruit and wild Jamun supports.

This variation might be attributed to the structural and physiological characteristics of the support trees. Vigorous and upright-growing trees like mango and Wild Jamun provide a robust vertical scaffold which allows the pepper vines to climb freely and attained impressive lengths. Moreover, the moderate shade under these trees creates ideal conditions for optimal photosynthesis and vine elongation (Nair, 2011). On the other hand, Jhika and Mandar had lower canopy height and moderate trunk strength which may limit the upward growth of the vines. However, these tree species compete with young vines for light and nutrients at the early stages, restricting vine vigor (Ravindran, 2000). Vines trailed on RCC poles exhibited an intermediate length, which was significantly lower than that observed on mango and wild jamun trees but significantly higher than that on Jhika and Mandar trees. This indicates that non-living (abiotic) supports can be useful in tight spaced areas but they may not provide the same growth enhancing microenvironment that suitable living standards (live trees) offered. These findings are in consonance with Anandaraj *et al.* (2014) who reported that black pepper responds well to living standards that provide mechanical support, favorable microclimatic and soil-root interactions.

East–West vine spreading: Significant differences were observed across treatments for vine spreading in East–West direction (Table 1). The widest spread was recorded in Wild Jamun (1.85 m in 2019, 2.15 in 2021 and 1.98 m in pooled mean, respectively) closely followed by Jackfruit support (1.81 m in 2019, 2.15 m in 2020 and 1.97 m in pooled mean, respectively). In 2020, Jackfruit support (1.96 m) performed better than Wild Jamun support (1.95 m) with regard to East-West vine spreading. These results suggested that, the pepper vines on broad-canopy trees benefitted from horizontal support and reduced inter-vine competition allowing lateral branches to expand more freely. In contrast, the narrowest East-west vine spreading was recorded in Areca nut support (0.65 m in pooled) followed by Mandar tree (0.72 m in pooled) and RCC Pole (0.79 m in pooled) in all the three years. The narrowest vine spread in East-west direction probably due to the erect growth habit and relatively narrow vertical structure of Mandar, Areca nut and RCC pole supports, which do not favor horizontal development of plagiotrops (fruiting vines). Due to their relatively lower canopy size and height, thereby limiting lateral branching and light interception (Sasikumar *et al.*, 2016).

North–South vine spreading: In the North–South direction as well, Jackfruit and Wild Jamun supports continued to show superior performance (Table 1). The highest North-South spread was recorded in Jackfruit support (1.90 m in 2020, 2.09 m in 2021, respectively followed by Wild Jamun support (1.86 m in 2020 and 2.05 m in 2021). In 2019, Wild Jamun support gave the maximum North-South spread (1.79 m) followed by Jackfruit support (1.75 m). The similar pooled mean (1.91 m) over three years was produced by both Jackfruit and Wild Jamun supports. In pooled mean, the second highest North-South spread (1.42 m) was recorded in Carambola support. This direction of spreading is critical for maximizing sunlight capture throughout the day and enhancing overall canopy efficiency. The spreading behavior also reflects the adaptability of pepper vines to the canopy architecture of the support trees, where broad and well-structured crowns allow symmetrical development. The minimum North–South spreading was observed with RCC poles (0.66 m in 2019, 0.69 m in 2020, 0.71 m in 2021 with a pooled mean of 0.68 m) being statistically similar with Areca nut support (0.67 m in 2019, 0.69 m in 2020 and 0.72 m in 2021 with a pooled mean of 0.69 m) followed by and Mandar support (0.76 m in 2019, 0.79 m in 2020 and 0.81 m in 2021 with a pooled mean of 0.79 m). Such results gave the idea that, a limited physical structure and a lack of living interaction limit the optimal canopy development. The superiority of Jackfruit and

Wild Jamun as support trees can be attributed not only to physical structure but also the partial shade, organic litter contribution and ecological synergy with black pepper vines. These support trees mimic the traditional models of forest-edge cultivation where black pepper evolved naturally (Nair, 2011; Sasikumar *et al.*, 2016).

Table 1. Effect of biotic and abiotic supports on vine height and vine spreading (E-W and N-S) of black pepper vines

Treatments	Vine height (m)				Vine spreading (m)							
					East–West				North–South			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	2.25	2.33	2.40	2.33	1.43	1.48	1.52	1.48	1.20	1.25	1.29	1.25
Mandar	2.48	2.58	2.65	2.57	0.69	0.73	0.75	0.72	0.76	0.79	0.81	0.79
Mango	6.02	6.50	7.14	6.55	1.07	1.17	1.28	1.17	0.96	1.02	1.13	1.04
Jackfruit	5.15	5.59	6.15	5.63	1.81	1.96	2.15	1.97	1.75	1.90	2.09	1.91
Wild Jamun	6.12	6.36	6.99	6.49	1.85	1.95	2.15	1.98	1.79	1.86	2.05	1.91
Carambola	2.44	2.56	2.63	2.54	1.37	1.43	1.47	1.42	1.37	1.43	1.47	1.42
Areca nut	4.90	5.09	5.24	5.08	0.63	0.66	0.68	0.65	0.67	0.69	0.72	0.69
RCC pole	2.59	2.69	2.76	2.68	0.76	0.79	0.81	0.79	0.66	0.69	0.71	0.68
LSD (0.05)	0.10	0.08	0.09	0.08	0.04	0.02	0.03	0.03	0.03	0.02	0.03	0.03
CV%	1.38	1.13	1.19	1.12	1.79	1.07	1.13	1.18	1.54	1.15	1.44	1.47

Number of Plagiotropes (per 0.25 m²): The number of plagiotropes per 0.25 m² was significantly influenced by different types of support structure across 3 years (2019–2021) (Table 2). Across three years (2019–2021), highest number of plagiotropes per 0.25 m^2 was consistently recorded under Wild Jamun support, with values of 15.56, 16.21, 17.83 in 2019, 2020 and 2021 respectively, resulting in a pooled mean of 16.53. The second highest plagiotropes per 0.25 m^2 (No.) were recorded under RCC Pole with values of 15.53, 16.11, 16.60 in 2019, 2020 and 2021 respectively with pooled mean of 16.08. In contrast, the lowest number of plagiotropes per 0.25 m^2 was observed under Carambola, which produced 7.77, 8.08, and 8.32 over the same period, with a pooled mean of 8.06 followed by mandar producing 8.77, 9.17, 9.45 across the years with 9.13 pooled value. Plagiotropes, being the lateral branches responsible for spike and fruit development, are a critical component of vine architecture and productivity. Trees like Wild Jamun and Jackfruit, which have a broader canopy, favorable branch spacing and partial shade, provide an ideal physical and microclimatic structure that supports vigorous lateral growth. On the other hand, Mandar and Carambola can have insufficient structural branching or create excessive shading or nutrient competition, thereby limiting lateral shoot proliferation (Ravindran *et al.*, 2000; Anandaraj *et al.*, 2014). Interestingly, RCC poles also supported a higher number of plagiotropes indicating that non-living supports can still promote considerable lateral branching if managed with proper spacing and pruning. However, the absence of organic interaction limits the other biological benefits those seen in living standards (Nair, 2011).

Number of productive plagiotropes (per 0.25 m²): Productive plagiotropes followed a similar trend like plagiotrope number (Table 2). The highest number of productive plagiotropes per 0.25 m^2 was obtained from the vines trained on Wild jamun (14.56 in 2019, 15.11 in 2020 and 16.62 in 2021 with a pooled mean of 15.43) followed by the vines trained on Jackfruit (12.62 in 2019, 13.63 in 2020 and 15.00 in 2021 with a pooled mean of 13.75) and the vines trained on RCC pole (11.66 in 2019, 12.12 in 2020 and 12.48 in 2021 with a pooled mean of 12.08). The vines trailed on Areca nut gave statistically similar results of the vines trained on RCC pole. Jhika support gave also the identical result of Mandar support. The lowest number of plagiotrope per 0.25 m^2 was found in Carambola support (6.80 in 2019, 7.06 in 2020 and 7.27 in 2021 with a pooled mean of 7.04). This suggests that not only the quantity of lateral branches but also their exposure to favorable environmental conditions determine their productivity. The significantly higher values under Wild Jamun and Jackfruit supports can be attributed to enhanced light availability, better branch positioning and potentially beneficial root interactions that promote flower and spike initiation (Sasikumar *et al.*, 2016). Supports like Mandar and Carambola may not provide sufficient vigor or support to encourage spike formation, possibly due to shading, weak branching or restricted airflow. These findings reinforce the importance of selecting support trees that balance light, structure and biological synergy with pepper vines (Zachariah *et al.*, 2011).

Table 2. Effect of biotic and abiotic supports on number of plagiotropes (per 0.25 m2), number of productive plagiotropes (per 0.25 m2) of black pepper vines

Treatments	Plagiotropes/0.25 m^2 (No.)				Productive plagiotropes/0.25 m^2 (No.)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	14.59	15.22	15.68	15.16	7.77	8.08	8.32	8.06
Mandar	8.77	9.17	9.45	9.13	7.77	8.06	8.30	8.04
Mango	10.75	11.74	12.91	11.80	9.72	10.51	11.56	10.59
Jackfruit	13.59	14.67	16.13	14.79	12.62	13.63	15.00	13.75
Wild Jamun	15.56	16.21	17.83	16.53	14.56	15.11	16.62	15.43
Carambola	7.77	8.08	8.32	8.06	6.80	7.06	7.27	7.04
Areca nut	11.65	12.10	12.46	12.07	11.65	12.10	12.46	12.07
RCC pole	15.53	16.11	16.60	16.08	11.66	12.12	12.48	12.08
LSD (0.05)	0.17	0.14	0.15	0.14	0.15	0.13	0.15	0.13
CV%	0.80	0.61	0.65	0.61	0.83	0.68	0.75	0.67

Individual plagiotrope length (cm): The length of individual plagiotrope was also significantly influenced by different types of support (Fig. 1). The longest plagiotrope was produced on Jackfruit support (36.91 cm in 2019, 39.90 cm in 2020 and 43.89 cm in 2021 with a pooled mean of 40.23 cm**)**, followed by Carambola support (34.99 cm in 2019, 36.41 cm in 2020 and 37.51 cm in 2021 with a pooled mean of 36.30 cm) and Wild Jamun (33.03 cm in 2019, 34.35 cm in 2020 with a pooled over three years 35.05 cm except 2021). In 2021, Wild Jamun support gave the similar result of Carambola support. Surprisingly, despite lower counts, Carambola support was recorded with a relatively long plagiotropes possibly indicating a compensatory growth response under stress conditions. Areca nut support showed the shortest plagiotrope length (15.54 cm in 2019, 16.17 cm in 2020 and 16.66 cm in 2021 with a pooled mean of 16.12 cm) followed by Mandar support (17.61 cm in 2019, 18.57 cm in 2020 and 19.13 cm in 2021 with a pooled mean of 18.44 cm), while Jhika support and RCC poles also recorded relatively lower values (16.12–24.27 cm). Shorter plagiotrope, while Areca nut and RCC poles also recorded relatively lower values (23.30-23.36 cm in 2018, 24.37-24.40 cm in 2020 and 25.10 cm in 2021 with a pooled mean of 24.27-24.30 cm). Shorter plagiotropes often interpret to reduce fruiting nodes and photosynthetic capacity per laterals, which may affect yield potential negatively. The plagiotrope length is a function of light interception, internodal elongation and hormonal regulation, all of which are influenced by the nature of the support. Vigorous support trees like Jackfruit, which provide ample lateral space and moderate shade seem to create optimal conditions for extended lateral growth and enhanced the plant's reproductive capacity (Anandaraj *et al.*, 2014; Nair, 2011).

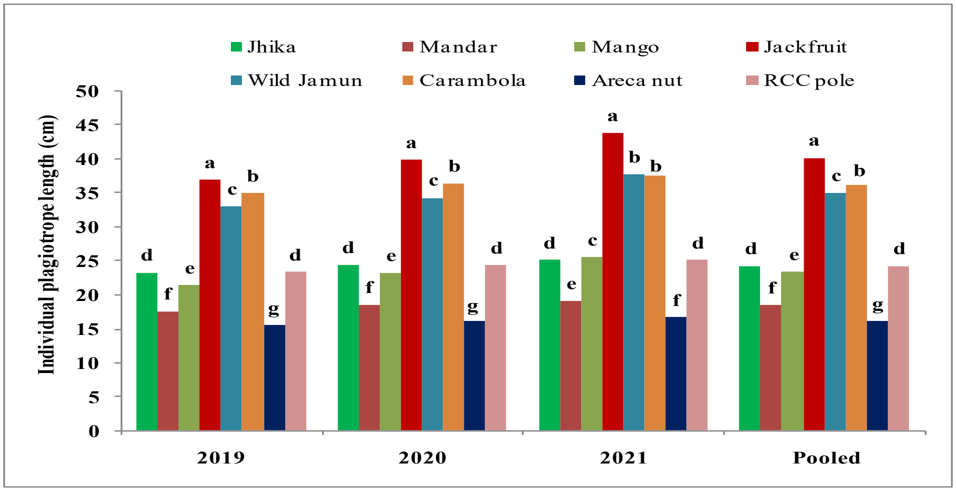

Fig. 1. Effect of biotic and abiotic supports on individual plagiotrope length (cm) of black pepper vines. Figures placed on each bar having similar letter (s) don not differ significantly at p≤0.05 by LSD test.

Number of leaves per lateral: The number of leaves per lateral was significantly influenced by the different support structures in all years (Table 3). In 2019 and 2020, the maximum number of leaves per lateral was recorded from the vines trailed on Mandar tree (15.66 and 16.52 respectively) closely followed by the vines grown on Jackfruit tree (14.59 and 15.82 in 2019 and 2020respectively) and RCC pole (13.67 and 14.34 in 2019 and 2020 respectively). In 2021, the vines trailed on Jackfruit gave the highest number of leaves per lateral (17.40) followed by the vines trailed on Mandar tree (17.02) and RCC pole (14.77). The highest pooled value was recorded in Mandar support with 16.40 leaves per lateral followed by Jackfruit support (15.93) and RCC pole (14.26). Conversely, Areca nut supports produced the lowest leaf numbers with pooled values of 9.28 followed by Mango with 9.28 respectively. Despite its lower performance in other growth parameters, Mandar demonstrated a remarkable ability to support leaf production per lateral. This may be due to its fast growth, open canopy structure and nitrogen-fixing potential which can indirectly enhance vine foliage (Anandaraj *et al.*, 2014). However, more leaves per lateral do not always translate to higher productivity if the leaf size and photosynthetic efficiency are compromised (Nair, 2011). In contrast, the lower leaf number from Mango and Areca nut supports could be attributed to denser canopy or competition for nutrients and water leading to stunted lateral growth and reduced leaf formation (Sasikumar *et al.*, 2016).

Average leaf area per lateral (cm²): During 2019, in terms of leaf area, the vines trailed on RCC pole recorded the highest average leaf area per lateral (1087.69 cm^2) followed by the vines grown on Carambola tree (1047.58 cm^2) and Jackfruit tree (1015.03 cm^2) and its lowest value was obtained from the vines supported on Areca nut support (560.55 cm^2) and Mandar tree (569.61 cm^2). In 2020, the maximum leaf area per lateral was observed in RCC pole support (1128.41 cm^2) followed by Jackfruit support (1094.75 cm^2) and Carambola support (1086.81 cm^2) and the lowest leaf area was noticed on Areca nut support (581.54 cm^2) closely followed by Mandar support (590.93 cm^2). But in 2021, the vines grown on Jackfruit tree gave the maximum average leaf area per lateral (1204.23 cm^2) followed by the vines trailed on RCC pole (1162.26 cm^2) and Wild Jamun support (1141.53 cm^2) and the minimum average leaf area per lateral was recorded from the vines supported on Areca nut tree (598.98 cm^2) followed by Mandar tree (608.66 cm^2). The highest pooled average leaf area per lateral was recorded from the vines grown on RCC pole (1126.26 cm²) followed by the vines trailed on Jackfruit tree (1104.67 cm²), Carambola tree (1084.60 cm²) and Wild Jamun (1059.86 cm²). The lowest values were recorded the vines trained on Areca nut tree (580.36 cm²) followed by Mandar tree (589.73 cm²). This finding highlights a trade-off between leaf number and leaf size. Mandar, despite having the most leaves per lateral, produced smaller leaves on average suggesting limited individual leaf expansion, possibly due to excessive shoot competition or suboptimal light conditions (Ravindran *et al.*, 2000). On the other hand, RCC poles and Jackfruit supports facilitated the development of fewer but significantly larger leaves which is beneficial for maximizing photosynthetic surface area and assimilate production. Larger leaves are often associated with improved photosynthetic efficiency and biomass accumulation (Zachariah *et al.*, 2011). This could explain the better overall performance of vines supported on Jackfruit and RCC poles in yield-related traits observed in earlier tables.

Table 3. Effect of biotic and abiotic supports on number of leaves lateral^{-1}, average leaf area lateral^{-1}, of black pepper vines

Treatments	Leaves lateral^{-1} (No.)				Average leaf area lateral^{-1} (cm^2)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	11.75	12.39	12.77	12.30	657.16	681.77	702.22	680.39
Mandar	15.66	16.52	17.02	16.40	569.61	590.93	608.66	589.73
Mango	8.73	9.43	10.37	9.51	694.86	749.42	824.37	756.22
Jackfruit	14.59	15.82	17.40	15.93	1015.03	1094.75	1204.23	1104.67
Wild Jamun	11.70	12.25	13.47	12.48	1000.30	1037.76	1141.53	1059.86
Carambola	10.67	11.08	11.41	11.05	1047.58	1086.81	1119.41	1084.60
Areca nut	8.83	9.37	9.65	9.28	560.55	581.54	598.98	580.36
RCC pole	13.67	14.34	14.77	14.26	1087.69	1128.41	1162.26	1126.12
LSD (0.05)	0.23	0.12	0.13	0.13	12.19	10.62	11.64	10.32
CV (%)	1.11	0.55	0.55	0.60	0.84	0.70	0.72	0.68

Internode thickness of laterals (cm): Internodal thickness is a vital structural trait affecting vine strength, nutrient transport, and overall vine vigor. In 2019, both Mango and Jackfruit support recorded the thickest laterals (0.69 cm) closely followed by Areca nut support (0.68 cm) and Wild jamun support (0.59 cm) being identical with Carambola support (0.59 cm) but Mandar support gave the lowest internode thickness (0.34 cm) (Fig. 2). In 2020 and 2021, the vines trailed on Jackfruit tree recorded the highest internode thickness (0.77 cm and 0.85 cm respectively) followed by Mango tree support (0.76 cm and 0.84 cm respectively) and Areca nut support (0.73 cm and 0.75 cm respectively). The vines grown on Jhika tree gave the lowest values of internode thickness (0.51 cm and 0.53 cm respectively followed by RCC pole (0.53 cm and 0.55 cm respectively). The pooled mean of internode thickness was found highest from the vines trailed on Jackfruit tree (0.77), which was statistically similar to the vines grown on Mango tree (0.76 cm) followed by Areca nut tree (0.71 cm) and Wild Jamun tree (0.64 cm). In contrast, Mandar (0.35 cm) and Jhika (0.51 cm) produced the thinnest laterals in respect of pooled mean of internode thickness. Thicker internodes are indicative of vigorous and healthy vascular development, suggesting better internal resource transport and support capacity. Mango and Jackfruit being large and well-branched support trees, likely offer structural and microclimatic advantages that encourage substantial lateral development. On the other hand, due to poor internode thickness of vines on Mandar trees reinforces its limited structural utility despite the high leaf count. The RCC pole, a non-living support noted the internode thickness (0.52 cm), possibly due to a lack of biotic interaction that living supports can provide (e.g., shade modulation, root-microbe interaction) (Nair, 2011).

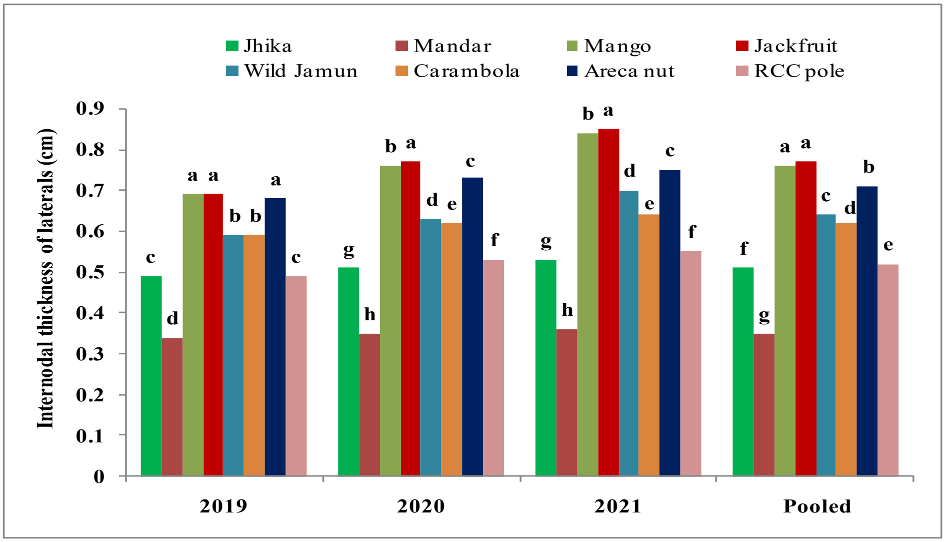

Fig. 2. Effect of biotic and abiotic supports on internode thickness of laterals (cm) of black pepper vines Figures placed on each bar having similar letter (s) don not differ significantly at p≤0.05 by LSD test.

Effect of biotic and abiotic supports on reproductive parameters

Number of spikes (per 0.25 m²): The data clearly indicate that, both living and non-living support had significant influence on spike production (Fig. 3). In 2019 and 2020, the maximum number of spikes per 0.25 m^2 was obtained from the vines trailed on Wild Jamun (29.15 and 30.31 respectively) followed by Jhika tree (26.24 and 27.29 respectively) and Jackfruit tree (24.33 and 26.38 respectively) and RCC pole (18.44 and 19.16 respectively). The lowest number of spikes was observed from the vines trailed on Carambola tree (13.65 and 14.30 respectively) followed by Areca nut support (15.53 and 16.13, respectively). In 2021, the pepper vines grown Jamun tree recorded the highest number of spikes (33.34) followed by those grown on Mandar (17.30) and Jhika tree (28.11) but the vines supported on Carambola tree gave the lowest number of spikes (14.73). The highest pooled number of spikes was recorded in Wild Jamun (30.93) followed by Jhika (27.21) and Jackfruit (26.57). The lowest pooled mean of number of spikes was produced on Carambola (14.23) and Areca nut support (16.09). The superior performance of Wild jamun may be attributed to its favorable canopy structure, which offers partial shade, reducing temperature stress, allowing enough light for optimal flowering and spike formation. Such moderated light levels have previously been reported to promote reproductive development in black pepper (Ravindran *et al.*, 2000; Sasikumar *et al.*, 2016). Similarly, the moderate light and moisture conditions under Jackfruit and Jhika canopies might have supported enhanced flowering. In contrast, Areca nut and Carambola, due to either excessive shading or poor compatibility with pepper physiology may restrict light interception and nutrient availability, leading to lower spike counts (Nair, 2011; Anandaraj *et al.*, 2014).

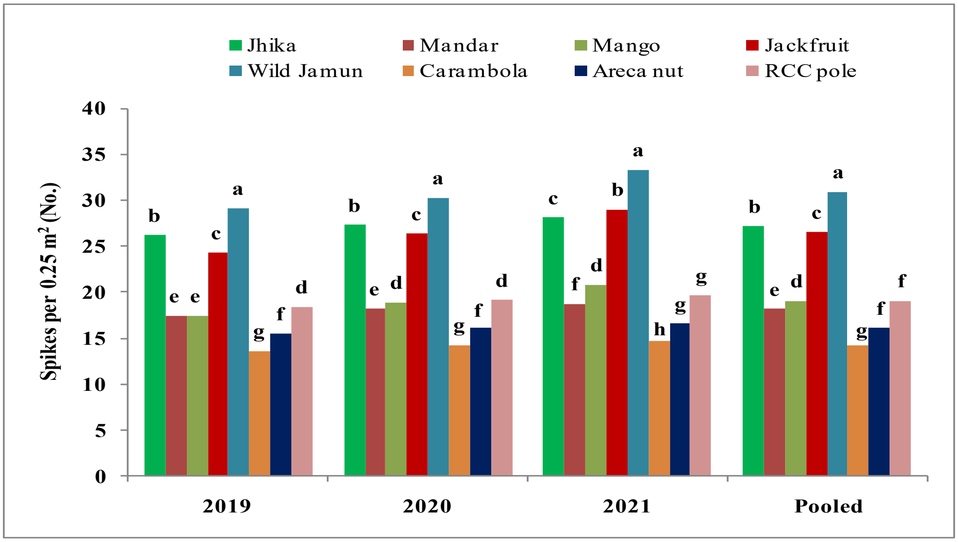

Fig. 3. Effect of biotic and abiotic supports on number of spikes per 0.25 m^2 of black pepper vines Figures placed on each bar having similar letter (s) don not differ significantly at $p \leq 0.05$ by LSD test.

Individual spike length (cm): Spike length, a direct indicator of floral development and reproductive health was also significantly influenced by the support system (Table 4). In 2019, the longest spikes were observed in Areca nut (12.23 cm) followed by both RCC pole and Wild Jamun (12.03 cm). The shortest spike length was recorded from the vines trailed on Carambola support (9.81 cm) followed by Mango support (9.81 cm). In 2020 and 2021, the pepper vines trailed on Jackfruit tree gave the maximum spike length (12.87 cm and 12.75 cm respectively) followed by Areca nut tree (12.68 cm and 12.56 cm respectively). The lowest spike length was found from the vines trailed on Carambola (10.17 cm and 10.07 cm) followed by Mandar tree (10.57 cm and 10.47 cm) respectively. The pooled mean of spike length was recorded highest from the vines trailed on Jackfruit (12.52 cm) followed by Areca nut (12.49), Wild Jamun (12.29 cm) and RCC pole (12.29 cm). Contrary, the shortest pooled spikes were observed in Carambola (10.02 cm) followed by Mango (10.38 cm) and Mandar (10.41 cm).

Wild jamun and Jackfruit, both possessing broader canopies with regulated light penetration, seem to provide a microenvironment conducive to reproductive growth. These findings are in line with earlier studies, suggesting that balanced light and moisture favor floral organ elongation in black pepper (Zachariah *et al.*, 2011). Interestingly, RCC poles, despite being non-living, supported good spike elongation, possibly due to reduced root-zone competition and customized microclimate management (e.g., drip irrigation, optimal spacing). Mango and Mandar, while beneficial in some vegetative traits may create dense shade effects (especially Mango), restricting light-dependent floral differentiation and spike elongation (Ravindran *et al.*, 2000). Faisal *et al.* (2024) reported that they used three support trees *viz.*, Jackfruit, Mango and Chapalish among them, the vines trailed on Jackfruit produced maximum spike length closely followed by Mango support.

Individual spike weight (g): The most vital yield parameter, spike weight showed significant variation across the treatments (Table 4). In 2019, the heaviest spikes were found in the vines trailed on Mandar (16.84 g) which was statistically similar to the vines grown on Mango (16.75 g) followed by Wild Jamun (15.86 g) and Jackfruit (14.80 g) but the lowest spike weight was recorded from the vines supported on Jhika tree (11.41 g) and followed by Carambola tree (11.94 g). In 2020, 2021 and pooled mean, the maximum spike weight was recorded from the vines grown on Mango tree (18.06 g, 17.87 g and 17.56 g respectively) followed by Mandar tree (17.47 g, 17.30 g and 17.20 g respectively) and Wild Jamun tree (16.46 g, 16.29 g and 16.20 g respectively) and Jackfruit tree (15.96 g, 15.80 g and 15.52 g respectively. The lowest spike weight was observed in Jhika tree (11.84 g, 11.72 g and 11.65 g respectively) followed by Carambola (12.39 g, 12.27 g and 12.20 g respectively) and RCC pole (13.94 g, 13.80 g and 13.72 g respectively). The unexpectedly higher spike weight in pepper vines trailed on Mango and Mandar trees may be a result of fewer but more resource-enriched spikes. Limited spike numbers may have led to more photosynthates allocation per spike, thereby increasing weight. This phenomenon agrees the concept of source-sink balance, where fewer sinks (spikes) receive greater assimilate flow resulting in larger individual organ weights (Nair, 2011; Sasikumar *et al.*, 2016). On the other hand, RCC pole, although promoting moderate spike length and number showed relatively lower spike weight, possibly due to higher spike load and limited biotic interaction from the support trees. This might lead to dilution of available nutrients per spike and reduced individual weight. These results corroborate earlier findings by Anandaraj *et al.* (2014) and Zachariah *et al.* (2011), who noted that the choice of support trees greatly influences the physiological and yield dynamics of black pepper, primarily through shade modulation, competition levels and support longevity.

Table 4. Effect of biotic and abiotic supports on number of spikes per 0.25 m^2 spikes, individual spike length, individual spike weight of black pepper vines

Treatments	Individual spike length (cm)				Individual spike weight (g)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	11.19	11.60	11.48	11.43	11.41	11.84	11.72	11.65
Mandar	10.19	10.57	10.47	10.41	16.84	17.47	17.30	17.20
Mango	9.89	10.67	10.57	10.38	16.75	18.06	17.87	17.56
Jackfruit	11.93	12.87	12.75	12.52	14.80	15.96	15.80	15.52
Wild Jamun	12.03	12.48	12.35	12.29	15.86	16.46	16.29	16.20
Carambola	9.81	10.17	10.07	10.02	11.94	12.39	12.27	12.20
Areca nut	12.23	12.68	12.56	12.49	14.19	14.71	14.57	14.49
RCC pole	12.03	12.48	12.35	12.29	13.44	13.94	13.80	13.72
LSD (0.05)	0.06	0.04	0.04	0.04	0.11	0.10	0.10	0.09
CV (%)	0.28	0.21	0.21	0.20	0.43	0.38	0.39	0.36

Berries per spike (No.): The number of berries per spike showed significant variation across different support types (Table 5). The maximum number of berries per spike was observed in the vines trailed on Wild jamun (80.65 in 2019, 83.90 in 2020 and 83.06 in 2021 with a pooled mean of 82.53) followed by the vines grown Mandar (78.68 in 2019, 81.78 in 2020 and 80.96 in 2021 with a pooled mean of 80.47) and Jackfruit (78.12 in 2020 and 77.34 in 2021 with a pooled mean of 75.82 over three years) and Areca nut (76.76 in 2020, 75.99 in 2021 with a pooled mean of 75.53 over three years). In 2019, the vines trailed on Areca nut gave higher number of berries per spike (73.83) than those of Jackfruit (72.02). The lowest values of berries per spike were recorded in Mango support (62.21 in 2019, 67.31 in 2020 and 66.63 in 2021 with a pooled mean of 65.38) and Carambola (66.17 in 2019, 69.02 in 2020 and 68.32 in 2021 with a pooled mean of 67.83). The higher berry count under the vines grown on Wild jamun and Mandar may be attributed to their ability to maintain moderate light levels, creating an environment that supports prolonged flowering and better fruit set. Similar findings were reported by Sasikumar *et al.* (2016), who observed that light intensity significantly affects flower retention and fruit development in black pepper. The relatively poor performance under Mango and Carambola supports could be due to excessive shading which negatively influences reproductive success by limiting photosynthetic efficiency and hormonal balance (Nair, 2011). Faisal *et al.* (2024) reported that they used three support trees *viz.*, Jackfruit, Mango and Chapalish among them, the vines trailed on Jackfruit produced maximum number no. of fruits spike-1 closely followed by Mango support.

Spike compactness (berries cm^{-1} of spike): Spike compactness which denotes the distribution of berries along the spike was significantly influenced by the support standards (Table 5). In 2019, the vines trailed on Jackfruit tree gave the maximum spike compactness (8.75 cm^{-1} of spike) followed by the vines grown on both Carambola and Jhika tree (7.80), RCC pole (7.78), Mandar (7.77) and Mango (7.76). The lowest spike compactness was recorded from the vines grown on Wild jamun (6.80) followed by Areca nut (6.84). In 2020, 2021 and pooled mean over three years, the highest compactness was found in the vines trailed on Jackfruit (9.47, 9.39 and 9.20 respectively) followed by the vines supported on Mango (8.38, 8.30 and 8.15 respectively) and Jhika (8.18, 8.09 and 8.02 respectively) which was identical with the vines trailed on Carambola (8.16, 8.08 and 8.01 respectively). Conversely, in 2020, 2021 and pooled mean over three years, the lowest spike compactness was observed in Wild jamun (7.08, 7.01 and 6.96 respectively) followed by Areca nut (7.18, 7.11 and 7.04 respectively). Although Wild jamun produced the highest number of berries, its low compactness suggests longer spike length with more dispersed berry arrangement, possibly due to extended internode development within the inflorescence (spike). In contrast, Jackfruit likely induced shorter spike internodes or more intense flowering clusters, resulting in denser spike structures (Ravindran *et al.*, 2000). Such compactness is often associated with cultivar genetics and environmental modulation through support systems. Compact spikes are generally preferred in commercial pepper due to their higher market appeal and easier processing (Anandaraj *et al.*, 2014).

Duration of spike maturity (days): The number of days taken for spike maturity in different support systems also differed significantly (Table 5). The longest maturity duration was observed in Mango support (221.27 days in 2019, 238.73 days in 2020 and 236.34 days in 2021 with a pooled mean of 232.11 days) followed by Jackfruit (219.37 days in 2019, 236.76 days in 2020 and 234.39 days in 2021 with a pooled mean of 230.17 days) and Wild jamun (218.42 days in 2019, 226.77 days in 2020 and 224.51 days in 2021 with a pooled mean of 223.23 days). In contrast, RCC pole support (190.26 days in 2019, 197.54 days in 2020 and 195.57 days in 2021 with a pooled mean of 194.46 days) showed the shortest duration, followed by Mandar (204.85 days in 2019, 212.76 days in 2020 and 210.63 days in 2021 with a pooled mean of 209.41 days) and Jhika (205.78 days in 2019, 213.64 days in 2020 and 211.50 days in 2021 with a pooled mean of 210.31 days). The extended duration under Mango and Jackfruit supports could be attributed to their shaded microclimate which may slow down the ripening process due to reduced photosynthetic activity and temperature. While longer duration may allow more resource accumulation, it could also delay harvest, affecting market dynamics (Nair, 2011; Zachariah *et al.*, 2011). On the other hand, RCC poles allow full sunlight exposure which may accelerate fruit maturity due to increased photosynthesis, temperature, and transpiration rates. However, such faster development might compromise berry quality if not managed properly (Ravindran *et al.*, 2000). The results are in agreement with the results of the previous studies emphasizing that support tree characteristics (shade, moisture regulation, root competition) directly influence reproductive efficiency and crop duration in black pepper (Anandaraj *et al.*, 2014; Sasikumar *et al.*, 2016; Nair, 2011).

Table 5. Effect of biotic and abiotic supports on berries spike^{-1}, spike compactness and duration to spike maturity of black pepper vines

Treatments	Berries spike^{-1} (No.)				Spike compactness (No.) (Berries cm^{-1} length of spike)				Duration to spike maturity (Days)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	69.07	71.99	71.27	70.78	7.80	8.18	8.09	8.02	205.78	213.64	211.50	210.31
Mandar	78.68	81.78	80.96	80.47	7.77	8.08	8.00	7.95	204.85	212.76	210.63	209.41
Mango	62.21	67.31	66.63	65.38	7.76	8.38	8.30	8.15	221.27	238.73	236.34	232.11
Jackfruit	72.02	78.12	77.34	75.82	8.75	9.47	9.39	9.20	219.37	236.76	234.39	230.17
Wild Jamun	80.65	83.90	83.06	82.53	6.80	7.08	7.01	6.96	218.42	226.77	224.51	223.23
Carambola	66.17	69.02	68.32	67.83	7.80	8.16	8.08	8.01	213.51	221.61	219.39	218.17
Areca nut	73.83	76.76	75.99	75.53	6.84	7.18	7.11	7.04	210.62	218.65	216.47	215.25
RCC pole	67.00	69.60	68.90	68.50	7.78	8.11	8.03	7.98	190.26	197.54	195.57	194.46
LSD (0.05)	0.37	0.28	0.27	0.27	0.05	0.03	0.02	0.03	0.53	0.60	0.59	0.52
CV (%)	0.29	0.21	0.21	0.21	0.39	0.23	0.18	0.21	0.14	0.15	0.15	0.14

Effect of biotic and abiotic supports on characteristics of hundred well developed berries

Fresh Weight of 100 Berries (g): The fresh weight of 100 well-developed berries was significantly influenced by support types (Table 6). In 2019, the vines trailed on Areca nut produced the maximum 100 well-developed berries' fresh weight (9.24 g) followed by those grown on Jackfruit tree (9.16 g), Mango tree (9.04 g) and both Jhika and Wild Jamun tree (8.98 g). The lowest fresh weight was obtained from the vines supported on Carambola (8.71 g) followed by RCC pole (8.88 g). In 2020, 2021 and pooled mean over three years, the highest fresh weight was recorded in the vines trailed on Jackfruit (9.88 g in 2020, 9.78 g in 2021 and 9.60 g respectively) followed by Mango support (9.75 g, 9.66 g and 9.48 g respectively) and Areca nut (9.59 g and 9.49 g and 9.44 g respectively) and Jhika (9.32 g, 9.23 g and 9.18 g respectively) and the lowest value was observed under Carambola (9.03 g, 8.93 g and 8.89 g respectively) followed by RCC pole (9.21 g, 9.12 g and 9.07 g respectively). The superior performance of jackfruit in fresh berry weight may be linked to its canopy architecture which provides moderate light interception, adequate humidity and reduced evapotranspiration losses fostering better cell expansion and turgidity in developing berries. This corroborates the findings of Ravindran *et al.* (2000), who noted that microclimatic conditions greatly influence the physical development of black pepper berries. Faisal *et al.* (2024) reported that they used three support trees *viz.*, Jackfruit, Mango and Chapalish among them, the vines trailed on Jackfruit produced maximum 100 fresh weight closely followed by Mango support.

Dry Weight of 100 Berries (g): Dry weight reflects the true biomass accumulation in berries. The dry weight of 100 well developed berries followed almost the same trend of fresh weight (Table 6). The dry weight was significantly influenced by different support types (Table 6). In 2019, the vines grown on Areca nut gave the maximum 100 well-developed berries' dry weight (3.28 g) followed by those trailed on Jackfruit tree (3.18 g), Mango tree (3.11 g) and RCC pole (3.10 g) but the lowest dry weight was obtained from the vines supported on Carambola (2.93 g) followed by Mandar tree (2.96 g). In 2020 and 2021, the highest dry weight was recorded from the vines grown on Jackfruit (3.43 g and 3.40 g respectively) followed by areca nut support (3.40 g and 3.36 g respectively) and Mango (3.36 g and 3.32 g respectively) and RCC pole (3.21 g and 3.18 g respectively) but the lowest value was observed under Carambola (3.02 g and 2.99 g respectively) followed by Mandar (3.07 g and 3.04 respectively). This consistency between high fresh and dry weights suggests that berries from Jackfruit and Areca nut supports possess higher photosynthate accumulation and translocation efficiency, possibly aided by better source–sink dynamics (Sasikumar *et al.*, 2016). The dry matter content is a critical determinant of pepper quality, as it directly relates to oleoresin and piperine content, a key quality parameter for spice processing (Nair, 2011). Faisal *et al.* (2024) reported that they used three support trees *viz.*, Jackfruit, Mango and Chapalish among them, the vines trailed on Jackfruit produced maximum 100 dry fruit weight closely followed by Mango support.

Volume of 100 Berries (cm^3): Berry volume followed the similar trend to weight parameters. The volume of 100 well developed berries was significantly affected by different biotic and abiotic supports (Table 6). In 2019, the vines grown on Areca nut gave the maximum volume (7.88 cm^3) which was statistically similar to those trailed on Jackfruit tree (7.84 cm^3) and followed by Mango tree (7.61 cm^3), Jhika tree (7.57 cm^3), Wild jamun (7.57 cm^3), RCC pole (7.55 cm^3) and Mandar tree (7.55 cm^3) but the lowest dry weight was obtained from the vines supported on Carambola (7.30 cm^3). In 2020 and 2021, the highest volume was recorded from the vines grown on Jackfruit (8.61 cm^3 and 8.52 cm^3 respectively), followed by Mango support (8.19 cm^3 and 8.11 cm^3 respectively) and Areca nut (8.17 cm^3 and 8.09 cm^3 respectively) and Jhika (7.87 cm^3 and 7.78 cm^3 respectively) being identical with Wild Jamun (7.87 cm^3 and 7.79 cm^3 respectively). The lowest value of volume was observed under Carambola (7.59 cm^3 and 7.52 cm^3 respectively). The pooled mean of volume over three years produced the highest volume was obtained from the vines trailed on Jackfruit tree (8.32 cm^3) which was followed by

Areca nut (8.05 cm^3), mango (7.97 cm^3) and Wild jamun (7.75 cm^3) being identical with Jhika (7.74 cm^3) but the lowest volume was noticed in the vines grown on Carambola support (7.47 cm^3). When volume and weight data interpreted together, it becomes clear that Jackfruit and Areca nut trees provide a physiologically balanced environment for pepper vines enhancing both berry size and quality. These findings support the results of Anandaraj *et al.* (2014), who emphasized the role of support systems' microclimate on fruit morphology.

Table 6. Effect of biotic and abiotic supports on characteristics of hundred (100) well developed berries of black pepper vines

Treatments	Characteristics of hundred (100) well developed berries											
	Fresh weight (g)				Dry weight (g)				Volume (cm^3)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	8.98	9.32	9.23	9.18	3.03	3.14	3.11	3.09	7.57	7.87	7.78	7.74
Mandar	8.96	9.30	9.21	9.16	2.96	3.07	3.04	3.02	7.55	7.84	7.76	7.72
Mango	9.04	9.75	9.66	9.48	3.11	3.36	3.32	3.26	7.61	8.19	8.11	7.97
Jackfruit	9.16	9.88	9.78	9.60	3.18	3.43	3.40	3.34	7.84	8.61	8.52	8.32
Wild jamun	8.98	9.31	9.22	9.17	3.08	3.20	3.17	3.15	7.57	7.87	7.79	7.75
Carambola	8.71	9.03	8.93	8.89	2.93	3.02	2.99	2.98	7.30	7.59	7.52	7.47
Areca nut	9.24	9.59	9.49	9.44	3.28	3.40	3.36	3.34	7.88	8.17	8.09	8.05
RCC pole	8.88	9.21	9.12	9.07	3.10	3.21	3.18	3.17	7.55	7.83	7.75	7.71
LSD (0.05)	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.08	0.02	0.02	0.03
CV (%)	0.07	0.07	0.08	0.07	0.17	0.36	0.36	0.27	0.61	0.13	0.16	0.21

Effect of biotic and abiotic supports on fresh yield and dry yield per vine and dry matter percentage

Fresh Yield Vine^{-1} (kg): Fresh berry yield per vine was significantly influenced by the treatments (Fig. 4). In 2019, the vines trailed on Wild Jamun produced the highest yield (15.64 kg) which was followed by those supported on Jackfruit (15.14 kg) and Mango (9.82 kg) but the lowest fresh yield was obtained from the vines supported on Mandar (2.98 kg) being statistically similar to Jhika tree (3.03 kg) and RCC pole (3.03 kg). In 2020 and 2021, the vines trailed on Jackfruit produced the highest yield (16.31 kg and 16.16 kg) followed by Wild Jamun (16.23 kg and 16.08 kg) respectively. On the Other hand, the lowest fresh yield was obtained from the vines supported on Mandar (3.09 kg and 3.06 kg) followed by Jhika tree (3.14 kg and 3.11 kg) and RCC pole (3.17 kg and 3.14 kg) respectively. For Pooled Data, Wild Jamun produced the highest yield (15.98 kg) followed by Jackfruit (15.88 kg) but the lowest fresh yield was obtained from the vines supported on Mandar (3.04 kg) being statistically similar to Jhika tree (3.09 kg) and RCC pole (3.11 kg). This yield advantage in Jackfruit and Wild jamun could be attributed to their favorable microclimatic effects—providing optimal shade, humidity and organic matter from leaf litter, which collectively enhance flowering, fruit set and berry retention (Sasikumar *et al.*, 2016). Moreover, the spreading canopy of Jackfruit ensures diffused light, improving photosynthesis without causing stress (Ravindran *et al.*, 2000) found the lowest fresh berry yield from the black pepper vines trailed on *Erythrina lithosperma* and the highest yield from the vines grown on *Termialia bellerica* and reported the reasons behind the better result is the total surface area available for the vines cling to the support trees and the distribution of sunlight under them. Faisal *et al.* (2024) reported that they used three support trees *viz.*, Jackfruit, Mango and Chapalish among them, Mango support produced maximum yield closely followed by Jackfruit support.

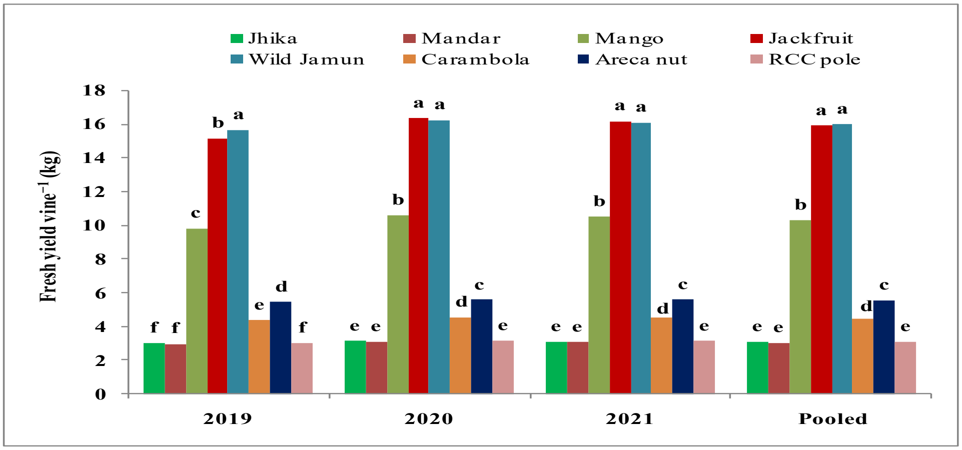

Fig. 4. Effect of biotic and abiotic supports on fresh yield vine^{-1} (kg) of black pepper vines. Figures placed on each bar having similar letter (s) don not differ significantly at p≤0.05 by LSD test.

Dry Yield Vine^{-1} (kg): Different support systems exerted a significant influence on dry berry yield per vine in all three years of experimentation (Table 7). In 2019, the highest dry yield per vine was recorded from the vines trailed on Wild Jamun (5.38 kg) followed by the vines grown on Jackfruit (5.26 kg) and Mango (3.38 kg) but the lowest yield was obtained from the vines supported on Mandar (0.98 kg) being identical with Jhika (1.02 kg) and RCC pole (1.05 kg). In 2020 and 2021, the vines trailed on Jackfruit produced the maximum dry yield (5.67 kg and 5.61 kg respectively) followed by the vines grown on Wild Jamun (5.58 kg and 5.52 kg respectively) and Mango (3.64 kg and 3.60 kg respectively) and Areca nut (2.00 kg and 1.98 kg). The vines supported on Mander tree gave the lowest yield (1.02 kg and 1.02 kg respectively) which was statistically similar to Jhika (1.06 kg and 1.05 kg respectively) and RCC pole (1.09 kg and 1.08 kg respectively). The pooled mean of dry yield over three years was found highest in the vines trailed on Jackfruit (5.52 kg) closely followed by Wild jamun (5.49 kg) and then followed by

Mango (3.54 kg) and Areca nut (1.97 kg) but the lowest pooled mean was recorded from Mandar (1.00 kg) being identical with Jhika (1.04 kg) and RCC pole (1.07 kg). Dry yield indicates that Jackfruit and Wild Jamun supports again outperformed other treatments. Dry yield is critical for post-harvest returns and spice quality. Higher dry matter in Jackfruit and Wild jamun treatments reflects improved nutrient uptake, translocation and water-use efficiency—possibly due to better rhizosphere conditions created by organic litter decomposition from the support trees (Anandaraj *et al.*, 2014).

Dry matter in berries (%): Dry matter percentage is a strong indicator of spice quality, especially piperine and oleoresin content. In 2019, the maximum dry matter percent was recorded from the pepper vines grown on Areca nut (34.45%) followed by RCC pole (33.83%), Jack fruit (33.72%) and Wild Jamun (33.36%) but the lowest from Mandar (32.03%). In 2020 and 2021, the vines trailed on Jackfruit gave the maximum dry matter percent (36.36% and 36.00% respectively) followed by Mango (36.04% and 35.68% respectively) and Areca nut (35.70% and 35.39% respectively) but the lowest dry matter percent was observed in Mandar (33.23% and 32.92% respectively). The highest pooled values of dry matter percent were observed under Jackfruit (35.36%) followed by Areca nut (35.19%), Mango (35.05%) and RCC pole (34.55%). The lowest dry matter (pooled) content was recorded in Mandar (32.73%) followed by Jhika (33.40%), Carambola (33.37%). Although RCC poles produced moderate yields, the dry matter content was comparatively high, indicating less water content and higher concentration of solids which may be favorable for certain processing requirements. However, the superior combination of high yield and high dry matter under Jackfruit trees makes it the most efficient support system. This aligns with the reports by Nair (2011), who noted that biological support contributes to organic nutrient cycling and reduce water stress tend to enhance the biochemical density in spice crops.

Table 7. Effect of biotic and abiotic supports on fresh yield vine^{-1}, dry yield vine^{-1} and dry matter percentage in barriers of black pepper vines

Treatments	Dry yield vine^{-1} (kg)				Dry matter in barriers (%)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled
Jhika	1.02	1.06	1.05	1.04	32.70	33.92	33.57	33.40
Mandar	0.98	1.02	1.01	1.00	32.03	33.23	32.92	32.73
Mango	3.38	3.64	3.60	3.54	33.42	36.04	35.68	35.05
Jackfruit	5.26	5.67	5.61	5.52	33.72	36.36	36.00	35.36
Wild Jamun	5.38	5.58	5.52	5.49	33.36	34.61	34.26	34.07
Carambola	1.47	1.53	1.51	1.50	32.67	33.89	33.55	33.37
Areca nut	1.93	2.00	1.98	1.97	34.45	35.7	35.39	35.19
RCC pole	1.05	1.09	1.08	1.07	33.83	35.09	34.74	34.55
LSD (0.05)	0.10	0.09	0.09	0.08	0.04	0.05	0.06	0.05
CV (%)	2.27	1.90	1.93	1.83	0.08	0.08	0.09	0.08

Conclusion

The experimental results demonstrated that Jackfruit, Wild Jamun and Mango were the most effective biotic supports (living standards) across vegetative, reproductive and yield parameters. Jackfruit excelled in promoting strong vine growth, larger leaf area, spike compactness and superior berry traits, while Wild Jamun offered the highest fresh and dry yield per vine along with optimal spike and berry development. Mango also contributed positively to berry size and dry matter content making it suitable for black pepper production. RCC poles as abiotic support performed better for leaf growth and early maturity but they failed to produce superior result with regard to vine productivity. Areca nut showed its potentiality for use in agroforestry systems but failed to show its performance like Jackfruit, Mango and Wid Jamun. Mandar, Carambola and Jhika repeatedly showed inferior result and are not recommended as supports for high-yielding black pepper production. It is concluded that structurally compatible and ecologically supportive living standards—particularly Jackfruit and Wild Jamun—can significantly enhance sustainable black pepper cultivation. RCC poles can be used where space, light or infrastructure limits the use of trees. However, farmers have to bear in mind regarding low productivity of RCC pole and should compensate through intensive management.

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IMPROVEMENT OF SOIL PROPERTIES AND SEED YIELD OF MUSTARD AS INFLUENCED BY RICE STUBBLE *IN-SITU* BURN ASH

M. I. NAZRUL[1]

Abstract

On-farm research was conducted at low land areas located at 24° 06' N and 91° 17' E with elevation of 5-8 m under Habigonj district during winter in consecutive years of 2020-21 and 2021-2022, respectively. Five rice stubble management practices viz., $T_{1:}$ rice straw burn + no tilth (Control), T_2: rice straw burn + no tilth + water spray, T_3: rice straw burn + one tilth, T_4: rice stubble burn + two tilths and T_5: common practice was evaluated in mustard cultivation. The experiment was setup in randomized complete block design with three replications. The mustard seed was sown in broadcast method. One of the locally popular broadcasts *Aman* rice cultivars (viz. Gota, Lucky, Kashi) followed by mustard var. BARI Sarisha-14 were used in this trial. The practice rice straw burn + soil tilth twice could be the good option for better seed yield of mustard with higher marginal benefit cost ratio.

Key words: Deep water rice, Straw management practices, Soil tilth, Mustard yield

Introduction

Mustard (*Brassica* spp) under Brassicaceae family is the most important oil crops in the world after soybean and groundnut (FAO, 2012). In Bangladesh, more than twenty mustard based cropping patterns (CPs) covering over 6% of the net cropped area (Nasim *et al*., 2017) of which broad cast *Aman* rice (Gota, Lucky, Kasha) followed by mustard containing CPs widely practices in low land areas. Mustard is being cultivating either monocrop or in cropping patterns under AEZ 20 of Surma-kushiyara floodplain soils (Nazrul and Akkas Ali., 2020; Ahmed and Kashem. 2017; Nazrul, 2020). The broadcast *Aman* rice followed by mustard cultivation is an important rotation in low lying areas of Sylhet region and extended to Brahmanbaria under AEZ 21. Straw is significant for organic substances to most rice growing farmers contain about 40, 35, 85, and 50% of N, P, K and S, respectively taken up by rice, rest remains in vegetative plant parts at crop maturity (Dobermann and Fairhurst, 2002). Straw is either removed from the field, burned in situ, piled or spread in the field, incorporated into soil, or used as mulch for the following crop. The removal of straw from the field is widespread in India, Bangladesh, and Nepal (Dobermann and Fairhurst, 2002).

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In paddy based cropping systems, huge quantities of rice straw are left for disposal after harvest (Sidhu and Beri, 2008; Jusoh *et al*, 2013) and most of this remains unutilized in the field. Management of paddy straw (6-8 t ha^{-1}) in fields is a serious problem (Chauhan *et al*., 2012). About 80% of rice straw produced is being burnt annually in just 3 to 4 weeks during October-November in between the rice harvest and wheat sowing in India (Sehgal *et al*., 1999). Rice stubble burning has advantages in terms of farm operations but disadvantages from an environmental perspective. The burning process eliminates many pathogens, and the practice is less laborious than straw incorporation (Kutcher and Malhi, 2010; Mendoza and Samson, 1999). In-situ burn changed the physicochemical properties of soil and affect the structure of soil bacterial communities due to the properties of rice straw ash (Luo *et al.,* 2017). The ash causes changes in the soil pH, affecting the abundance of soil microorganisms (Zhao *et al.,* 2017) due to changes in nitrogen, phosphorus, and potassium levels. Burning causes atmospheric pollution and results in nutrient loss, but it is a cost-effective method of straw disposal and helps reduce pest and disease populations (Dobermann and Fairhurst 2002).

Therefore, an appropriate in-situ burn rice straw ash management is required for enhancing the system productivity of broadcast *Aman* rice-mustard pattern with a view of changing physio-chemical properties of soil.

Materials and Methods

On-farm trial was conducted at low land areas located at 24° 06' N and 91° 17' E with elevation of 5-8 m under Habigonj district during winter in consecutive years of 2020-21 and 2021-2022 in Sylhet Basin under the Agro-Ecological Zone (AEZ-21). However, five rice stubble management practices viz. T_1: rice straw burn + no tilth (Control), T_2: rice straw burn + no tilth + water spray, T_3: rice straw burn + one tilth, T_4: rice stubble burn + two tilths and T_5: common practice (straw removed from field before plough) was evaluated in mustard cultivation. The experiment was setup in randomized complete block design with three replications. The mustard seed was sown in broadcast method and each unit plot size was 20 m^2. Locally popular broadcast *Aman* rice cultivars (viz. Gota, Lucky, Kashi) was followed by mustard var. BARI Sarisha-14 was used. The soils of experimental area are grey silty clay loams, acidic in nature, topsoil quickly becomes dry during winter with medium to high level of soil fertility. During experimentation the pre-and-post soil samples were collected from trial plots and then sent to the laboratory of Soil Resource Development Institute (SRDI), Sylhet to perform chemical analysis, and the methods viz. core sampler, volumetric and gravimetric have been used for measuring the bulk density (gcm^{-3}), porosity (%) and moisture content (%) of soil, respectively.

The monthly temperature, rainfall, relative humidity, and visibility of experimental site has been presented in Figure 1. The two years average climatic data of experimental site shows that the minimum and maximum temperature was 12.82

and 35.31 0^C in the months of January and April, respectively. The rainfall of the area was uni-modal, usually occurring during April to October, and the highest precipitation of 480.93 mm occurred in June, whereas in November no rain at all and the lowest amount of rainfall occurs in January followed by February. Monson starts in April and continue to October.

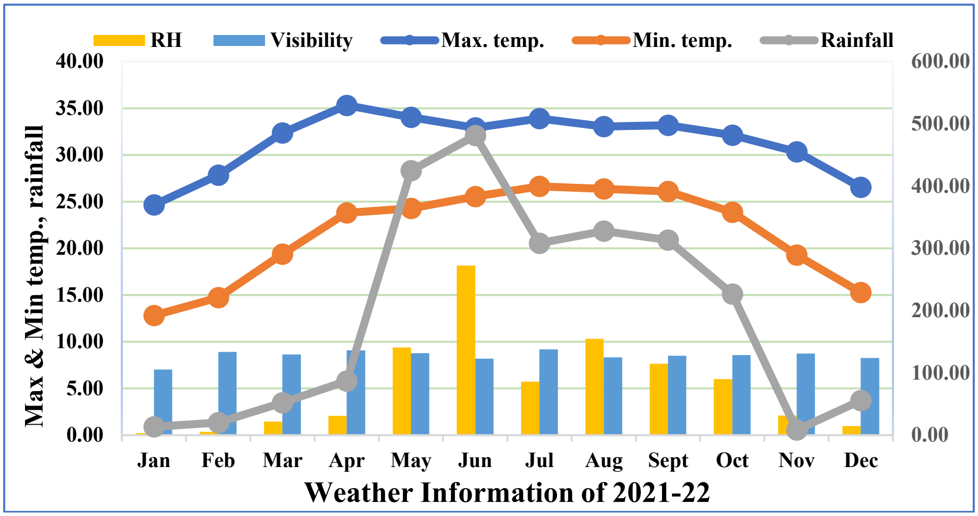

Fig. 1. Average of two years (2021-22) weather information of experimental site.

The experimental plots were tilth by power tiller followed by laddering and *Aman* seeds was broadcasted in first to second week of April depending on the set off sufficient rainfall. Due to rain fed cultivation, no irrigation was provided or even any weeding was done during cultivation. The rice harvesting was started from October last week to first week of November of each year. After harvest, rice straw remains left in the field for 3-5 days to air dry thereafter set fire normally at noon when the ash becomes cool at afternoon; the mustard seeds have been sown over the ash. No weeding and irrigations were provided. But insecticide viz., Fighter 2.5 EC @ 1 ml/L and fungicide Rovral 50 wp @ 2g/L of water was sprayed once at pod setting stage for preventing pod borer and leaf blight diseases.

The crop was fertilized with 95-35-42-7-1 kg ha^{-1} of NPKSB, respectively as basal dose. The fertilizer nutrients were used in the form of Urea, TSP, MoP, Gypsum and Boric acid. Half of urea and all of TSP, MoP, Gypsum and Boric acid were applied at 10-15 days after sowing (DAS) of mustard seeds. Remaining half of urea was applied at 20-25 DAS in top dress at the time of flowering. Mustard was harvested in first week of February. Data on yield and yield components were collected from 10 plants selected at random in each plot and seed yield was recorded plot wise. The collected data were analysed statistically using "STAR" software package and means were separated by using LSD test.

Results and Discussion

Soil physical and chemical properties

There were no significant differences in bulk density, porosity, soil pH, % organic matter, and the levels of S, Zn and B after two years after experimentation (Table1). At a depth of 0-15 cm, the highest soil moisture (22.19 %) was found in T_4, where rice straw was burn followed by soil was tilth twice before sowing of mustard seeds. Significantly, the highest per cent of N, P and K was detected in post burning soil samples collected from T_4 (rice stubble burn + two tilths). On the contrary, the levels of other micro-nutrients statistically unchanged compared with control and general practice along with the soil physical properties.

Table 1. Physiochemical properties of initial and post soil of experimentation 2021-23

Treatments	Bulk density (gcm^{-3})	Porosity (%)	Moisture content (%)	pH (1:1)	OM (%)	N (%)	P	K	S	Zn	B
							(meq.100g^{-1})		(µg g^{-1})		
T1	1.20	43.23	21.52	5.40	2.87	0.15	7.42	0.12	10.08	1.49	0.53
T2	1.23	44.24	22.15	5.30	2.89	0.17	7.51	0.13	10.15	1.52	0.54
T3	1.22	44.03	22.18	5.30	2.91	0.17	7.50	0.14	10.15	1.52	0.57
T4	1.23	44.22	22.19	5.50	2.93	0.18	7.57	0.15	10.14	1.54	0.54
T5	1.21	44.23	21.20	5.17	2.85	0.14	7.13	0.11	10.11	1.45	0.55
CV (%)	1.38	1.22	1.38	3.90	3.42	7.48	0.74	4.54	0.31	2.07	4.90
LSD (0.05)	NS	NS	1.26	NS	NS	0.02	0.10	0.01	NS	NS	NS
Initial soil status	1.23	44.16	22.17	5.37	2.91	0.17	7.53	0.14	10.15	1.53	0.55

T_1: rice straw burn + no tilth (Control), T_2: rice straw burn + no tilth + water spray, T_3: rice straw burn + one tilth, T_4: rice stubble burn + two tilths and T_5: common practice

Plant height (cm)

Plant height is one of the most important growth contributing characters for any corps which would be related on several factors like genetic makeup, nutrient availability, environmental or climatic condition, soil characteristics, regional adaptability etc. Though the plant height of mustard was non-significant, but numerically higher plant height was found in T_2 (rice straw burn + no tilth + water spray) followed by T_3 (rice straw burn + one tilth), and T_4 (rice stubble burn + two tilths), where rice straw burn ash incorporated in soil through ploughing. This indicated the influence of ashes is very prominent on making soil friable and loose for roots water to penetrate the soil deeply (Shukla and Mishra, 1986 and Yeledhalli, 2007).

Plant population $^{-2}$

Optimum sowing time, planting geometry and plant population are the important factors affecting the yield of any crops. Good tilths are an important factor influencing the germination and seedling establishment for achieving desired populations. Different rice stubble management practices for mustard cultivation significantly affected plant populations m^{-2}. The maximum number of plant population was recorded in T_4 followed by T_2 and T_3. On the contrary, minimum plants population was observed in T_1 (Table 2).

Number of silique plant^{-1}

The maximum number of siliqua plant^{-1} (98.25) was obtained in T_4 (rice stubble burn + two tilths) which was statistically similar to that of T_3 practice. Results revealed that the treatments consist of tilth performed better and produce maximum number of siliques which might be due to proper mixture of ash into soil which helps for better soil amendment. A study reported that the highest diameter of capitulum, seeds capitulum^{-1}, and weight of 1000-seeds of sunflower was recorded in fly ash amendment soil (Kabal et al., 2015). This finding was in conformity with the findings of Rahman *et al.,* (2022) who stated that mustard var. BARI Sarisha-14 produced the highest number of siliqua plant^{-1} (81.26). This maximum number of siliques can be contributed to seed yields (Table 2).

1000-seed weight (g)

The weight of seeds expresses the size and development of individual, which is an important yield determinant and plays a decisive role in showing potentiality of a crop (Mamun *et al.,* 2014). Significant variation was observed in 1000-seed weight of mustard in different rice stubble management practices. The maximum 1000-seed weight was recorded from T_4 (3.65 g) which was statistically similar to that of T_2 followed by T_3 (Table 2). However, this yield contributing character of mustard (*Brassica napus* L.) sharply responded where rice straw burn ash incorporated to soil by ploughing beyond which these parameters decreased. Ash addition to soil improves various physical, chemical and biological properties and thereby is also beneficial for mustard plant growth with increased 1000- seed yield. This result coincides with the findings of Pani et al., (2015) on sunflower (*Helianthus annuus* L.). On the contrary, lowest weight of 1000-seeds 2.64 and 2.79 g were recorded from T_5 and T_1, respectively.

Number of seeds per siliqua

The number of seeds siliqua^{-1} was found non-significant; it was ranged from 22.00 to 25.12. The higher number (25.12) of seeds siliqua^{-1} was produced by T_4 (rice stubble burn + two tilths) followed by (23.78) T_2 (rice straw burn + no tilth + water spray). On the contrary, the rice stubble management practice viz. *rice straw burn + no tilth (Control)* gave lower number of seeds per siliqua. Islam *et al*., (2015) also reported that BARI Sarisha-14 gave higher seeds siliquae^{-1} (31) and the lowest number of seeds (12) in BARI Sarisha-11. Ahmed and Kashem (2017) reported that significantly the highest seed siliquae^{-1} was recorded in BARI Sarisha-14 (22.93) and the lowest in var. BADC-1 (9.71).

Table 2. Yield attributes of mustard under different management practices of rice stubble in pooled of 2 years (2021-22 and 2022-23)

Treat.	Plant height (cm)			Plants m^{-2}			Siliqua $plant^{-1}$			1000-seed wt. (g)			Seeds $Siliqua^{-1}$			Seed yield (tha^{-1})		
	Y1	Y2	Pooled mean	Y1	Y2	Pooled mean	Y1	Y2	Pooled mean	Y1	Y2	Pooled mean	Y1	Y2	Pooled mean	Y1	Y2	Pooled mean
T_1	79.63	80.03	79.83	18.02	19.32	18.67	87.41	87.45	87.43	2.78	2.8	2.79	19.65	22.35	21	1.19	1.25	1.22
T_2	83.33	84.01	83.67	20.35	23.03	21.69	87.25	88.35	87.8	3.5	3.62	3.56	23.69	23.87	23.78	1.49	1.57	1.53
T_3	80.67	82.43	81.55	20.67	22.67	21.67	91.41	95.35	93.38	2.94	3.02	2.98	22.93	23.87	23.4	1.4	1.5	1.45
T_4	83.59	84.25	83.92	25.18	25.5	25.34	96.83	99.67	98.25	3.57	3.73	3.65	23.68	26.56	25.12	1.66	1.8	1.73
T_5	79.07	80.93	80	21.08	21.58	21.33	85.98	87.36	86.67	2.46	2.82	2.64	20.64	23.36	22	1.13	1.25	1.19
CV (%)	3.35	4.01	3.68	8.35	7.58	9	3.46	3.53	2.8	9.88	10.35	11.5	10.98	11.55	13.24	10.21	10.87	11.93
LSD (0.05)	3.87	NS	NS	3.85	3.45	3.72	4.57	4.35	4.78	0.66	0.71	0.68	NS	3.45	NS	0.27	0.35	0.32

Note: Treat. =Treatment; Y1=2021-22; and Y2=2022-23.

Seed yield (t ha^{-1})

A significant effect on seed yields of mustard was varied with different rice straw management techniques. Seed yield is the reflection of siliqua plant^{-1}, weight of 1000-seeds and seeds siliqua^{-1}. The maximum seed yield (1.73 t ha^{-1}) was recorded in T_4 (rice stubble burn + two tilts) but statistically similar to that of T_2 (1.53 t ha^{-1}). It shows an increase of seed yields under rice straw burn + two tilths (T_4), over other cultivation practices; it might be due to fact that the rice straw burn ash more properly mixed with soil and helps to conserve moisture and increases the levels of N P and K in soils. The seed yield of mustard was found to increase significantly due to incorporation of rice straw burn ashes compared to control and common practice. This is the combined effect of ash and tilth practices.

Financial analysis

The economic returns from mustard cultivation under different rice straw management practices were furnished in Table 3. The practices rice straw burn + two tilths) performed better and contributed higher gross return of Tk. 121100 ha^{-1} with higher variable cost. As such, the treatment T_4 and T_2 showed very close marginal benefit cost ratio (MBCR) of 6.18 and 6.16, respectively. Total cost was varied due to variation of excess operational costs.

Table 3. Cost benefit analysis of mustard under different *in-situ* management practices of rice stubble for two years of experimental results (based on pooled mean values)

Treatments	Gross return (Tk. ha^{-1})		Variable cost (Tk. ha^{-1})		Marginal benefit cost ratio (MBCR)
	Actual	over control	Actual	over control	
T_1	84000	0	51280	0	0
T_2	107100	23100	55030	3750	6.16
T_3	101500	17500	54280	3000	5.83
T_4	121100	37100	57280	6000	6.18
T_5	83300	-7000	59530	8250	-0.85

T_1: rice straw burn + no tilth (Control), T_2: rice straw burn + no tilth + water spray, T_3: rice straw burn + one tilth, T_4: rice stubble burn + two tilths and T_5: common practice

Mustard seed: Tk. 70 kg^{-1}

Conclusion

The rice stubble management practice has some impact on soil moisture (%), chemical composition (N, P, & K) but nutrients of soil (S, Zn, B) do not affect the seed yield of mustard. The practices, rice straw burn + soil tilth twice (T_4) and rice straw burn + no tilth + water spray (T_2) could be the good option for better seed yield of mustard with higher marginal benefit cost ratio in low land areas by managing the rice straw with burn process.

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FIELD EVALUATION OF MUNGBEAN VARIETIES AGAINST THE INCIDENCE AND DAMAGE OF FLEA BEETLE

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Abstract

A field evaluation of ten mungbean varieties for flea beetle tolerance was conducted in Sonakhali, Barguna sadar, Barguna, Bangladesh from January to April 2016. No variety was found completely free from the attack. BARI Mung-5 and BARI Mung- 6 exhibited the lowest mean flea beetle populations (1.93/m^2 and 2.00/m^2, respectively) indicating least susceptibility. The local variety had the lowest percentage of leaf infestation per plant (13.95%), followed by BARI Mung-5 (14.84%). Flea beetle appeared in 16 days after germination (16th February) and peaked in the third week (February 23rd). No variety was found to be free the leaf area damage by flea beetle. BARI Mung-6, GK Mung-27, Binamoog-2 and IPSA Mung-5 had the highest leaf damage, indicating greater susceptibility to flea beetle infestation. Beetle populations increased with rising temperature and relative humidity. A negative correlation existed between beetle numbers and yield, showing yield decreased progressively with infestation increase. BARI Mung- 5 and BARI Mung-6 demonstrated comparatively better tolerance.

Keywords: Tolerance, susceptible, temperature, humidity.

Introduction

Mungbean [*Vigna radiata* (L.) R. Wilczek] belongs to the family Fabaceae (Lambridge and Godwin, 2006). It is an important pulse crop and is extensively grown in tropical and subtropical countries of the world (Asante *et al*., 2002). After chickpea, mungbean is called as poor man diet due to its protein content and is fulfilling the major protein demand of the people (Shafique *et al*., 2009). It is a short duration crop and its seeds bear high price. Due to its high protein level and easy digestibility, it consumed as food and has an edge over other pulses (Ghafoor *et al*., 2003). It has the capability to fix atmospheric nitrogen to the soil because of its root nodules (Hoorman *et al*., 2009). Two hundred insect pest that belongs to 48 families from the Orders, Coleoptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Orthoptera, Thysanoptera and 07 mites of the Order Acarina are known to infest green gram and blackgram (Swaminathan *et al*, 2012). More than 12 species of insect pests were found to attack mungbean in Bangladesh

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(Hossain *et al*., 2004; Kabir *et al*., 2014). The percentage of leaf area damaged by flea beetle on BARI Mung-6 is 11.33% (Islam et al., 2021). Among major insect pests, flea beetle is the most damaging at seedling to vegetative stage on mungbean as early as the end of February and pest pressure is high by mid-March. Mungbean is attacked severely which first appear at the seedling stage of the crop and maintain their population up to pod formation. The larvae live in the soil and fed on root hairs and roots of the host plants, and depending on soil temperature, they develop into the pupae within 8-10 weeks. A new generation of adults then emerges from the pupae. The newly emerged flea beetles have a strong propensity to feed (John Colvin, 2010). Flea beetles feed on the cotyledons, making the severe innumerable round holes on leaves of young plants and ultimately dried the older damaged leaves. The damaged leaves dried up and the plant growth is rendered with few pods (Hossain, 2015).

Management of insect pests at farmers' level has largely been relied on synthetic chemical insecticides. However, the demand for safe food and ecologically sound control strategies, careful planning for rationalizing the insecticides interventions. In this regard, varieties can play an important role in producing high yield of mungbean because different varieties perform differently due to their genetic variations. Development of resistant varieties is an ideal component against buildup of insect population without any extra cost, compatible with other pest control method and free from environmental pollution. The exploitation of host plant resistance, an economically viable varieties measure against insect pests has become necessary to find out resistant variety with higher yield (Tamang et al., 2017). Different research institutes of Bangladesh have released different varieties of mungbean against insect pests. There is no definite and conclusive work against flea beetle of mungbean. Considering the above fact, the present study was undertaken to find out the resistance of variety against flea beetle through recording the incidence and damage of the flea beetle during cultivation period.

Materials and Methods

The experiment was conducted at the farmers' field at Sonakhali village, sadar upazila of Barguna district, Bangladesh to screen mungbean varieties against flea beetle during January to April 2016. Ten mungbean varieties *viz.*, BARI Mung-2, BARI Mung-5, BARI Mung-6, BU Mung-1, BU Mung-2, IPSA Mung-5, IPSA Mung-12, GK Mung-27, Binamoog-2 and local mung were used as treatments for this study. The seeds of these mungbean varieties were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, and local mung variety from farmers' of Barguna. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The whole field was divided into 3 equal blocks representing 3 replications. Each block was divided into 10 sub plots resulting 30 plots in total. The size of each unit plot was 3.0m × 2.0m. The distance maintained between two blocks and two-unit plots were 1.0 m and 0.75m, respectively. The treatments were randomly assigned to the plots within a block. The mungbean seeds were sown on 30th January 2016 @ 30 kg ha^{-1} (BARI, 2011). The fertilizers were applied as per fertilizers recommendation guide (BARI, 2011). The plants were exposed to natural insect pests' infestation and insecticide was not applied during the experimental.

Number of flea beetle

Population of flea beetle per square meter was recorded at an interval of 7 days commencing from first incidence. Data on the number of flea beetle was collected 4 times (16, 23, 30 37 DAS) at early in the morning (7.00 am to 9.00 am) at seedling and vegetative stages, respectively. All plants of one square meter were observed individually.

Percentage of leaf area damaged by flea beetle

Data on the percentage of leaf area damaged by flea beetle from 5 randomly selected plants of each unit plot were measured separately by eye estimation and recorded at vegetative stage.

Statistical analysis

The collected data were statistically analysed through the analysis of variance using Web Agri Stat Package (WASP 1.0). Means were separated by using Least Significant Difference (LSD) test at 5% level of significance.

Results and Discussion

Incidence of flea beetle on different varieties of mungbean at different DAS

Mean number of flea beetle per square meter was recorded at different days after sowing (DAS) on different mungbean varieties and is presented in Table 1 and Plate 1 A. At 16 DAS, the highest number of flea beetle/m^2 was observed in the variety IPSA Mung-5 (5.33). The second highest number was recorded in BARI Mung-6 (5.00) which was similar to Binamoog-2 (5.00) followed by IPSA Mung-12 (4.67) and BU Mung-2 (4.67). IPSA Mung-12 was identical with BU Mung-2. However, the lowest number of flea beetle was observed in the variety BARI Mung-2 (3.0) followed by BARI Mung-5 (4.0), BU Mung-2 (4.0), local Mung (4.0) and GK Mung-27 (4.33). BARI Mung-5, BU Mung-2 was identical with local mung.

At 23 DAS, significantly the highest population of flea beetle (9.00) was recorded in the variety of local Mung followed by IPSA Mung-5 (7.67), BU Mung-1 (7.67), BU Mung-2 (7.0), IPSA Mung-12 (7.0), GK Mung-27 (6.33) and Binamoog-2 (6.33). BU Mung-2 was statistically identical with IPSA Mung-12, similar to GK Mung-27 and BINA Mung-2. The lowest number of flea beetle was found in the variety of BARI Mung-5 (5.00) followed by BARI Mung-6 (5.33), BARI Mung-2 (6.0).

At 30 DAS, significantly the highest number of flea beetle/ m^2 was observed in the variety of BU Mung-2 (7.67) which was statistically similar to BARI Mung-2 (7.67). The second highest number was recorded in local mung (7.33) followed by IPSA Mung-5 (7.0), BARI Mung-2 (6.67), GK Mung-27 (6.67). BARI Mung-2 was statistically identical with GK Mung-27. However, the lowest number of flea beetle was observed in the variety of BARI Mung-5 (4.67) followed by BARI Mung-6 (6.0), BU Mung-1 (6.0) and IPSA Mung-12 (6.0). BARI Mung-6, BU Mung-1 was statistically also identical with IPSA Mung-12.

At 37 DAS, significantly the highest population of flea beetle (2.41) was recorded in the variety of local Mung followed by BARI Mung-5 (1.74), BARI Mung-2 (1.68), IPSA Mung-12 (1.68), IPSA Mung-5 (1.64), BU Mung-1 (1.60) and BU Mung-2 (1.60). BARI Mung-2 was statistically identical with IPSA Mung-12. Likewise, variety of BU Mung-1 (1.60) was statistically similar with the variety of BU Mung-2 (1.60) in respect of flea beetle population (Table 2). The lowest number of flea beetle was found in the variety of BARI Mung-6 (0.99) followed by GK Mung- 27(1.27), BARI Mung-2 (1.39).

Table 1. Flea beetle population of mungbean on selected varieties at different DAS

Varieties name	Number of flea beetle /m^2 at				Mean/m^2
	16 DAS	23 DAS	30 DAS	37 DAS	
BARI Mung - 2	3.00	6.00 b-d	6.67ab	1.68 b	4.34 b-d
GK Mung - 27	4.33	6.33 b-d	6.67ab	1.27 bc	4.46 b-d
Binamoog - 2	5.00	6.33 b-d	7.67a	1.38 bc	5.10 a-c
IPSA Mung - 5	5.33	7.67 ab	7.00ab	1.64 bc	5.41 ab
IPSA Mung - 12	4.67	7.00 a-d	6.00bc	1.68 b	4.88 a-d
BU Mung - 1	4.00	7.33 a-c	6.00bc	1.56 bc	4.72 b-d
BU Mung - 2	4.67	7.00 a-d	7.67a	1.56 bc	5.22 a-c
BARI Mung - 5	4.00	5.00 d	4.67c	1.74 ab	3.85 d
Local mung	4.00	9.00 a	7.33ab	2.41 a	5.69 a
BARI Mung - 6	5.00	5.33 cd	6.00bc	0.99 c	4.33 cd
Level of significance	NS	*	*	*	*
CV (%)	20.10	19.19	11.86	24.84	7.56

* Significant at 5 % level

Means within column followed by the same letter are not significantly different from one another by LSD test. Values are average of three replications.

From the mean of all varieties regarding flea beetle population, it was evident that local Mung, BU Mung-2, IPSA Mung-5 and Binamoog-2 had highest population of flea beetle which indicated that these varieties were highly susceptible to flea beetle. On the other hand, IPSA Mung-12, GK Mung-27, BARI Mung-2 and BU Mung-2 had lowest population of flea beetle, which indicated that these varieties were least susceptible to flea beetle. Among all tested varieties, none showed complete resistance against flea beetles. However, BARI Mung- 5 and BARI Mung- 6 had the lowest mean population of flea beetle and showed comparatively better resistance against flea beetle.

The abundance of flea beetle on mungbean at different growth period

Abundance of flea beetle varied throughout the growing period (Figure 1). Flea beetle appeared in 16 days after seed germination (February 16th) and reached its peak in the third week (February 23rd) because of soft and succulent leaves of mungbean at active vegetative stage. After that its population decreased gradually with the increasing of plant age.

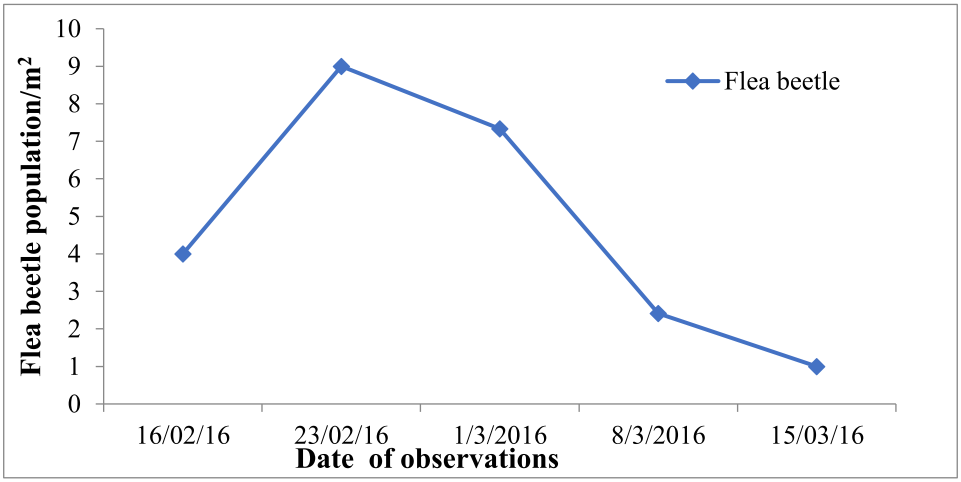

Fig. 1. The abundance of flea beetle on mungbean at various dates of observation during the year of 2016.

Percent leaf area damaged by flea beetle

Mean leaf area damaged by flea beetle on different mungbean varieties at different days after sowing is presented in Table 2 and Plate 1 B. At 16 DAS, among the varieties, significantly the highest percent leaf area damage (8.00%) was recorded from the variety Binamoog-2 followed by BARI Mung-6 (6.33%), BARI Mung-5 (6.0%), BU Mung-1 (5.33%), BU Mung-2 (5.33%), IPSA Mung-5 (5.00%) and BARI Mung-2 (5.00%). BU Mung-1 (5.33%) was statistically identical with BU

Mung-2 (5.33%), IPSA Mung-5 (5.00%) and BARI Mung-2 (5.00%). However, the lowest percent leaf area damage (3.00%) was found in the variety of IPSA Mung-12 followed by local Mung (3.67%) and GK Mung-27 (4.67%).

At 23 DAS, among the varieties, significantly the highest percent leaf area damage (15.0%) was recorded from the variety BARI Mung-6. The second highest damage leaf area was recorded in BU Mung-1 (13.33%), which was statistically similar with GK Mung-27 (13.00%), IPSA Mung-5 (12.67%) followed by Binamoog-2 (12.33%) and BARI Mung-5 (12.00%). BINA Mung-2 (12.33%) was statistically similar with BARI Mung-5 (12.00%). However, the lowest percent leaf area damage (9.33%) was found in the variety of BU Mung-1 followed by BARI Mung-2 (10.00%), BU Mung-2 (11.00%) and IPSA Mung-12 (11.00%). BU Mung-2 was statistically identical with local mung.

At 30 DAS, among the varieties, significantly the highest percent leaf area damage (24.0%) was recorded from the variety local mung. The second highest damage leaf area was recorded in IPSA Mung-12 (22.67%) and BINA Mung-2 (22.67%) followed by GK Mung-27 (22.33%), IPSA Mung-5 (22.0%), BU Mung-2 (21.33%) and local mung (21.33%). BU Mung-2 was statistically identical with local mung and which was statistically similar with Binamoog-2 (23.67%), BARI Mung-6 (22.67%), IPSA Mung-5 (22.67%), BARI Mung-6 (22.67%), IPSA Mung-12 (22.67%), GK Mung-5 (22.0%) and BARI Mung-5 (22.0%). However, the lowest percent leaf area damage (14.0%) was found in the variety of BARI Mung-5 (16.67%) followed by BU Mung-1 (19.33%) and BARI Mung-2 (18.67%).

At 37 DAS, among the varieties, significantly the highest percent leaf area damage (26.33%) was recorded from the variety BARI Mung-6, which was statistically similar with BARI Mung-2 (26.33%). The second highest damage leaf area was recorded in BU Mung-1 (25.00%) followed by IPSA Mung-27 (24.33%), BARI Mung-5 (24.07%), BINA Mung-2 (24.00%) and GK Mung- 27 (23.67%). BU Mung-1 was statistically similar with IPSA Mung-27, BARI Mung-5, Binamoog-2 and GK Mung-27. However, the lowest damage leaf area (21.33%) was recorded in the variety of local Mung. The second lowest damage leaf area IPSA Mung-12 (22.67%), which was statistically similar with BU Mung-12 (22.67%).

From the average mean percentage of leaf area damage of all varieties, it was observed that the varieties of BARI Mung-6, GK Mung-27, Binamoog-2 and IPSA Mung-5 had the highest percentage of leaf area damaged by flea beetle which indicated that these varieties were more susceptible to flea beetle infestation than other varieties. On the other hand, the varieties, BU Mung-1, BU Mung-2, BARI Mung-2, IPSA Mung-12 and BARI Mung-5 had the lowest percent leaf area damaged by flea beetle which indicated that these varieties were marginal leaf area damage by flea beetle. Among all tested varieties, none showed complete absence of leaf area damage by flea beetle. However, local Mung showed comparatively least leaf area damage (13.95%) by flea beetle. From the results of Table 2, it was evident that the percent leaf area damaged by flea beetle increasing gradually with the age of plant because of availability of maximum number of leaves in plant.

Table 2. Damaged severity of flea beetle attacking mungbean in different dates of observation during the year of 2016

Varieties name	% Damaged leaf area by flea beetle/plant at				Mean % damaged leaf area
	16 DAS	23 DAS	30 DAS	37 DAS	
BARI Mung - 2	5.00 bc	10.00 de	18.67 de	26.33 a	15.00
GK Mung - 27	4.67 b-d	13.00 b	22.33 ab	23.67 b	15.92
Binamoog - 2	8.00 a	12.33 bc	22.67 ab	24.00 b	16.75
IPSA Mung - 5	5.00 bc	12.67 b	22.00 ab	24.33 b	16.00
IPSA Mung - 12	3.00 d	11.00 cd	22.67 ab	22.67 bc	14.84
BU Mung - 1	5.33 bc	13.33 b	19.33 cd	25.00 b	15.75
BU Mung - 2	5.33 bc	11.00 cd	21.33 bc	22.67 bc	15.09
BARI Mung - 5	6.00 b	12.00 bc	16.67 e	24.07 b	14.84
Local mung	3.67 c	9.33 e	21.33 bc	21.33 c	13.95
BARI Mung - 6	6.33 ab	15.00 a	24.00 a	26.33 a	17.92
Level of significance	**	**	**	**	NS
CV (%)	22.19	8.03	7.26	5.87	10.64

** Significant at 1 % level, NS- Non significant

Means within column followed by the same letter are not significantly different from one another by LSD test. Values are average of three replications.

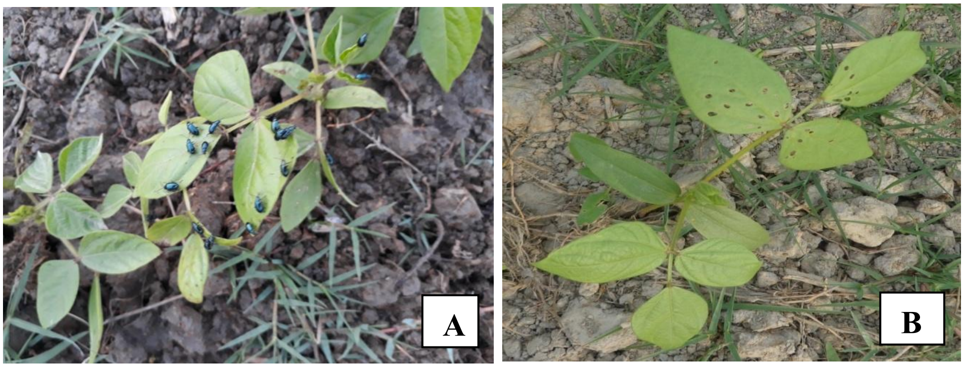

Fig. 1. Flea beetle incidence (A) and damage (B) on mungbean.

Population fluctuation of flea beetle with weather parameters on local variety of mungbean

The results of the seasonal fluctuation of flea beetle infestation are shown in Fig. 2. Flea beetle infestation started in the 3rd week of February on local variety of mungbean. The figure revealed that the population of flea beetle gradually increased with temperature and relative humidity and it was reached maximum in the 4th week of February at active vegetative stage of the crop. After 4th week of February beetle population declined gradually up to the 2nd week of March in 2016 (Figure 2) then reached to zero at 3rd week of March end of the season. This might be due to prevailing high temperature and relative humidity. The present findings are in agreement with Sharma and Dutta (1997).

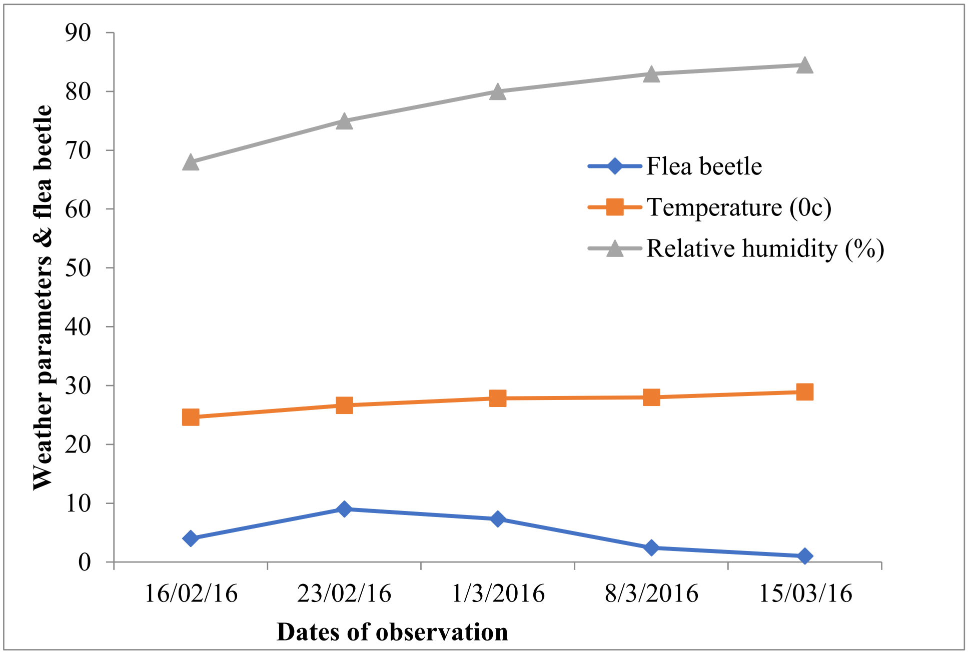

Fig. 2. Trend in population fluctuation of flea beetle with mean temperature (^{0}C) and mean relative humidity (%) on local variety of mungbean during 2016.

Relationship between flea beetle population and yield

Fig. 3 illustrated that there was a negative correlation between number of flea beetle and total yield. It indicated that with the increase of flea beetle there was progressive fall in the yield of mungbean. A linear regression was fitted between flea beetle abundance and total yield. The correlation coefficient (r) was 0.53 and the contribution of the regression ($R^2 = 0.289$, when $Y = -36.188x + 854.02$) was 29.90%.

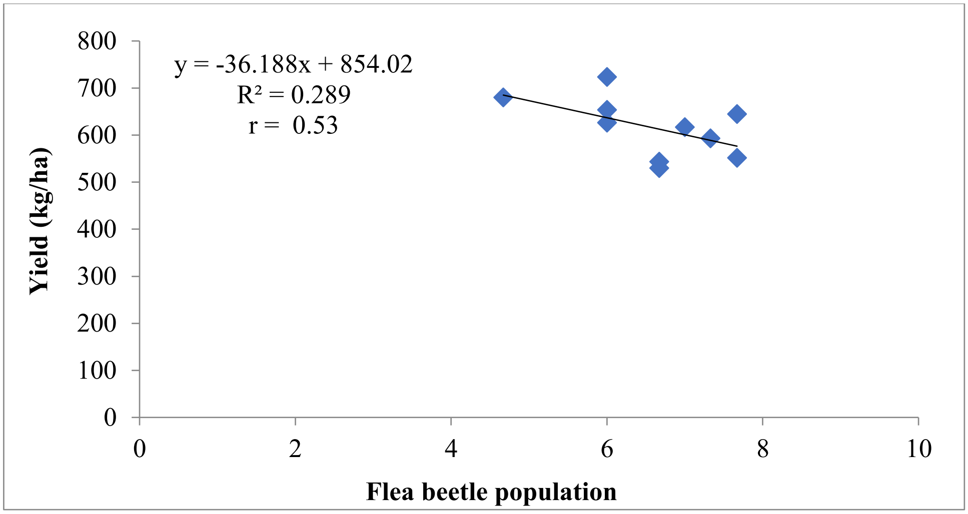

Fig. 3. Relationship between flea beetle population and yield of mungbean.

It was evident that BARI Mung-5 and BARI Mung-6 were superior mungbean variety among tested varieties in terms of flea beetle incidence and infestation, and showed the best performance regarding yield which is similar to the findings of Islam *et al*. (2021) and Islam *et al*. (2008). The results of the present study are comparable with results of experiment conducted by Khan *et al*. (2018) where they found mutant MBM-347-13 had the lowest number of flea beetle indicating lower susceptibility to flea beetle. They also found flea beetle abundance gradually increased with decreasing average temperature. Abdullah-Al-Rahad et al. (2018) found that among the varieties, BARI Mung-6 showed the least whitefly and aphid population and indicated highest resistance against whitefly and aphid infestations at different stages than all other varieties. The highest seed yield (1.82 t ha^{-1}) was recorded from BARI Mung-6, while the lowest (1.30 t ha^{-1}) was recorded from BARI Mung-4. It means that BARI Mung-6 was superior to other varieties in terms of lowest whitefly and aphid infestation and maximum yield. A group of researchers observed that the incidence and development of all insect pests are much dependent upon the prevailing weather conditions, such as temperature, relative humidity and precipitation (Aheer *et al*., 1994; Yadav and Singh, 2013 and Yadav *et al*., 2015).

Conclusion

Among 10 tested mungbean varieties, no variety was found free from insect attack and leaf area was damaged by Flea beetle. Beetle populations increased with increasing temperature and relative humidity. BARI Mung- 5 and BARI Mung-6 were comparatively better tolerance to Flea beetle.

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Ahmed, F. and M. Z. Alam. 1993. Mango leaf consumption by *Cricula trifenestrata* Heifer (Lepidoptera: Saturnide) larvae under field conditions. *Bangladesh J. Entomol.* **31:** 9-17.

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