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EFFECT OF NITROGEN, PHOSPHORUS, POTASSIUM AND SULPHUR ON GROWTH, YIELD AND NUTRIENT BALANCE OF FENNEL

M. N. YOUSUF[1], S. BRAHMA[2], M. A. A. KHAN[3], M. I. HAQUE[4] AND M. M. KAMAL[5]

Abstract

The experiment was conducted at Regional Spices Research Centre, BARI, Gazipur during two consecutive years, 2020-2021 and 2021-2022 to observe the response of fennel (var. BARI Mouri-2) to N, P, K and S for maximizing the yield and quality. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments were each of four levels of N (0, 80, 130 and 180 kg ha^{-1}), P (0, 50, 70 and 90 kg ha^{-1}), K (0, 40, 80 and 120 kg ha^{-1}) and three levels of S (0, 20 and 30 kg ha^{-1}). The N, P, K and S showed significant effect on the yield and yield attributes of fennel. The highest seed yield (1.98 tha^{-1}) and the maximum harvest index (94.18%) of fennel were found in 130-70-80-30 kg NPKS ha^{-1}. The net N, P, K and S balance ranged from -150 to -62.0, 0.12 to 5.68, 29.97 to 0.51 and 4.24 to 0.27 kg ha^{-1}, respectively. The cost benefit analysis also indicate that the highest net income (Tk.180947.00) was estimated in 130-70-80-30 kg NPKS ha^{-1} of fennel cultivation. The response curve reveled that application of 145-62.5-77.5-22.86 kg NPKS ha^{-1} might be the recommended nutrient package for achieving higher seed production in in Grey Terrace Soil of Madhupur Tract (AEZ-28).

Keywords: Fennel, Seed yield, nutrient management, nutrient balance sheet, MRR.

Introduction

Fennel (*Foeniculum vulgare* Mill. or *F. officinale* All.) belongs to Apiaceae family originated in Mediterranean region, used as spices as medicine and perfumary for its remarkable medicinal and aromatic properties (Devi *et al*., 2022). The edible protion of the crop is leaves, stalks, seeds, oils and bulbs (produced some species). The fennel seeds are aromatic, stimulant and carminative which contain volatile and fixed oil (Shehata and Moubarak, 2020). It is cultivated over in the Faridpur, Sariatpur, Madaripur, Gopalgonj, Pabna, Sirajganj, Jessore, Kushtia, Bogura, Rangpur, Natore and Jamalpur districts as a secondary crop with few hundred hectares of land most of the cases as a bordar crops. The average productivity is less, so the efforts have made to enhance the productivity of the fennel by the agronomic and soil management. Lake of HYV & hybrid varieties with modern production technologies, appropriate fertilizer recommendations, water stress, disease & insect pest infestations, climate change, inadequate marketing facilities

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etc., are the major constraints in upscaling the production. Farmers use imbalanced fertilizers to cultivate hybrid/ HYV crops that leads to mining out of the inherent plant nutrients from the soil and thus, fertility status of the soil severly declined in Bangladesh. Macro and micro-nutrients are essential components for providing crop nutrients needs in satisfactory crop production and maintain crop quality (El-Seifi *et al.*, 2015). Nitrogen is the element that limits crop yields. Most of the N in plants is in organic form: nucleic acid, some vitamins, hormones, membrane component, coenzymes and pigment. P is an essential component of the energy transfer compounds (ATP and other nucleiproteins), the genetic information system, cell membranes and phospho-proteins. K is serving as an enzyme activator or cofactor for some enzymes. It also aids in the maintenance of osmotic potential and water uptake. Sulphur helps in the synthesis of amiono acids, enzymes, vitamins, proteins, oils and chlorophyll. Among the various levels of NPK @ 60-40-40 kg ha^{-1} exhibited significant maximum growth, yield & yield attributes, and quality of fennel (Kusuma *et al*., 2019 and Waskela *et al.*, 2017). Fertilizer package for fennel production in Grey Terrace soil has not been reported yet. Therefore, this study was initiated keeping the above fact in view, (i) to develop a suitable fertilizer package for sustainable fennel production (ii) to make a nutrient balance sheet for proper soil management and (iii) to observe the cost and benefit of fennel cultivation.

Materials and methods

The study was conducted at the Regional Spices Research Centre, BARI, Gazipur during two consecutive years of 2020-2021 and 2021-2022. The experimental site was situated at $23^0 59^/$ North Latitude and $90^0 24^/$ East Longitude, at an altitude of 8.4 m above the mean sea level. The soil of the experimental site belongs to Chhiata Soil series and has been classified as Grey Terrace Soil, which falls under Inceptisol in Taxonomy under the AEZ-28 (Madhupur Tract) Brammer, 1971. The initial soil samples of the experimental field were analyzed following standard and recommended methods (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) having three replications. There were four levels of nitrogen (0, 80, 130 and 180 kg ha^{-1}), four levels of phosphorus (0, 50, 70 and 90 kg ha^{-1}), four levels of potassium (0, 40, 80 and 120 kg ha^{-1}) and three levels of sulphur (0, 20 and 30 kg ha^{-1}). The treatment combinations were: T_1= 180-70-80-30 kg NPKS ha^{-1}, T_2= 130-70-80-30 kg NPKS ha^{-1}, T_3= 80-70-80-30 kg NPKS ha^{-1}, T_4= 0-70-80-30 kg NPKS ha^{-1}, T_5= 130-0-80-30 kg NPKS ha^{-1}, T_6=130-50-80-30 kg NPKS ha^{-1}, T_7= 130-90-80-30 kg NPKS ha^{-1}, T_8= 130-70-0-30 kg NPKS ha^{-1}, T_9= 130-70-40-30 kg NPKS ha^{-1}, T_{10}= 130-70-120-30 kg NPKS ha^{-1}, T_{11}= 130-70-80-0 kg NPKS ha^{-1}, T_{12}= 130-70-80-20 kg NPKS ha^{-1}. The cowdung used in the experimental soil contained 0.98% N, 0.21% P, 0.61% K, 0.123% S, 0.49% Ca and 0.28% Mg on dry basis. The whole amount of cowdung (5 t ha^{-1}), TSP, MoP, gypsum, zinc sulphate (5 kg ha^{-1}) and boric acid (6 kg ha^{-1}) was applied as basal and $1/3^{rd}$ urea was applied in three equals at 5^{th}, 9^{th} and 11^{th} week after sowing. The seeds of fennel var. BARI Mouri-2 were sown on 17 November both the years in 3 m x 3 m plot at line-to-line distance 30 cm. Seeds were soaked in water for 24 hours to facilitate germination, then the seeds were dried and treated with Autoistin (carbendazim) @ 2g kg^{-1} seeds to minimize the primary seed-borne disease. The seeds were mixed with some loose soil to allow uniform sowing in rows with a seed rate of 10 kg ha^{-1} at a depth of about one cm. The seeds were covered with loose soil properly just after sowing and gently pressed by hands with slight watering to enhance proper germination. Continuous sowing was done during sowing time but maintained plant to plant distance of 10 cm by thinning at 25 DAS. Intercultural operations such as four irrigations, three weeding and three times spray of Autoistin @ 2g l^{-1} of water for controlling damping off disease was done during the whole cropping period. The crops were harvested on 11-20 May both the years. Ten plants were selected randomly from each plot for counting some growth and yield parameters. For computing nutrient uptake at 60 DAS plants in every plot were cut at the bottom, chopped with a sharf knife, air dried for 3 days then oven dried for 72 hours at 65^0C followed by grinding the oven-dry samples by an electric grinding machine.Ten matured selected fennel plants from each plot were cut at the colar region, air-dried in the laboratory and finally oven-dried for 72 hours at 65^0C to estimate dry matter production. The dry matter was calculated by the following formula:

DM = [{(DY /10) X NP} X 10000)]/1000

Where, DM = Dry matter (kg ha^{-1})

DY = Total dry matter yield of 10 plants per plot (g)

NP = Total number of plants per m^2

Nutrient uptake from the soil was calculated by using the formula:

Nutrient uptake = % A x Y / 100 kg ha^{-1}

Where, % A = Nutrient content of plant in percent; Y = Total dry matter production of plant (kg ha^{-1})

Nutrient balance sheets were estimated by using the formula (Singh *et al.*, 2017):

Nutrient balance (N, P, K, S) = Σ Input (N, P, K, S) – Σ Output (N, P, K, S)

Where,

Input: Chemical fertilizer, manure, BNF, deposition (rain), airborne, sedimentation

Output: Harvested crop parts, crop residues, leaching, gaseous losses, soil erosion

However, the nutrient balance did not account for the addition of nutrients from rainfall, dry deposition, BNF and removal of nutrient by leaching, gaseous losses of N, or weed uptake of nutrients from the soil.

Harvest index was calculated by the following formula (AVRDC, 1990):

HI = EY / BY x 100

Where,

HI = Harvest index (%)

EY = Seed yield (kg)

BY = Biological yield (kg)

The analysis of variance of crop characters and nutrient uptake of the plant samples were done following the ANOVA test and the mean values were adjusted by LSD (Least Significant Difference) test at 5% level. R software (version 3.5.0) was used to analyse the data.

Table 1. Observed soil physical and chemical properties of the experimental site

Soil Chemical Properties	Analytical value	Analytical method
Textural class	Clay loam	Hydrometer method (Bouyoucos, 1962)
Bulk density (g cm^{-3})	1.39	Core sampling method (Blake, 1965b)
Particle density (g cm^{-3})	2.69	Pycnometer method (Blake, 1965a)
Soil pH	6.2	Soil: water=1:2.5 (Jackson, 1962)
Organic carbon (%)	0.89	Wet oxidation method (Walkley and Black, 1934)
Total N (%)	0.08	Micro Kjeldhal Method (Black, 1965)
Available P (ppm)	7.77	Bray and Kurtz method (Bray and Kurtz, 1945)
Exchangeable K (meq 100 g^{-1} soil)	0.08	N NH_4OAc Extraction method (Jackson, 1962)
Available S (ppm)	6.84	Calcium dihydrogen phosphate extraction method (Hesse, 1971)
Available B (ppm)	0.19	Calcium chloride extraction method (Christian and Feldman, 1970)
Available Zn (ppm)	0.58	DTPA Extraction method (Christian and Feldman, 1970)
Available Cu (ppm)	0.16	DTPA Extraction method (Christian and Feldman, 1970)
Available Mn (ppm)	0.72	DTPA Extraction method (Christian and Feldman, 1970)
CEC (meq 100 g^{-1} soil)	7.9	N NH_4OAc Extraction method (Yoshida et al., 1972)

Results and Discussion

Yield attributes/ plant parameters

The yield attributes of fennel were significantly variable among the treatments (Table 2). The plant received the maximum days (116 days) to 50% flowring in T_2 (130-70-80-30 kg NPKS ha^{-1}) followed by T_1 (180-70-80-30 kg NPKS ha^{-1}) and T_7 (130-90-80-30 kg NPKS ha^{-1}). T_4 (70-80-30 kg PKS ha^{-1}) showed the minimum period (91.8 days) to reach 50% flowering. Treatment T_2 supplied optimum nutrients (both chemical and organic sources) attained better and prolonged growth and development subjected to delayed maturity. On the other hand, plant receiving inadequate of N, leads to early flower initiation in the plants in T_4. Similar result was reported by Ayub *et al.* (2011). The maximum plant height (153.8 cm) was found in T_2 (130-70-80-30 kg NPKS ha^{-1}) which was stastically identical to T_1 and the lowest plant height (113.8 cm) in T_4. This might be due to better availability of the nutrients to the plants. Application of N, P, K and S fertilizers enhanced the availability of nutrient elements which resulted in increased photosynthetic activities and translocation of photosynthates from source to sink then increased plant height. The results confirm the findings of Shehata and Moubarak (2020) and Godara *et al.* (2014). The maximum number of branches per plant (11.0) was recorded in T_2while minimum (4.7) in T_4. It may be due to application of N, P, K and S fertilizers maintained the soil fertility and enhance the phytohormones helps rapid multification of cells and celluatr elongation resulting in better growth of branches in plants. These results are in harmony with those obtained by Shehata and Moubarak (2020) and Moradi *et al.* (2011).

The number of umbels per plant was significantly influenced by the treatments (Table 3). The maximum number of umbels per plant (33.5) was found in T_2, while the minimum 12.0) in T_4. It is observed that the number of umbellets per plant directly influenced the number of capsules per plant. This was probably due to adequate nutrient uptake by plant in T_2 treatment resulting production of more branches as well as a greater number of umbels per plant. The present results are in agreement with the findings of Shehata and Moubarak (2020), Valiki *et al.* (2015) and Tuncturk *et al*. (2011). The highest number of umbellets (24.5) per umbel was recorded in T_2 and the lowest value (13.7) in T_4. Total number of umbellets per plant appeared to be the most important component since it is closely related with seed yield. Increase in number of umbellets per umbel indicated production of a greater number of seed per umbel, higher percentage of seed set and reduced shedding of seeds which resulted in increased yield (Koyani *et al.*, 2014). The maximum number of seeds per plant (202.8) was recorded in T_2 and the minimum number (112.2) in T_4. It may be due to application of N, P, K and S improved soil fertility in soil and supply nutrient elements to plant. Similar result was repported by Kusuma *et al*. (2019) and Kucha *et al.* (2018). The highest 1000-seed weight (6.17 g) was recorded in T_2 and the lowest seed weight (4.4 g) in T_4 (Table 4). The applied NPKS have facilitated the availabilty of balanced amount

Table 2. Effects of N, P, K and S on different growth parameters of fennel

Treatment	Days to 50% flowering			Plant height (cm)			Number branch per plant		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	114a	115ab	114ab	153.7a	143.7ab	148.7ab	6.7ab	10.9b	8.8b
T_2	115a	118a	116a	158.7a	149.0a	153.8a	7.7a	14.3a	11.0a
T_3	110ab	114abc	112.2ab	149.7a	143.3ab	146.5b	5.7bcd	9.0cd	7.3cd
T_4	94e	90f	91.8e	110.0c	117.7e	113.8d	4.3d	5.0g	4.7g
T_5	99de	97e	97.8d	125.0b	124.0de	124.5c	4.7d	6.0fg	5.3fg
T_6	112a	113a-d	112.2ab	148.0a	138.5bc	143.3b	5.7bcd	9.0cd	7.3cd
T_7	113a	115ab	114.2ab	147.0a	140.6b	143.8b	5.7bcd	8.0de	6.8de
T_8	103cd	109cd	105.8c	129.0b	131.0cd	130.0c	5.0cd	7.0ef	6.0ef
T_9	118a	115ab	113.5ab	151.0a	142.0ab	146.5b	6.3abc	9.3c	7.8c
T_{10}	112a	114abc	113.3ab	147.7a	139.2b	143.5b	5.0cd	8.7cd	6.8de
T_{11}	105bc	107d	106.0c	126.7b	122.0e	124.3c	5.0cd	6.7f	5.8f
T_{12}	110ab	111bcd	110.8b	148.3a	140.8b	144.6b	5.3bcd	9.4c	7.4cd
CV (%)	3.02	3.11	3.07	5.17	3.46	4.43	15.15	7.29	10.66

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Table 3. Effects of N, P, K and S on different yield contributing parameters of fennel

Treatment	No. of umbels per plant			No. of umbellets per umbel			No. of seeds per plant		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	25.0b	31.3b	28.2b	13.3b	25.9ab	19.6a	218.7bc	140.6a	179.7abc
T_2	31.0a	36.0a	33.5a	18.7a	30.3a	24.5a	261.3a	144.3a	202.8a
T_3	23.3b	31.9b	27.6b	14.3b	22.4bc	18.4b	255.7ab	131.4ab	193.7ab
T_4	15.0d	9.0h	12.0f	8.0d	19.4c	13.7cd	118.7d	105.7c	112.2h
T_5	17.0cd	10.7gh	13.8ef	11.7bc	22.8bc	17.2bcd	124.0d	112.3bc	118.7gh
T_6	21.0bc	27.3cd	24.2cd	12.3bc	24.9b	18.6b	197.3c	130.2ab	163.8cde
T_7	22.0b	22.9e	22.5d	13.0bc	24.0bc	18.5b	190.7c	126.8abc	158.7cde
T_8	17.0cd	12.7gh	14.8e	10.3cd	22.7bc	16.5bcd	139.7d	133.4ab	136.5fg
T_9	25.0b	27.8c	26.4bc	12.0bc	23.7bc	17.8bc	208.0c	142.3a	175.2bcd
T_{10}	25.0b	29.8bc	27.4b	11.7bc	23.6bc	17.7bc	205.3c	145.1a	175.2bcd
T_{11}	16.7d	15.0f	15.8e	10.3cd	23.0bc	16.7bcd	143.7d	145.9a	144.8de
T_{12}	23.0b	24.0de	23.5d	13.0bc	23.1bc	18.1b	208.0c	132.1ab	170.1cd
CV (%)	11.71	8.81	10.27	12.85	11.90	12.7	2.07	10.39	12.05

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

of essential nutrients throughout the whole plant growing season resulting better nourishment of plants and the formation of bold seeds ultimate increased the seed weight. These results are in agreement with the results observed by Kusuma *et al*. (2019) and Koyani *et al.* (2014).

Biomass and Seed yield

The biomass and seed yield of fennel were significantly influenced by the nutrient management (Table 4). The maximum biomass yield (4758.7 kg ha^{-1}) was found in T_2 (130-70-80-30 kg NPKS ha^{-1}), which was stastically similar to T_1 and T_9. The minimum biomass yield (2689.0 kg ha^{-1}) was noted in T4 (70-80-30 kg PKS ha^{-1}). The increament of biomass production might be attained to optium vegetative growth and production of more fresh weight of fennel crops. The maximum seed yield (1.98 t ha^{-1}) was found in T_2, which was followed by T_1 and T_9. The lowest seed yield (0.79 t ha^{-1}) was observed in T_4. The increased level of NPKS in plant due to increased availability in the soil medium and there after eficient absorption and translocation in various growths by way of active cell division and elongation resulting in higher plant height, number of primary and secondary branches. The growth and development of crops might be inluenced by NPKS elements have expressed larger canopy and considering higher chlorophyll content in leaves favored, cell elongation, photosynthates, metabololites and pro-active to reproductive phase which produe higher yield of crops. The indings of this investigation were in close conformity with those of Shehata and Moubarak (2020) and Waskela *et al*. (2017).

Days to maturity

Maturity at harvest is an important crop stage which can influence the quality of seeds. The seed vigority and longevity grdually increase from physiological maturity phase to late maturation phase (Sripthy and Groot, 2023). Matuity date of fennel was significantly influenced by the nutrient management (Table 5). The maximum maturation date (162 DAS) was required in T_2 (130-70-80-30 kg NPKS ha^{-1}) followed by T_1 and T_9. The minimum maturity date (145 DAS) was noted in T_4. This could be associated with the combined effect of NPKS with higher rates in extending the vegetative growth period of plants while delaying maturity. These results are agreed with the results noted by Godar *et al*., 2014.

Harvest index

The harvest index was influenced by the NPKS treatments (Table 5). The maximum harvest index (41.61 %) was observed in T_2, followed by T_1 and T_9. The minimum harvest index (29.38 %) was noted in T_4. Maintaining optimum nutiernt availability resulted in better vegetative and reproductive growth and contributed to good harvest index of crops. Harvest index governed by several factors such as variety, growing condition, environmental factors, irrigation management and agronomic management. These results have also been opined by Kusuma *et al.* (2019).

Table 4. Effects of N, P, K and S on the yield components of fennel

Treatment	1000-seed weight (g)			Seed yield (tha^{-1})			Biomass yield ($kgha^{-1}$)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	5.3ab	6.0a	5.65ab	1.91a	1.83a	1.87ab	4646.7a	4609.3a	4628.0ab
T_2	5.7a	6.7a	6.17a	1.99a	1.98a	1.98a	4753.7a	4763.7a	4758.7a
T_3	5.4ab	6.0a	5.70ab	1.65b	1.77ab	1.71bcd	4281.0bcd	4554.0a	4417.5bc
T_4	4.5c	4.3b	4.40c	0.85d	0.73e	0.79f	2951.7g	2426.3c	2689.0e
T_5	5.0abc	4.3b	4.67c	0.98d	0.88e	0.93f	3294.3f	2554.0c	2924.2e
T_6	5.1abc	5.7a	5.37b	1.64b	1.71ab	1.67cd	4317.0bc	4519.3a	4418.2bc
T_7	5.1abc	6.3a	5.73ab	1.65a	1.61bc	1.63cd	4372.0b	4406.7a	4389.3bc
T_8	4.5c	4.3b	4.40c	1.32c	1.34cd	1.33e	4079.7de	3750.0b	3914.8d
T_9	4.9abc	6.3a	5.63ab	1.65b	1.97a	1.81abc	4402.3b	4754.7a	4578.5abc
T_{10}	4.8bc	6.7a	5.72ab	1.52bc	1.70ab	1.61d	4116.3cde	4563.7a	4340.0c
T_{11}	4.9abc	4.3b	4.65c	1.30c	1.28d	1.29e	4034.7e	3707.3b	3871.0d
T_{12}	4.8bc	6.0a	5.42b	1.52bc	1.77ab	1.65cd	4258.7bcd	4551.7a	4405.2bc
CV (%)	9.27	10.69	10.1	9.98	10.62	10.32	2.89	6.68	5.13

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Table 5. Effects of N, P, K and S on the yield and yield components of fennel

Treatment	Days to maturity			Harvest index (%)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	158abc	159ab	158ab	41.1	39.7	40.41
T_2	162a	161a	162a	41.86	41.56	41.61
T_3	155b-e	157abc	156bc	38.54	38.87	38.71
T_4	147g	144e	145d	28.79	30.09	29.38
T_5	149fg	146e	148d	29.75	34.46	31.8
T_6	156bcd	152c	154c	37.99	37.84	37.79
T_7	157abc	152c	155bc	37.74	36.53	37.13
T_8	1501d-g	144e	147d	32.36	35.73	33.97
T_9	160a	157abc	158ab	37.48	41.43	39.53
T_{10}	159ab	155bc	157bc	36.93	37.25	37.09
T_{11}	150efg	147de	148d	32.22	34.53	33.32
T_{12}	153c-f	154bc	154c	35.69	38.89	37.46
CV (%)	2.24	2.11	2.18	-	-	-

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Response of fennel to N, P, K and S

Fennel responsed significantly to added N, P, K and S. Howerver, from regression analysis, a quadratic response of fennel to N, P, K and S (R^2 =0.999, 0.9257, 1.3395 and 1, respectively) was recorded (Table 6). The seed yield increased upto 130, 70, 80 and 20 kg NPKS ha^{-1} and there after yield declined due tofurther application of higher dose. From the quadratic response function, the optimum dose of N, P, K and S for fennel cultivation estimated to be (145, 62.5, 77.5 and 22.86 kg ha^{-1}, respectively) and the maximum seed yield expected to be (1.99, 1.71, 1.94 and 1.65 t ha^{-1} for N, P, K and S respectively). Up to the optimum level (8.7, 12.5, 7.75 and 16 kg ha^{-1} for N, P, K and S) increased seed yield may be obtained for 1 kg NPKS application (use efficiency). Beyond optimum level reduction of seed yield (0.06, 0.2, 0.01 and 0.7 kg ha^{-1}) may be obtained for 1 kg NPKS (yield reduction).

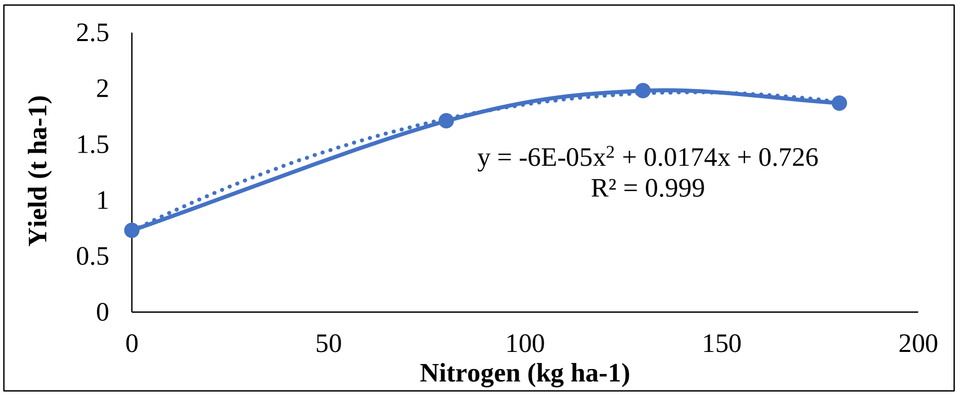

Fig. 1a. Relationship between seed yield and application of nitrogen on fennel.

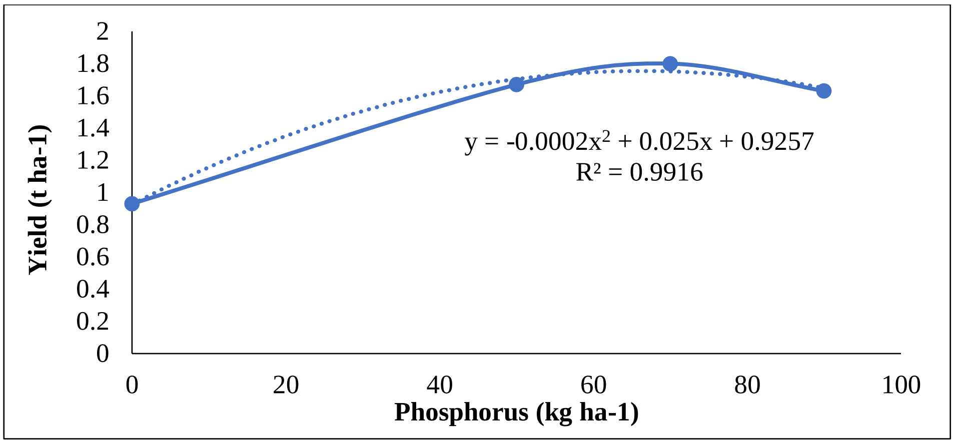

Fig. 1b. Relationship between seed yield and application of Phosphorus on fennel.

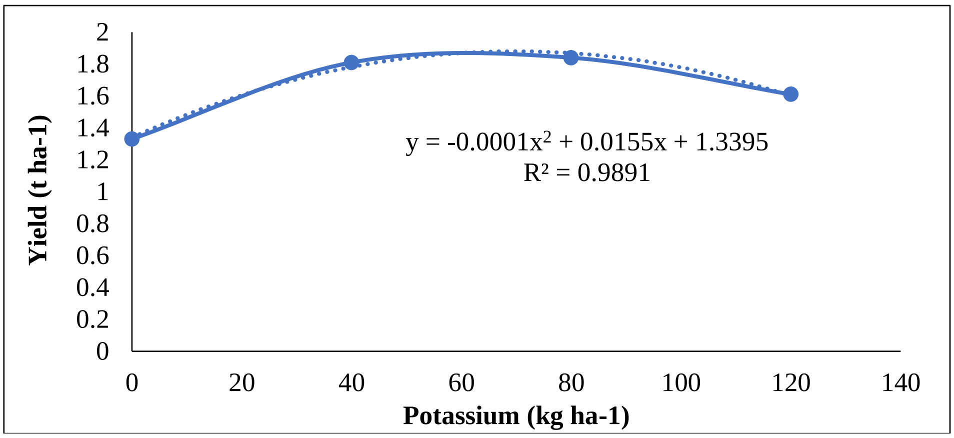

Fig. 1c. Relationship between seed yield and application of Potassium on fennel.

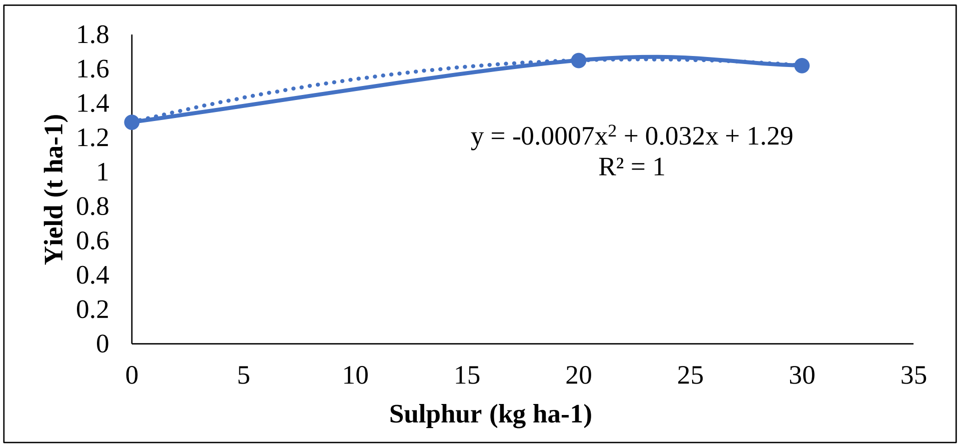

Fig. 1c. Relationship between seed yield and application of Sulphur on fennel.

Table 6. Response function of fennel to N, P, K and S for seed yield

Response function	Nitrogen	Phosphorus	Potassium	Sulphur
Regression equation	$Y = -6E\text{-}05N^2 + 0.0174N + 0.726$	$Y = -0.0002P^2 + 0.025P + 0.9257$	$Y = -0.0001K^2 + 0.0155K + 1.3395$	$Y = -0.0007S^2 + 0.032S + 1.29$
R^2	0.999	0.9916	0.9891	1
Optimum rate of Nutrient (kg ha^{-1})	145	62.5	77.5	22.86
Maximum seed yield (tha^{-1}) for optimum nutrient level	1.99	1.71	1.94	1.65
Production of seed (kg) for 1 kg Nutrient (use efficiency)	8.7	12.5	7.75	16
Beyond optimum level the reduction of seed (kg) for each 1 kg Nutrient	0.06	0.2	0.01	0.7
Optimum economic rate of Nutrient (kg ha^{-1})	144.99	62.49	77.5	22.87

Uptake of N, P, K and S

N, P, K and S uptake by the fennel were influencedby the treatments (Table 7-10). The maximum uptake of N, P, K and S (72.35, 15.35, 36.18 and 9.04 kg ha^{-1}, respectively) was found in T_2. The minimum uptake of N, K, S (33.89, 12.11 and 2.96 kg ha^{-1}, respectively) were recorded in T_4 and P (5.11 kg ha^{-1}) in T_5. Maintenance of optimum levels of N, P, K and S in soil had led to favoured in better plant growth and higher transpiration rate, thus the movement of nutrients was also higher. These findings are in agreement with reported by Kucha *et al*., 2018.

Residual soil N, P, K and S after crop harvest

The data presented in Table 7-10 reveled that application of N, P, K and S influenced the residual N, P, K and S fertility status of soil under fennel cultivation. The maximum residual N (1698 kg ha^{-1}), P (21.22 kg ha^{-1}), K (61.89 kg ha^{-1}) and S (13.21 kg ha^{-1}) were recorded in T_1, T_2, T_{10} and T_5, respectively. The minimum residual N (1610 kg ha^{-1}), P (15.66 kg ha^{-1}), K (32.43 kg ha^{-1}) and S (9.44 kg ha^{-1}) were recorded in T_4, T_5, T_8 and T_9, respectively. It can be inferred from the results that higher nutrient availability leds to higher N, P, K and S mining and ultimately resulted in less N, P, K and S reserves in soil.

Apparent N, P, K and S balance

Apparent N, P, K and S balance of fennel were influenced by the application of N, P, K and S fertilizers (Table 7-10). The apparent NPKS balance ranged from (-204.87 to -95.47, -72.64 to 5.67, -87.53 to 12.38 and -27.43 to -1.15 kg ha^{-1} for N, P, K and S, respectively). The maximum apparent balance of N (-95.47 kg ha^{-1}), P (5.67 kg ha^{-1}), K (-12.38 kg ha^{-1}) and S (-1.15 kg ha^{-1}) were recorded in T_2, T_5, T_8 and $T_{11,}$ respectively. The minimum apparent balance of N (-204.87 kg ha^{-1}), P (-72.64 kg ha^{-1}), K (-87.53 kg ha^{-1}) and S (-27.43 kg ha^{-1}) were noted in T_8, T_7, T_{10} and T_4, respectively. The apparent negative N, P, K and S balance of soil indicate that soil is unable to supply sufficient N, P, K and S for proper growth and development of crops. The findings of Singh *et al*. (2017) also confirm these results.

Net N, P, K and S balance

Nutrient balance might be termed as nutrient budget or nutrient audit in cultivated land to maintain higher soil productivity in the future. Positive balance indicated the nutrient accumulation and negative balance shows nutrient depletion. To achieve nutrient sustainability, the quantity of nutrient inputs and outputs should be equal. Negative nutrient balance may eventually cause soil degradation and adversely affect crop production. On the other hand, excess nutrient accumulation may lead to soil, water and air pollution. The net N, P, K and S balance are presented (Table 7-10). The net NPKS balance ranged from (-150.0 to -62.0, 0.12 to 5.68, -29.97 to -0.51 and -4.24 to -0.27 kg ha^{-1}, respectively. The maximum net balance of N (-62 kg ha^{-1}), P (5.68 kg ha^{-1}), K (-0.51 kg ha^{-1}) and S

(-0.22 kg ha^{-1}) were recorded in T_1, T_4, T_{10} and T_5, respectively. The minimum net balance of N (-150 kg ha^{-1}), P (0.12 kg ha^{-1}), K (-29.97 kg ha^{-1}) and S (-4.24 kg ha^{-1}) were obtained in T_4, T_5, T_8 and T_{11}, respectively. It may be due to higher availability of nutrients in root zone and enhanced bio-chemical activities of fennel plants.

Table 7. Effect of N, P, K and S on N balance sheet of fennel

Treatment	Initial soil N status	Added N through fertilizer	N uptake	Residual soil N after harvest	Apparent N balance	Net N balance
	A	B	C	D	D-{(A + B)-C} =E	D-A= F
	(kg ha^{-1})					
T_1	1760	180	69.76	1698	-172.24	-62
T_2	1760	130	72.35	1620	-197.65	-140
T_3	1760	80	64.53	1680	-95.47	-80
T_4	1760	0	33.89	1610	-116.11	-150
T_5	1760	130	38.25	1688	-163.75	-72
T_6	1760	130	66.30	1660	-163.7	-100
T_7	1760	130	64.09	1685	-140.91	-75
T_8	1760	130	55.13	1630	-204.87	-130
T_9	1760	130	70.39	1675	-144.61	-85
T_{10}	1760	130	64.23	1688	-137.77	-72
T_{11}	1760	130	55.34	1670	-164.66	-90
T_{12}	1760	130	65.71	1629	-195.29	-132

Table 8. Effect of N, P, K and S on P balance sheet of fennel

Treatment	Initial soil P status	Added P through fertilizer	P uptake	Residual soil P after harvest	Apparent P balance	Net P balance
	A	B	C	D	D-{(A+B)-C} = E	D-A= F
	(kg ha^{-1})					
T_1	15.54	70	15.28	16.98	-53.28	1.44
T_2	15.54	70	15.35	16.22	-54.93	0.68
T_3	15.54	70	12.38	19.57	-53.59	4.03
T_4	15.54	70	5.11	21.22	-59.21	5.68
T_5	15.54	0	5.55	15.66	5.67	0.12
T_6	15.54	50	12.82	15.98	-36.74	0.44
T_7	15.54	90	12.73	20.17	-72.64	4.63
T_8	15.54	70	9.78	18.24	-57.52	2.7
T_9	15.54	70	15.11	16.68	-53.75	1.14
T_{10}	15.54	70	13.45	17.02	-55.07	1.48
T_{11}	15.54	70	9.68	19.05	-56.81	3.51
T_{12}	15.54	70	12.35	17.56	-55.63	2.02

Table 9. Effect of N, P, K and S on K balance sheet of fennel

Treatment	Initial soil K status	Added K through fertilizer	K uptake	Residual soil K after harvest	Apparent K balance	Net K balance
	A	B	C	D	D-{(A+B)-C} = E	D-A= F
	(kg ha^{-1})					
T_1	62.4	80	33.34	42.49	-66.57	-19.91
T_2	62.4	80	36.18	41.85	-64.37	-20.55
T_3	62.4	80	31.82	45.5	-65.08	-16.9
T_4	62.4	80	12.11	60.68	-69.61	-1.72
T_5	62.4	80	13.72	58.22	-70.46	-4.18
T_6	62.4	80	31.82	48.92	-61.66	-13.48
T_7	62.4	80	32.99	47.22	-62.19	-15.18
T_8	62.4	0	17.59	32.43	-12.38	-29.97
T_9	62.4	40	35.27	45.23	-21.9	-17.17
T_{10}	62.4	120	32.98	61.89	-87.53	-0.51
T_{11}	62.4	80	19.66	59.47	-63.27	-2.93
T_{12}	62.4	80	30.43	47.96	-64.01	-14.44

Table 10. Effect of N, P, K and S on S balance sheet of fennel

Treatment	Initial soil S status	Added S through fertilizer	S uptake	Residual soil S after harvest	Apparent S balance	Net S balance
	A	B	C	D	D-{(A+B)-C} = E	D-A= F
	(kg ha^{-1})					
T_1	13.68	30	8.79	11.69	-23.2	-1.99
T_2	13.68	30	9.04	12.48	-22.16	-1.02
T_3	13.68	30	6.19	12.69	-24.8	-0.99
T_4	13.68	30	2.96	13.29	-27.43	-0.39
T_5	13.68	30	3.79	13.41	-26.48	-0.27
T_6	13.68	30	7.07	12.99	-23.62	-0.69
T_7	13.68	30	6.59	12.91	-24.18	-0.77
T_8	13.68	30	5.48	12.98	-25.22	-0.7
T_9	13.68	30	8.7	12.75	-22.23	-0.93
T_{10}	13.68	30	8.25	12.01	-23.42	-1.67
T_{11}	13.68	0	3.09	9.44	-1.15	-4.24
T_{12}	13.68	20	7.94	10.41	-15.33	-3.27

Cost-benefit analysis of NPKS Fertilizer for fennel

The results of cost-benefit analysis related with application of different rates of NPKS fertilizer are presented in Table 10-11. Generally, the benefits of NPKS fertilizer application exceed the farmer`s traditional practice both in yield and return. The highest gross margin (Tk 267300 ha^{-1}) was found in T_2 (130-70-40-30 kg NPKS ha^{-1}) while its variable cost was Tk. 86353 ha^{-1}. The purpose of marginal analysis is to reveal how the net benefit increases as the amount of investment increases (Perrin *et al.*, 1979). The marginal rate of returns (3060%) was also recorded in the same treatment (T_2) followed by T_9 (441%). The finding is in close conformity with reported of Koyani *et al.* (2014).

Table 10. Cost benefit analysis of fennel as influenced by NPKS fertilizers

Treatment	Variable cost (Tk.)				Income (Tk.)		Rank
	Input cost	Labor cost	Fixed cost	Total variable cost	Gross income	Net income	
	A	B	C	D=A + B +C	E	F = E-D	
T_1	18434	29250	41755	89439	252450	163011	2CD
T_2	16698	27900	41755	86353	267300	180947	1CUD
T_3	14962	27000	41755	83717	230850	147133	5CD
T_4	12185	26550	41755	80490	106650	26160	12CD
T_5	8998	27450	41755	78203	125550	47347	11CD
T_6	14498	27000	41755	83253	225450	142197	6CD
T_7	18898	29700	41755	90353	220050	129697	8CD
T_8	14298	26550	41755	82603	179550	96947	9CD
T_9	15498	28350	41755	85603	244350	158747	3CUD
T_{10}	17898	28800	41755	66203	217350	151147	4CUD
T_{11}	14613	27450	41755	83818	174150	90332	10CD
T_{12}	16003	27450	41755	85208	222750	137542	7Cd

Unit price: Urea=16 $Tk.kg^{-1}$, TSP=22 $Tk.kg^{-1}$, MoP=15 $Tk.kg^{-1}$, Gypsum=12.5 $Tk.kg^{-1}$, Cowdung= 1.5 $Tk.kg^{-1}$, Boric acid= 150 $Tk.kg^{-1}$, Zinc sulphate=180 $Tk.kg^{-1}$, irrigation cost =3175 $Tk.ha^{-1}$, land rent=20000 $Tk.ha^{-1}$, tractor cost=4500$Tk.ha^{-1}$, seed cost=180 $Tk.kg^{-1}$, seed sale price= 135 $Tk.kg^{-1}$ (2021-22), respectively, labor=450 $Tk.day^{-1}person^{-1}$ and marketing cost= 2500 Tk. (2021-22).

Table 11. Marginal analysis of cost undominated treatment of NPKS fertilizers on yield of fennel

Treatment	Gross margin (Tk. ha^{-1})	Variable cost (Tk. ha^{-1})	Marginal increase in gross margin (Tk. ha^{-1})	Marginal increase in variable cost (Tk. ha^{-1})	Marginal rate of return (%)
T_2	267300	86353	22950	750	3060
T_9	244350	85603	27000	19400	441
T_{10}	217350	66203	-	-	-

Conclusion

It may be conculated from the results of the present investigation that seed yield of fennel increased with the application of NPKS. The highest seed yield of 1.98 tha^{-1} and the highest net income (Tk. 180947.00) and the maximum marginal rate of returns (3060%) for fennel cultivation were achieved by maintaining 130-70-80-30 kg NPKS ha^{-1}. The net balance of N, P, K and S by fennel crop was highly favoured by the application of N, P, K and S fertilizers. The net nutrient balance of N, K and S showed negative balance but P was positive. The response curve showed, 145-62.5-77.5-22.86 kg NPKS ha^{-1} might be the best nutrient management package for fennel cultivation in Grey Terrace Soil of Madhupur Tract (AEZ-28).

Reference

AVRDC. 1990. Vegetable production training manual. Asian Vegetables Research and Development Centre (AVRDC). Shanhua, Tanian. Taiwan. pp. 87-184.

Ayub, M., M. Naeem, M.A. Nadeem, A. Tanveer, M. Tahir and R. Alam. 2011. Effect of nitrogen application on growth, yield and oil contents of Fennel (*Foenoculum vulgare* Mill.). *J. Medi. Plants Res.,* **5(11):** 2274-2277.

Black, C.A. 1965. Methods of soil analysis part II and I. American Soc. Agron. Inc. Madison, Wisconsin, pp. 325-333.

Blake, G.R. 1965a. Particle density. In methods of soil analysis, part-I. C.A. Black, (Ed.). American Soc. Agron. Inc. Madison, Wisconsin. pp. 371-373.

Blake, G.R. 1965b. Bulk density. In methods of soil analysis, part-I. C.A. Black, (Ed.). American Soc. Agron. Inc. Madison, Wisconsin. pp 374-390.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agron. J.*, **54:** 464-465.

Brammer, H. 1971. Soil Resources. Soil Survey project Bangladesh AGL. SF/Pak.6. Technical Report 3. pp 320-340.

Bray, R.H. and L.T. Kurtz. 1945. Determination of total, organic and available form of phosphorus in soils. *Soil Sci.,* **59:** 39-45.

Christan, G.D. and F.J. Feldman. 1970. Atomic absorption spectroscopy, application in agriculture, biology and medicine. Wiley Inter Science, New York.

Devi, B., S.R. Bhunia, Sunita and Sarita. 2022. Effect of irrigation levels on yield, water use, water use efficiency and NPK utake of fennel (*Foenoculum vulgare* Mill.). *Pharam Inov. J.,* **11(4):** 1994-1996.

El-Seifi, S.K., M.A. Hassan, M.W.M. Elwan and O.G. Haggag. 2015. Plant growth, macro and micro-nutrients uptake of fennel (*Foeniculum vulgare* Mill.) positively affected by N-sources and rates as well as foliar application of micronutrients. *Hort Sci. J. Suez Canal Uni.***4:** 7-16.

Godara, A.S., U.S. Gupta, G. Lal and R. Singh. 2014. Influence of organic and inorganic sources of fertilizers on growth, yield and economics of fennel (*Foeniculum vulgare* Mill.) cultivation under semi arid conditions. *J. Spices Arom. Crops,* **23(2):** 200-204.

Hesse, P.R. 1971. Soil chemical analysis. Chemical publishing Co., NewYork.

Jackson, M.L. 1962. Soil chemical analysis. Prentice-Hall of India (Pvt.) Ltd. New Delhi.

Koyani, C.R., P.K. Chovatia and B.S. Gohil. 2014. Effect of nitrogen and phosphorus on growth, yield attributes and yields of *rabi* fennel (*Foenoculum vulgare* Mill.). *Agriculture: Towards a paradigm of sustainability.* 167-171.

Kucha, H.C., H.L. Sakarvadia, L.C. Vekaria and K.B. Paramar. 2018. Effect of different levels of nitrogen and Sulphur on yield and nutrient uptake by fennel (*Foenoculum vulgare* Mill.). *Agropeologyy.* **28(1):** 70-74.

Kusuma, M.V., J. Venkatesha, P.M. Ganghadarappa, J.S. Hiremath, A.B. Mastiholi and G. Manjunatha. 2019. Effect of integrated nutrient management on growth and yield of fennel (*Foeniculum vulgare* Mill.). *Int. J. Curr. Microbiol. App. Sci*., **8(1):** 2782-2794.

Shehata, A.M. and M. Moubarak. 2020. Using nana-fertilization of improve yield, vegetative growth and essential oil contents of fennel plants. *Future. J. Biol*., **3:** 10-15.

Singh, A., S.K. Sharma, R. Chopra, S.C. Meena and H. Mali. 2017. Evaluation of nutrient balance sheet as influenced by drip fertigation in cauliflower. *Int. J. Curr. Microbiol. Appl. Sci.,* Special issue-**4**: 25-29.

Sripathy, K.V. and S.P.C. Groot. 2023. Seed Development and Maturation. In: Dadlani, M., Yadava, D.K. (eds) *Seed Science and Technology*. Springer, Singapore. pp 17-18

Tuncturk, R., M. Tuncturk and D. Turkozu. 2011. The effects of different phosphorous and nitrogen doses on the yield and quality of fennel (*Foeniculum vulgare* Mill.) in Van ecological conditions. *YuzuncuYil Uni. J. Agril. Sci*., **21(1):** 19-27.

Valiki, S.R.H., S. Ghanbari, S. Golmohammadzadeh and O.F. Tat. 2015. The effect of vermicompost and NPK fertilizer on yield, growth parameters and essential oil of fennel (*Foeniculum vulgare* Mill.). *Int. J. Life Sci*., **9(4):** 38-43.

Walkley, A.C. and T.A. Black. 1934. Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.* **47:** 29-38.

Waskela, P., I.S. Naruka and R.P.S. Shaktawat. 2017. Effect of row spacing and level of NPK on growth and yield of fennel (*Foeniculum vulgare*). *J. Krishi Vigyan*. **6(1):** 78-82.

Yoshida, S., D.A. Fomo, J.H. Cock, and K.A.Gomez, 1972. Laboratory manual of physical studies of rice. IRRI, Los Banos, pp. 7-71.

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A SOCIOECONOMIC STUDY OF SOYBEAN PRODUCTION IN BANGLADESH

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Abstract

This study was undertaken to estimate the financial profitability and to assess the factors affecting adoption of soybean production in Noakhali and Lakshmipur districts of Bangladesh. To collect primary data, a structured interview schedule was used to interview 90 farmers using stratified random sampling technique. A combination of descriptive, mathematical and statistical techniques were employed to analyze the data. According to the findings, 47 percent of farmers were small in farm size category. Financial profitability analysis shows that soybean production was profitable with benefit cost ratio (1.43). The logit regression model demonstrated that farmers' education, farm size, farm income, extension contact, crop diversification practiced, and distance to market had a significant effect on farmers' decision to pursue soybean cultivation.The research findings also indicated that higher price of seed and fertilizer, low price of output and lack of transportation facilities were the major problems for input, production and marketing of soybean, respectively. Among all the problems, high price of seed and fertilizer had the highest problem confrontation index value (255) as first rank. The study recommended for ensuring affordable price of seed and fertilizers along with better infrastructure and transportation facilities to overcome the problems. Furthermore, government needs to implement subsidy scheme and assistance should be provided from the personnel of Department of Agricultural Extension to enhance soybean production in Bangladesh.

Keywords: Adoption, Bangladesh, financial profitability, potential and Soybean.

Introduction

Bangladesh has suitable environment and soil conditions for the production of oilseed species all the year round. Since our country's independence, there has been a severe lack of edible oil. Currently, about 975 thousand metric tons of oilseeds are produced from 484 thousand hectares of land which is 3.1% of the country's total cultivable land (BBS, 2017). The indigenous production of major oilseeds can only meet about 40% of the country's annual demand and the rest 60% is imported from outside (UNB, 2019).

Soybean, recognized as 'golden bean' is a very well-known oil seed and protein crop in the world. It is considered as an important economic food legume cultivated

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worldwide because of its superior nutritional and industrial values (Bisaliah, 1986). Global soybean output was projected to reach 346.0 million tons annually in 2017–18 (INFO, 2018). Bangladesh has 78.95 thousand hectares of total land dedicated to soybean farming, yielding 1420 MT in 2018–19. (Krishi Diary, 2020). Bangladesh produces 1.59 tons of soybeans per hectare, far less than the global average of 2.76 tons per hectare (Terzić*et al*., 2018). Bangladesh's own output of oil is insufficient to fulfill the country's yearly needs. The oil crop acreage of Bangladesh is steadily shrinking due to its replacement by HYV *Boro* rice. As a result, the government must import oilseeds and oil each year, primarily soybeans, at a significant financial loss (Amin *et al.*, 2009). Considering the rising demand of edible oil in our country, it is extremely needed to increase the total production of oil crops through increasing the area of cultivation where possible. However, research on farmers' perceptions and the factors influencing the adoption of soybean cultivation in Bangladesh is scarce and many concerns at the policy level remain unsolved.

Salam and Kamruzzaman (2015) discovered that Bangladesh's soybean output has a competitive advantage over imports. Uddin and Nasrin (2013) assessed the farming patterns and farmers’ livelihood in coastal regions of Bangladesh; and found that the amount of land devoted to agricultural crop cultivation was declined due to shrimp cultivation for all categories of farmers. Alam *et al.* (2009) studied on nodulation, yield and quality of soybean as influenced by integrated nutrient management in Bangladesh while Amin *et al.* (2009) estimated the growth dynamics of soybean as affected by varieties and timing of irrigation. It is evident from the aforementioned discussion that till now very limited empirical research has been conducted concerning farmers’ perception and factors affecting soybean production in Bangladesh. The specific objectives of the study are as follows:

i) To assess farmers’ perception of soybean production and calculate its financial profitability;

ii) To explore the factors affecting adoption of soybean production by the farmers; and

iii) To identify the potentials and problems associated with the production of soybean.

Methodology

The study was carried out at several villages of Subornachor and Ramgati *Upazilas* in Noakhali and Lakshmipur districts, respectively in order to gather the necessary data. These two districts are important hubs for soybean production in Bangladesh, for this they were chosen as the research region. So, it was simple to get relevant and reliable data for completing the study successfully. Data were collected for two groups of farmers (those who cultivate soybean in their farm and those who do not cultivate soybean).

Table 1. Sample size distribution in the study area

Districts	Upazilas	Unions	Villages	No. of farmers	
				Adopter	Non-adopter
Noakhali	Subarnachar	Char Jubli	Kocchopia	6	2
			Tumchar	3	3
		Char Jobbar	Char Hasan	10	6
			Jahazmara	9	6
Sub-total				28	17
Lakshmipur	Ramgati	Poragacha	Char kolakopa	11	9
			Sayed Nagar	2	0
		Char Aalgi	Char Neyamot	4	3
			Char Meher	8	8
Sub-total				25	20
Sample size in each group				53	37
Total sample size				90	

Source: Field survey, 2022.

After collecting necessary data and information from field surveys, interviews, communications and interactions, those were classified, edited and coded. To assess farmers' perception of soybean production, descriptive statistics (i.e., sum, average, percentages, ratios, etc.) with the support of tables was used. The financial profitability of soybean production from the individual farmer's point of view was measured in terms of gross return, gross margin, net return and benefit cost ratio (undiscounted). Logit regression model was used to identify the determinants that affect adoption of soybean production. Here, the dependent variable that is adopting soybean production was coded as 1 for farmers adopting soybean production and it was coded as 0 for otherwise. The logit model used in this analysis is given below:

$$Li = \ln\left(\frac{p}{1-p}\right) = \propto + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + Ui$$

Where,

P = Probability that the farmers will adopt soybean production;

1-P = Probability that the farmers will not adopt soybean production;

X_1= Age of household head (years);

X_2= Education of household head (years);

X_3 = Farm size (decimal);
X_4= Farm income (Tk./farm/year);
X_5= Off-farm employment (1=Involved in off-farm employment, 0 = otherwise);
X_6= Crop diversification (1= Farmers who practice crop diversification, 0 = otherwise);
X_7= Extension contact (1=Received extension services in previous season, 0 = otherwise);
X_8= Distance to market (km);
X_9= Fallow land (1 = Having fallow land during last year, 0 for otherwise);
$\propto$ = Constant/Intercept;
$\beta_1, \beta_2,\ldots\ldots\ldots\ldots\ldots,\beta_9$ = Coefficients of the respective variables; and
U_i = Error term.

To address the problems in relation to input, production and marketing of soybean, problem confrontation index (PCI) was used. For input related problems, three selected items were computed. For problems related to production and marketing, four items were calculated, respectively using the following formula:

$$PCI = (P_s \times 3) + (P_m \times 2) + (P_l \times 1) + (P_n \times 0)$$

Where,

P_s = Number of respondents with severe problems;

P_m = Number of respondents with moderate problems;

P_l = Number of respondents with low problems; and

P_n = Number of respondents with no problems.

The value of problem confrontation index (PCI) for any of the selected problems regarding input availability, production and marketing of soybean could vary from 0 to 270, where 0 means no problems and 270 means severe problems.SWOT analysis was done to identify the prospects and challenges of soybean production. SWOT is an acronym for Strengths, Weaknesses, Opportunities and Threats. SWOT analysis guides to identify the positives and negatives inside of the organization (S-W) and outside of it, in the external environment (O-T) (Kotler *et al.,* 2009). Recommendations pointed out the facts of intervention for enhancing soybean production in the study areas.

Results and Discussion

Assessing farmers' perception of soybean production

To assess farmers' perception towards soybean production a set of particulars were employed. It can be seen from Table 2 that cultivation time, minimum tillage, cropping pattern and soil fertility are the main factors that influence farmers' positive perception towards soybean production. It is noted that the respondents in the study areas were agreed on these particulars in different extents. Majority (98%) of farmers agreed that selection of time of cultivation and minimum tillage were the major driving force for adopting soybean cultivation followed by cropping pattern (85%), soil fertility (73%), soil organic matter content (65%), etc. Very few farmers agreed on access to training facilities as well as credit facilities of having influence on farmers' decision of adopting soybean cultivation followed by credit facilities (16%).

Table 2. Farmers' perceived factors affecting adoption of soybean production

Particulars	Agree		Disagree	
	No. of farmers	% of farmers	No. of farmers	% of farmers
Credit facilities	14	16	74	84
Training facilities	12	14	76	86
Selection of time of cultivation	86	98	2	2
Cropping pattern change	75	85	13	15
Soil fertility	64	73	24	27
Soil organic matter content	57	65	31	35
Extension services	46	52	42	48
Minimum tillage	86	98	2	2

Source: Field survey, 2022.

Profitability of soybean production

For determining the viability of soybean production, it is necessary to estimate the financial profitability. Farmers in the study areas incurred following cost items for soybean production:

Cost of human labour: Human labours were required from the beginning of the soybean production process to the end of it. They are required for land preparation, planting, mulching, fertilizer application, manure application, weeding, irrigation, harvesting, carrying, drying and sorting. Table 3 shows that about 52 man-days of labours were required for producing soybean in one hectare of land and average cost on them was Tk. 21840 (31 % of the total cost).

Cost of power tiller: It is one of the modern agricultural tools which is now frequently used for land preparation for soybean production. Cost of power tiller for producing one hectare of soybean land was calculated at Tk. 7500 and it covers 11% of total cost (Table 3).

Cost of fertilizers: Fertilizer is generally used in the field to provide environment which facilitates an increase in production of soybean. Farmers in the study area generally used 94 kg urea, 45 kg TSP, 24 kg MoP and 53 kg gypsum, respectively for producing soybean in one hectare. Average per hectare costs were Tk. 1504, Tk. 990, Tk. 360 and Tk. 530 for urea, TSP, MoP and gypsum, respectively and fertilizer cost covers 5% of total cost.

Cost of manure: Cowdung was used as manure for producing soybean. It helped to improve the quality of the soil. Farmers used 1167 kg cowdung per hectare and incurred a cost of Tk. 2451 for soybean production which covers 3 % of the total cost.

Cost of irrigation: Farmers also use irrigation for soybean production. Cost of irrigation was Tk. 2000 (3 % of the total cost) for producing per hectare soybean in the study area.

Cost of seed: It was calculated based on actual market price. A total of 72 kg seed was required for producing one hectare of soybean and the cost was Tk. 8520 which covered 12 % of the total cost.

Cost of pesticide: Pesticide is also applied for soybean production. It is generally required if there is any diseases and insects attack. Cost of pesticide for per hectare soybean production was Tk. 3600 and it covers 5 % of the total cost(Table 3).

Total cost: Total cost was calculated by summation of variable costs and fixed costs. Fixed cost itemincludes land use cost. Land use cost for producing one hectare of soybean was calculated at Tk. 19500 which is 28% of the total cost. It has been calculated that farmers spent Tk. 70767 for producing one hectare of soybean (Table 3).

Table 3. Input use and cost of soybean production per hectare

Cost items	Input use (Quantity/ha)	Cost (Tk./ha)	% of total cost
Human labour	52 man-days	21840	31
Power tiller	-	7500	11
Fertilizers			5
Urea	94 kg	1504	2
TSP	45 kg	990	1
MoP	24 kg	360	1
Gypsum	53 kg	530	1
Manure: Cowdung	1167 kg	2451	3
Irrigation	-	2000	3
Seed	71 kg	8520	12
Pesticide	-	3600	5
Interest on operating capital		1972	3
A. Total variable cost		51267	72
Land use cost	-	19500	28
B. Total fixed cost		19500	28
C. Total cost (A + B)		70767	100

Source: Authors'estimation based on field survey, 2022.

Gross return: It was calculated by multiplying the total production of soybean with its respective market price. Table 4 showed that gross return for producing one hectare of soybean was Tk.100880/-.

Gross margin: Gross margin was calculated by deducting the variable cost from the gross return. Gross margin for producing one hectare of soybean was Tk. 49613/-.

Net return: Net return is the actual amount of money that farmer gets after subtracting all the cost items from the total return. Table 4 showed that net return for per hectare soybean production was Tk. 30113 (Table 4).

Benefit cost ratio: Benefit cost ratio is the ratio of gross return to gross cost. It was calculated to summarize the overall relationship between the relative cost and benefits of soybean production. Benefit cost ratio for per hectare soybean production was 1.43 (Table 4). The result is similar with the study of Salam and Kamruzzaman (2015) where the authors also found that soybean production is profitable than other comparative crops in the areas.

Table 4. Financial profitability of soybean production per hectare

Item	Amount (Tk./ha)
Total fixed cost (TFC)	19500
Total variable cost(TVC)	51267
Total cost (TC = TVC + TFC)	70767
Total production (kg/ha)	1552
Price (Tk./kg)	65
Gross return (GR)	100880
Gross margin (GM = GR - TVC)	49613
Net return (GR – TC)	30113
BCR (Undiscounted) (BCR = GR / TC)	1.43

Source: Authors' estimation based on field survey, 2022.

3.3 Factors Affecting Adoption of Soybean Production

A dichotomous logistic regression model was employed to ascertain the variables influencing the adoption of soybean production. For logistic model, marginal effects have been interpreted below. Marginal effect was computed differently for discrete (i.e., categorical) and continuous variables. Marginal effect is estimated for a discrete change of dummy variable i.e., how predicted probabilities were changed as the binary independent variable changed from 0 to 1. Marginal effects for continuous variables measured the instantaneous rate of change. The association between the dependent and explanatory variables is also strong, as described by pseudo $R^2 = 0.714$, indicating fitness of model predictors for prediction of dichotomous dependent variable.

The result shows that the age of household head influences adoption of soybean production technology positively although insignificant. The implication is that the increase in farmers' age increases farmers' experience and understanding of the benefits of soybean production. This could also mean that farmers who have more years of farm experience are more likely to adopt soybean production technology than those who have less number of years of farm experience. The positive relationship was also found in the study of Miruts (2016). However, this result is in contrary to the findings of Akudugu *et al.* (2012), Samuel and Wondaferahu (2015) and Diro *et al.* (2017) who found negative significant relationship between age and adoption of soybean production. Education level of household head positively and significantly influences the probability of adoption of soybean production at 1% level. The result indicates that, the increase in schooling year of the head of a householdwould lead to increase in the likelihood of adopting soybean production by 8.1% (Table 5). The result of this study was consistent with the findings by Eba and Bashargo (2014), Afework and Lemma (2015), Sisay (2016), Abebe (2017), Iticha and Taresa (2020) who stated that adoption of soybean production was positively associated with level of farmers' education.

Farm size had a positive and significant influence on adoption of soybean production at 10% level. One percent increase in land size would increase the probability of adopting soybean production by 3.7 percent. This indicates that farmers who have large farm land are more likely to adopt soybean production. The reason for this could be that a farmer with large farm size will harvest more and likely to generate sufficient income, which could help them to buy agricultural inputs. This is similar to the findings of Gibegeh and Akubuilo (2013), Miruts (2016) and Diru *et al.* (2017).

Farm income was found to be positively and statistically significant at 5% level of significance in influencing the adoption of soybean production. Accordingly, as farm income of the head of household increase by one percent, this would lead to the increase in the probability of adopting soybean production by 2.9%. Apparently, farmers who obtained comparatively higher income from their annual agricultural production could invest his / her proportion of income to buy soybean improved seed as well as purchasing other agricultural inputs. The result is in line with the results found by Musba (2017) and Iticha and Taresa (2020).

Farmers can earn additional income by engaging in different off-farm activities. Off-farm activities are believed to raise farmer's financial position to acquire new inputs. Based on this assumption the variable was hypothesized that there will be a positive significant relationship between adoption of soybean production and farmers' participation in off-farm activities. However, this variable turns out insignificant although positive. Similar result was found by Miruts (2016). On the other hand, it can be seen from Table 5 that, the marginal effect for crop diversification was 0.301 which means that likelihood of adopting soybean production for farmers who diversified their farm production are 0.301percent higher than their counterparts. Crop diversification is one of the major decision making tools for minimizing risk in farm production. On that regard, including soybean production in the farm plan could improve farmer's risk taking capability.

The study also reveals a positive and significant relationship between extension contact and adoption of soybean production. This shows that the households, who had contact with the extension personnel, are more probable to adopt soybean production technology than those who have no contact and the expected level of adoption would increase by 0.305 percent (Table 5). Extension contact determines the information which the farmers obtain and apply in farm production through counseling, meeting and demonstration. Thus, increased farmers' interaction with extension agents greatly increases farmers' knowledge of available technologies and their potential benefits. Saka and Lawal (2009), Olagunju *et al*. (2010), Miruts (2016), Dereje *et al.* (2016) and Iticha and Taresa (2020) also found similar results in their respective studies.

Table 5. Result of logistic regression on adoption of soybean production

Variables	Coefficients	Standard Error	P value	Marginal effect (dY/dX)
Constant	2.201	1.738	0.883	0.812
Age (years)	0.507	1.138	0.650	0.055
Education (years)	1.302**	0.644	0.032	0.081
Farm size (decimal)	0.425**	0.062	0.042	0.037
Farm income (Tk. /year)	1.706**	0.514	0.011	0.294
Off-farm employment (1 = involved in off-farm employment)	1.374	1.883	0.738	0.182
Crop diversification (1= practice crop diversification)	2.001*	0.428	0.007	0.301
Extension contact (1= received)	0.276**	0.059	0.017	0.305
Distance to market (Km)	-1.448**	0.722	0.029	0.016
Fallow land (1= had fallow land)	1.024	0.982	0.325	0.431
Model summary				
Log likelihood ratio		29.48		
LR chi^2 (10)		258.93		
Prob> chi^2		0.000		
Pseudo R^2		0.714		
Total number of observations		90		

Source: Authors' estimation based on field survey, 2022.

Note: * and ** indicate significant at 1% and 5% probability level, respectively.

Distance to market is measured in kilometers and the result of the model revealed that the coefficient is negatively and significantly related to adoption of soybean.

It is consistent with the hypothesized sign. This result is also supported by the findings of Samuel and Wondaferahu (2015), Sisay (2016) and Musba (2017).The increase in the distance from household to market would lead to the decrease in the probability adoption of soybean production by 1.6%. It implies that since the farmer is far from market, he / she cannot obtain enough information about price, quality and transportation. The result indicates that farmers with fallow land have 0.431 percent more likelihood of adopting soybean production as opposed to those who does not have fallow land.

Problems Related to Input, Production and Marketing of Soybean

Among the identified problems related to production, high price of seed and fertilizer has the highest PFI value which is 255 and it is at the rank of 1 (Table 6). Inadequate extension service is at the bottom of the table with a PFI score of 204 meaning it creates lesser problem for soybean production among the three problems. Lack of quality seed and fertilizer has a PFI score of 224 with a rank order of 2.

Table 6. Problems along with problem facing index and rank order

Particulars	Extent of problems				PFI	Rank order
	Severe (3)	Moderate (2)	Low (1)	Not at all (0)		
Input related problems						
High price of seed and fertilizer	81	5	2	0	255	1
Lack of good quality seed and fertilizer	58	22	6	2	224	2
Inadequate extension service	42	36	6	4	204	3
Product related problems						
Low price of output	76	8	2	2	248	1
Storage of product during harvesting	62	18	6	2	234	2
Temporal and spatial price fluctuation	43	28	14	3	199	3
Lack of fair market	38	32	13	5	191	4
Marketing related problems						
Lack of transport facility	58	15	4	1	212	1
Lack of facilities to develop value added product	44	28	14	2	202	2
Lack of grading knowledge	36	25	23	4	181	3

Source: Authors' estimation based on field survey, 2022.

Four problems related to products were identified and opinions about them were asked to the farmers. Table 6 showed that low price of output has the highest PFI value which is 248 and hence it secures the 1st rank. Other product related problems such as: storage of product during harvesting, temporal and spatial price fluctuation and lack of fair market had a PFI score of 234, 199 and 191 with a rank order of 2, 3 and 4, respectively. Among marketing related problems, lack of transport facility had a PFI score of 212 which is highest among all the three identified problems and had a rank order of 1. Lack of facilities to develop value added product and lack of grading knowledge had a PFI score of 202 and 181 with a rank order of 2 and 3, respectively.

SWOT Analysis for Soybean Production

SWOT analysis was conducted to find out the strengths, weakness, opportunities and threats for soybean production. Soil fertility (76.2%) and availability of human labour (64.7%) were the major strengths for soybean production. High price of seed and fertilizer (85.4%), low price of output (71.7%) and lack of transport facility (61.8%) were found to be the weakness of soybean production. High local demand for soybean (88.3%), wide export market (67.0%) and infrastructural development could facilitate soybean production (57.6%) were the major opportunities of soybean production. Lack of training (82.6%), lack of credit facilities (62.1%) and disease and insect infestation (73.8%) were found as the major threats.

Table 7. SWOT analysis for soybean production

	Statements	% of farmers		Statements	% of farmers
Strengths	Appropriate climate and environment for soybean production	80.0	Weakness	High price of seed and fertilizer	85.4
	Soil fertility	76.2		Low price of output	71.7
	Availability of human labour	64.7		Lack of transport facility	61.8
Opportunities	High local demand for soybean	88.3	Threats	Lack of training	82.6
	Wide export market	67.0		Lack of credit facilities	62.1
	Infrastructural development could facilitate soybean production	57.6		Disease and insect infestation	73.8

Source: Authors' estimation based on field survey, 2022.

Conclusion

The research evaluated farmers' perceptions on soybean production and determined the socio-economic level of soybean growers. The results of the study demonstrated that time of cultivation, minimum tillage, cropping pattern and soil fertility were the major drivers that influence farmers' adoption towards soybean production. The calculated benefit cost ratio implied that soybean farming in the research regions was profitable. Regression analysis revealed that farmers' decision to embrace soybean production was significantly influenced by their level of education, farm size, farm income, extension contact, practiced crop diversification, and distance to market. The analysis also showed that the main issues with input, production, and marketing of soybean were rising costs for seed and fertilizer, low output prices, and a lack of transportation infrastructure. The provision of formal and informal education in rural regions should be improved through various GOs and NGOs. Extension contacts should be improved by the personnel of the Department of Agricultural Extension (DAE). The government should implement a subsidy scheme for the production of soybeans, especially to provide farmers with high quality seed, as the enterprise is time demanding and has the potential to advance agricultural growth as a whole. The government should take action to dissolve market syndicates in order to guarantee reasonable market prices.

References

Abebe G. (2017). Adoption of Improved Soybean Varieties: The Buno Bedele and East Wollega Zones of Oromia Region, Ethiopia (Doctoral dissertation, Haramaya University).

Afework, H. and Lemma, Z. (2015). Determinants of Improved Rice Varieties Adoption in Fogera District of Ethiopia. *Science, Technology and Arts Research Journal*, **4(1):** 221-228.

Agarwal, P.K. and Singh, O.P. (2014). An Economic Analysis of Soybean Cultivation in Narsinghpur District of Madhya Pradesh, India. *Indian Journal of Agricultural Research*, **48(3):** 185-191.

Akudugu M.A, Guo E. and Dadzie S.K. (2012). Adoption of Modern Agricultural Production Technologies by Farm Households in Ghana: What Factors Influence their Decisions? *Journal of Biology, Agriculture and Health Care*, **2:**3.

Alam, M.A., Siddiqua, A., Chowdhury, M.A.H. and Prodhan, M.Y. (2009). Nodulation, Yield and Quality of Soybean as Influenced by Integrated Nutrient Management. *Journal of Bangladesh Agricultural University*, 7(2): 229-234.

Amin, A.K.M.R., Jahan, S.R.A., Karim, M.F. and Hasanuzzaman, M. (2009). Growth Dynamics of Soybean (*Glycine max* L.) as Affected by Varieties and Timing of Irrigation. *American- Eurasian Journal of Agronomy*, **2(2):** 95-103.

BBS (2017). Yearbook of Agricultural Statistics-2015. Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh.

Bisaliah, S. (1986). Soybean Development in India. CGPRT Paper No. 5, UN/ESCAP CGPRT Centre, Bogor, Indonesia.

Diro, S., Asfaw, E.,Erko, B. and Anteneh, M.(2017). Factors Affecting Adoption and Degree of Adoption of Soybean in Ilu-Ababora Zone; Southwestern Ethiopia. *Agricultural Science Research Journal*, **7(1):** 15-26.

Eba, N. and Banshargo, G. (2014). Factors Affecting Adoption of Chemical Fertilizer by Smallholder Farmers in Guto Gida District, Oromia Regional State, Ethiopia. *Science, Technology and Arts Research Journal*, **3(2):**237. DOI: 10.4314/star.v3i2.31.

Gibegeh, B.D and Akubuilo J.C. (2013). Socio-economic Determinants of Adoption of Yam Minister by Farmers in Rivers States, Nigeria. *Wudpecker journal of Agricultural Research*.

Krishi Diary (2020). Field Services Wing, Department of Agricultural Extension, Ministry of Agriculture, Government of the People's Republic of Bangladesh.

INFO (2018). World Soybean Production. INFO Source Newsletter, https://www.soymeal.org/newsletter/march-2018/.

Iticha, M. D. and Taresa, E. B. (2020). Factors Affecting Adoption of Soybean Production Technologies in Ethiopia. *Food Science and Quality Management*, **96:** 11-20.

Lende, S.G. and Velázquez, G. (2017). Soybean Agribusiness in Argentina *(1990–2015): Socio-Economic, Territorial, Environmental, and Political Implications, Agricultural Value Chain*, Gokhan Egilmez, Intech Open, DOI: 10.5772/intechopen.70463.

Musba K. (2017). Adoption and Impact of Improved Soybean (Belessa-95) Variety Among Smallholder Farmers in Bambasi Woreda, Benishangul Gumuz Regional State (Doctoral dissertation, Haramaya University)

Miruts, F. (2016). Analysis of the Factors Affecting Adoption of Soybean Production Technology in Pawe District, Metekele Zone of Benshangul Gumuz Regional State, Ethiopia. *World Scientific News*, **53(3):** 122-137.

Olagunju, F. I., Lyabo, S. and Kayode, K. (2010). Effects of Adoption Pattern of Fertilizer Technology on Small Scale Farmer's Productivity in Boluwaduro, Nigeria. Department of Agricultural Economics and Extension, Ladoke Akintoala University of Technology.

Saka, J. and Lawal, B. (2009). Determinants of Adoption and Productivity of Improved Rice Variety in South Nigeria. *African Journal of Biotechnology*, **8 (19):** 4923- 4932.

Salam, M.A. and Kamruzzaman, M. (2015). Comparative and Competitive Advantage of Soybean Cultivation in Noakhali and Laxmipur District of Bangladesh. *Journal of Bangladesh Agricultural University*, **13(2):** 265-272.

Samuel, D. and Wondaferahu M., 2015. Determinants of Adoption of Soybean and its Impact on the Livelihood of Smallholder Farmers in Jimma zone. *ZENITH International Journal of Multidisciplinary Research.* **5(4):** 119-138.

Sisay, D. (2016). Agricultural Technology Adoption, Crop Diversification and Efficiency of Maize-Dominated Smallholder Farming System in Jimma Zone, South-Western Ethiopia. PhD Dissertation, Haramaya University, Ethiopia.

Terzić, D., Popović, V., Tatić, M., Vasileva, V., Đekić, V., Ugrenović, V., Popović, S. and Avdić, P. (2018). Soybean Area, Yield and Production in World. 22th International ECO-Conference, 10th Eco-Conference on Safe Food, 26-28 September, Novi Sad, Serbia.

Uddin, M.T. and Nasrin, M. (2013). Farming Practices and Livelihood of the Coastal People of Bangladesh. *Progressive Agriculture*, **24(1& 2):** 251-262.

UNB (2019). Boosting of Soybean Production Needed. The Independent, http://www.theindependentbd.com/printversion/details/193234.

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EVALUATION OF POTASSIUM NUTRITION IN PRODUCTIVITY, QUALITY AND POTASSIUM USE EFFICIENCY OF GARDEN PEA IN TERRACE SOILS

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Abstract

Potassium (K) is key element for crop productivity and soil fertility. High demand of crop, K fertilization is ignored as appropriate amount in agriculture. Hence, an experiments was conducted in the research field of Horticulture Research Centre, BARI, Gazipur during *Rabi* season of 2017-18 and 2018-19 to find out the effective dose of potassium to improve growth, yield and quality of garden pea (*Pisum sativum* L.). Treatments were T_1 = Control, T_2 = K 30 kg ha^{-1}, T_3= K 40 kg ha^{-1}, T_4= K 50 kg ha^{-1} and T_5= K 60 kg ha^{-1} following Randomized Complete Block Design with three replications. Application of 50 kg ha^{-1} K produced highest green pod (5352 kg ha^{-1}) and seed yield (1568 kg ha^{-1}), and increased 22.3 and 47.6% higher over K control. The highest amount of vitamin C (42.0 mg/100g) and protein (22.4%) were also noted under application of 50 kg ha^{-1} but. total K uptake (42.4 kg ha^{-1}) was highest with 60 kg ha^{-1} K. The highest agronomic efficiency (10.1 kg kg^{-1}), physiological efficiency of K (27.0 kg kg^{-1}), and apparent K recovery efficiency (26.2%) were recorded of 50 kg ha^{-1} K. The maximum benefit cost ratio 5.67 for green pod and 2.91 for seed yields were registered with 50 kg ha^{-1} K and also superior based on growth, yield traits, nodulation, nutrient content in garden pea and soil fertility enhancement. Results suggest that application of K 50 kg ha^{-1} could support to achieve the maximum yield and quality of garden pea in experimental K deficient terrace soil.

Keywords: Garden pea, yield, potassium uptake, agronomic efficiency, profitability.

Introduction

Potassium (K) is the vital nutrient involved in many essential physiological processes in plants; it can increase crop productivity and quality, and capability of plants to survive adverse conditions (Zhao et al., 2014). Potassium deficiency is a world-wide problem, although cropping intensity and improved variety enhance K deficiency in soil. The crop is grown on such soil show potassium deficiency (Akter *et al*., 2020; Zhao et al., 2014). The garden pea (*Pisum sativum L.*) crop well adapted to such deficiencies can produce reasonable yield through supplying proper dose of potassium fertilizer. Due to the high mobility of K in plants and its

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considerably high accumulation in the cytoplasm as compared with other essential cations, its deficiency is frequently encountered in most of the soils of Indo-Gangetic plain (Das *et al*., 2022). Except nitrogen, potassium is a mineral nutrient which plants require in the dominant amounts (Sustr *et al*., 2019). Adequate supply of potassium (K) during growth period improves the water relations of plant and photosynthesis (Wang *et al*., 2021). Potassium helps to improve the uptake efficiency of other nutrients ultimately improved the crop productivity and quality (Das *et al*., 2022). Quddus (2019) observed that pulses crops are need a sizable amount of potassium for good vegetative growth and reproductive phase due to higher uptake from soil. Most of the farmers in Bangladesh, who can afford to apply only urea and phosphate fertilizers, while potassium application is often neglected in pulse crop.

Little has been done to investigate the requirement of potassium for garden pea yield, quality, and nutrient use efficiency. The study was undertaken to (i) determine the effective dose of potassium to improve growth, yield, and quality of garden pea, and (ii) to findout the responses of garden pea to different doses of K application in terrace soils of Bangladesh.

Materials and Methods

The experiment was conducted during two consecutive Rabi seasons of 2017-18 and 2018-19 at the research field of Soil and Water Management Section under Horticulture Research Centre of Bangladesh Agricultural Research Institute (BARI) Gazipur. The research field of Gazipur was high land and the soil was terrace of *Chhiata* series under the AEZ Madhupur Tract (AEZ-28) (Shil *et al*., 2016). Texturally the soil was clay loam having 6.4 pH, 1.20% organic matter, 0.062% total N, 13.5 ppm P, 0.10 meq./100 g soil K, 14.4 ppm S, 0.78 ppm Zn and 0.16 ppm B. The particle and bulk density of the soil was 2.48 g/cc and 1.33 g/cc, respectively and the field capacity (FC) was 26.8% by weight. Analyses of initial and post-harvest soils were done following the standard methods (Page *et al*., 1982). Information on weather conditions (temperature and rainfall) during the cultivation period at the experimental site are presented in Figure 1a and Figure 1b.

The treatments were T_1 = Control, T_2 = K 30 kg ha^{-1}, T_3 = K 40 kg ha^{-1}, T_4 = K 50 kg ha^{-1} and T_5 = K 60 kg ha^{-1} following Randomized Complete Block Design with three replications. The blanket dose of N, P, S, Zn and B was 40 kg, 24 kg, 10 kg, 3 kg and 2 kg ha^{-1}; respectively along with 5 t ha^{-1} decomposed cowdung. The experimental unit plot size was 4 m × 3 m. Entire quantity of cowdung and full of urea, TSP, gypsum, zinc sulphate and boric acid were applied manually during the final land preparation at two days before seed sowing. The total amount of MoP was applied as per treatment during bed preparation at two days before seed sowing. The seeds of garden pea var. BARI Motorshuti-3 were sown (80 kg seed ha^{-1}) and treated with Provax 200 WP @ 2.5 g/kg seed. The crop was sown on 22 November 2017 and 23 November 2018 with the spacing of 30 cm × 10 cm.

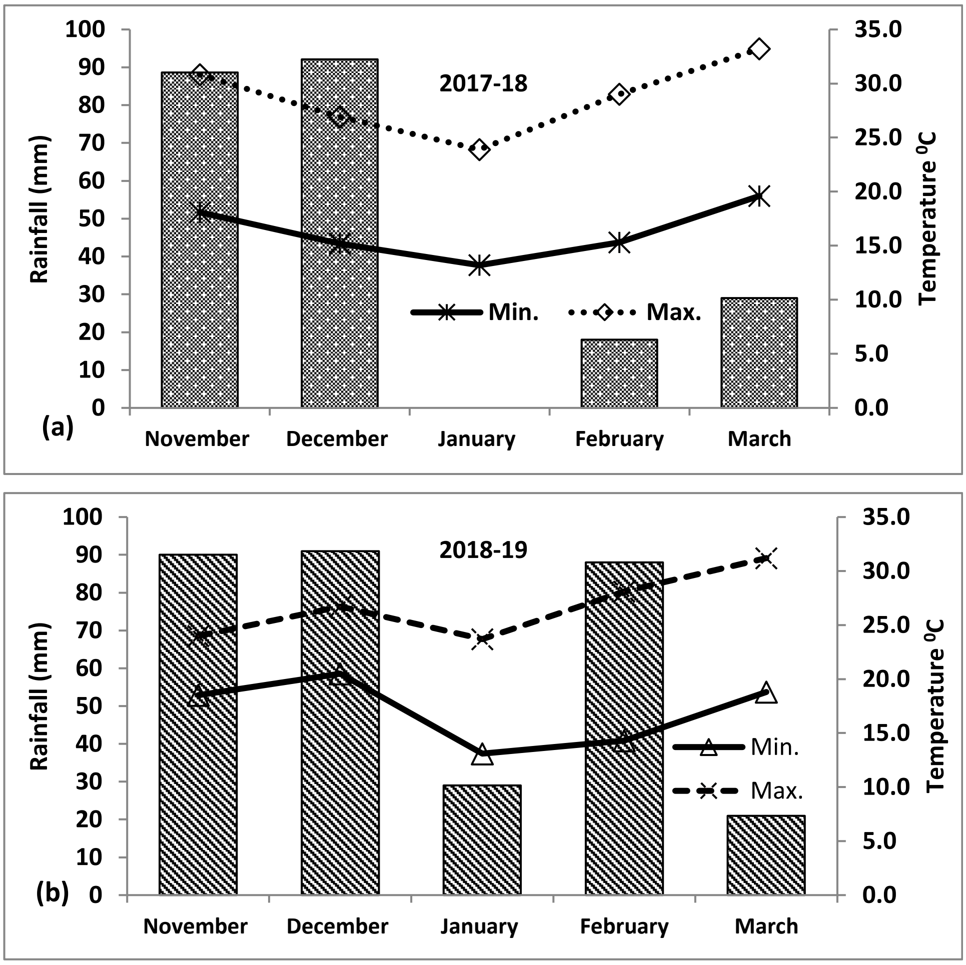

Fig. 1. Monthly mean minimum and maximum temperature ^{0}C and rainfall (a, b) during the experiment period of 2017-18 and 2018-19.

Light irrigation was applied immediately after seed sowing to enable germination. Then irrigation was also applied as per requirement on soil moisture condition. Weeding was done manually twice at 25 and 40 DAS, respectively. Pod borers and aphids were controlled by spraying of Ripcord 10 EC @ 2 ml L^{-1} water at 35 and 45 DAS, respectively. The test crop was harvested plot wise in two dates, half at green pod stage and half at dry seed stage. Green pods were harvested at tender stage on 20 January 2018 and 21 January 2019 from five rows in each plot. The rest crop in the plot was allowed to grow until maturity and matured pods were harvested for dry seed yield.

After harvest pods were separated from plants. Then plants and pods were weighed. The entire yield contributing characters such as plant height, branches plant^{-1}, number of pods plant^{-1}, pod length, number of seeds pod^{-1} and 100- seed weight were recorded from five plants selected randomly from each unit plot. Data on nodulation were noted from 5 plants in each collection. Number of nodules per plant was recorded four times at 30 DAS, 42 DAS, 54 DAS and 66 DAS. A drop of garden pea green seed juice was placed on the prism of hand refractometer (Atago Ltd., PAL-1, Tokyo, Japan) for estimating total soluble solid (TSS) and it was stated in °Brix according to an accepted method (932.12; Anon., 1994). Sample juice was prepared treatment wise through grinding the green seeds. Vitamin C in green seed was assessed by the standard method (Anon., 1994).

Plant samples (straw and seed) were oven-dried at 70° C for 48 h and ground by a Cyclotec^{TM} 1093 sample Mill (Made in Sweden). Ground plant samples were digested using di-acid mixture (HNO_3-$HClO_4$) (5:1) as outlined by Piper (1966). The digested mixtures were used for determination of total N (Micro-Kjeldahl method), P (spectrophotometer method), K (atomic absorption spectrophotometer), and S (turbidity method using $BaCl_2$ by spectrophotometer). Zinc concentration in the digested plant samples was directly measured by atomic absorption spectroscopy (VARIAN SpectrAA 55B, Australia). Boron concentration was determined by spectrophotometer following azomethine-H method (Page *et al*., 1982).

Protein content in seed of garden pea was estimated by multiplying the total N contents with the constant food factor of 6.25 (Hiller *et al*., 1948).Nutrient (K) uptake was estimated by multiplying the total dry matter yields of garden pea with corresponding K concentrations according to Sharma *et al*. (2012) equation-

$$\text{Nutrient uptake (kg per ha.)} = \frac{Nutrient\ concentration\ (\%) \times Dry\ matter\ yield\ (kg\ per\ ha.)}{100} \ldots (1)$$

Nutrient (K) use efficiency calculation

Agronomic efficiency (AE_k; kg seed yield increase kg^{-1} applied K) was calculated using the equation:

$AE_k = (Y_{+k} – Y_{0k}) \div R_k$-----------(2)

where, Y_{+k} is the seed yield in the treatment with K application (kg ha^{-1}), Y_{0k} is the seed yield in the treatment without K application (kg ha^{-1}), and R_k is the rate of applied K (kg ha^{-1}).

Physiological efficiency (PEk) was calculated according to Paul *et al*. (2014) equation: $PEk = \frac{Y-Y_0}{U-U_0}$---------- (3)

Where, Y is the yield of the K fertilized plot, Y_0 is the yield of the K unfertilized plot, U is the total nutrient uptake in above ground plant with K fertilized plot and U_0 is the total nutrient uptake in above ground plant with K unfertilized plot. The apparent nutrient (K) recovery efficiency (ANR) was calculated on dry weight basis according to Baligar *et al.* (2001). The equation as follows-

$$\text{ANR} = \frac{\text{Nutrient uptake(kg/ha)} - \text{control value}}{\text{Applied nutrient (kg/ha)}} \text{x } 100\text{-------------} (4)$$

Potassium harvest index (KHI) = (Ks÷Kt) × 100-------- (5)

where, Ks = Potassium uptake by seed at harvest, Kt = Potassium uptake by total plant (seed +straw) at harvest. Apparent potassium balance was calculated based on K input (only K fertilizer) and K output (K uptake by only test crop) (Anon., 2018).

In the experiment, treatment wise variable cost was calculated by adding the cost incurred for labours, ploughing and inputs. The green pod and seed yield of each treatment was converted as kg ha^{-1}. These yields were used to compute the gross return. The rent of experimental land and straw cost was not counted. Gross return of each treatment was calculated by multiplying with the green pod and seed yield by the current unit price of garden pea. Gross margin was calculated by deducting the variable cost from gross return. Benefit cost ratio (BCR) was determined from the formula: BCR = GR ÷ TVC --------- (6)

Where, GR= Gross return and TVC= Total variable cost.

Statistical analysis was done on the average data of two years. However, the data of growth, yield and yield attributes, nodulations, nutrient content, and nutrient uptake and others were subjected to statistical analysis of variance (ANOVA) according to Statistix 10 software (www.statistix.com). The means of each treatment were compared using the least significant difference (LSD) at significant level $p \leq 0.05$ (Statistix-10, 1985).

Results and Discussion

Yields of garden pea

The green pod, dry seed and straw yields of garden pea were influenced significantly by the application of potassium (Table 1). The increase yield of green pod (5352 kg ha^{-1}) and seed yield (1568 kg ha^{-1}) of garden pea was recorded in T_4 treatment comparable with T_5 treatment. The lowest values being noted in control (T_1) treatment. The maximum straw yield (1651 kg ha^{-1}) was obtained from the same T_4 (50 kg K ha^{-1}) treatment which was statistically similar to T_5 and T_3 treatments. The lowest straw yield was noted in control (T_1) plot (Table 1). Result indicated that potassium might be involved in numeric metabolic activities also facilitated to improve nitrogen and phosphorus (P) use efficiency; increasing quantity and quality of crop produce (Das *et al*., 2022). Garden pea yield obtained higher from K application 50 kg ha^{-1} (T_4) might have favored in producing higher number of pods per plant, seeds per pod, and seed weight. By regulating biosynthesis, conversion, and allocation of essential metabolites, however K works towards increasing crop yields (Xu *et al*., 2020). The control plot (T_1) lacking in K showed lower yield than other treatments, because yields of legume considerably respons to K application. The increased pod yield ranged from 7.79 to 22.3% and seed yield varied from 21.5 to 47.6% among treatments compared to the K control treatment where the highest yield increase was recorded from the treatment receiving at 50 kg K ha^{-1} over K control (Table 1). Quddus *et al*. (2019) reported similar results in mungbean where higher yield increase of 39.5% was recorded from application of 60 kg K ha^{-1}. Chaudhari *et al.* (2018) reported that K application contributed to increase in seed yield of black gram in all the treatments over control. This indicates the fact that K application might be involved in activation of enzymes related to starch synthesis, N metabolism and respiration, translocation of sugars from leaves to other parts, regulation of stomatal openings and imparts disease and drought resistance to plants ultimately augmented the garden pea yield.

Table 1. Effect of potassium on yields of garden pea (pooled data of two years)

Treatment	Green pod yield (kg ha^{-1})	% Pod yield increase over control	Seed yield (kg ha^{-1})	% Seed yield increase over control	Straw yield (kg ha^{-1})
T_1 = Control	4376d	-	1062c	-	1100c
T_2= 30 kg K ha^{-1}	4717c	7.79	1290bc	21.5	1382b
T_3= 40 kg K ha^{-1}	4932bc	12.7	1391ab	31.0	1491ab
T_4= 50 kg K ha^{-1}	5352a	22.3	1568a	47.6	1651a
T_5= 60 kg K ha^{-1}	5150ab	17.7	1478ab	39.2	1572ab
CV (%)	4.40	-	9.62	-	9.76
LSD (0.05)	407	-	246	-	264

Values within the same column with a common letter do not differ significantly at 5% level according to LSD test.

Effect of K on growth and yield contributing characters of garden pea

Growth and yield contributing characters like plant height, number of branches per plant, pod length, number of pods per plant, 100-green seed wt. and 100-dry seed wt. of garden pea were influenced significantly except number of seeds per pod due to application of potassium (Table 2). The tallest plant (34.9 cm) was recorded from the treatment T_4 (50 kg K ha^{-1}) comparable with T_5 and T_3 treatments. Result exhibited that the plant height increased with increasing the rate of K application up to 50 kg ha^{-1} which is similar to the findings of Laghari *et al*. (2016) who reported that increasing potassium application markedly increased the growth of peas. The maximum number of branches per plant (5.43) was found in the same T_4 treatment which was statistically similar to most of the treatments. Mazed *et al*. (2015) also reported that K nutrition significantly increased number of branches per plant of mungbean. The lowest values of both characters were noted in K control (T_1) treatment (Table 2). In case of pod length, the increased pod length (6.39 cm) was found from T_4 treatment statistically alike with T_5 and T_3 treatments. The response of pod length is in agreement with findings of Quddus *et al*. (2019) in mungbean who reported that the increased pod length is with increasing the rate of K application up to 60 kg ha^{-1}. The maximum number pods per plant (8.53) were recorded from T_4 treatment, which was statistically identical to T_5, T_3 and T_2, and the minimum in T_1 treatment (Table 2). Kumar *et al.* (2018) reported that highest number of pods per plant (26.7) was recorded when K applied at 90 kg per hectare. In the study, the maxium number of seeds per pod (5.60) was observed in T_4 followed by T_5 and the lowest value from T_1 treatment. Potassium application might have favored the availability of other nutrients as per plant requirement and also involved in photosynthetic activity and led to increase number of seeds per pod (Ali *et al.*, 2007). The hundred green seed and dry seed weights ranged from 50.2 to 54.8 g and 25.8 to 29.5 g, respectively having the highest values in T_4 treatment where lowest values in K control treatment (Table 2). The increase K application contributed to get higher seed weight which might be due to role of K and also donated to increase photosynthates translocation from source to sinks and its ability to develop bold seeds of garden pea. Similar information was reported by Ali *et al.* (2007) and Sadaf and Tahir (2017) in chickpea.

Table 2. Effect of potassium on growth and yield contributing characters of garden pea (pooled data of two years)

Treatment	Plant height (cm)	No. of branches plant^{-1}	Pod length (cm)	No. of pods plant^{-1}	No. of seeds pod^{-1}	100-green seeds wt. (g)	100-seeds wt (g)
T_1 = Control	30.5c	4.63b	5.52c	6.80b	5.09	50.2b	25.8b
T_2= 30 kg K ha^{-1}	32.5bc	4.88ab	5.88bc	7.53ab	5.31	53.3a	28.8ab
T_3= 40 kg K ha^{-1}	33.0ab	5.15ab	6.21ab	8.11ab	5.49	54.2a	29.1ab
T_4= 50 kg K ha^{-1}	34.9a	5.43a	6.39a	8.53a	5.60	54.8a	29.5a
T_5= 60 kg K ha^{-1}	34.4ab	5.29ab	6.25ab	8.29ab	5.59	54.5a	29.4a
CV (%)	3.79	8.10	3.80	11.6	7.69	2.03	6.59
LSD (0.05)	2.35	0.77	0.44	1.72	ns	2.04	3.54

Values within the same column with a common letter do not differ significantly at 5% level according to LSD test.

Effect of K on nodulation in garden pea

Nodulation, nodule length and diameter and nodule weight of garden pea was influenced considerably by potassium application (Table 3). Result of nodulation per plant at 30 days after sowing (DAS) varied from 6.44 to 6.84, at 42 DAS from 16.8 to 21.6, at 54 DAS from 20.6 to 23.3 and at 66 DAS; it varied from 16.8 to 19.4 among the treatments (Table 3). The maximum numbers of nodules per plant were recorded from the treatment T_4 followed by T_5 except in 66 DAS. The lowest number nodules per plant were noted in T_1 treatment where no K fertilizer was added to the soil (Table 3). These findings were supported by Pranav *et al.* (2014) in mungbean. From the results of different dates, nodule formations were less at 30 DAS and 66 DAS but the formation were maximum between 42 and 54 DAS. It seems that the maximum nodules formations occurred in early pod formation stage. After completion of pod formation, nodule formation and efficiency might be reduced towards plant maturity and nodule formation. Quddus *et al.* (2019) reported similar observation in mungbean. Data on nodule length of garden pea was collected at 54 days after sowing. The length varied from 3.39 to 3.64 mm across the treatments, where the increase nodule length (3.64 mm) was noted from T_4 treatment. The maximum nodule diameter (2.70 mm) was also found in T_4 treatment followed by T_5. The nodule weight varied from 0.0041 to 0.0069 g among the treatments though the heaviest nodule (0.0069 g) was recorded from T_4 followed by T_5 treatment (Table 3).

Table 3. Effect of potassium on nodulation per plant in different dates, nodule length, nodule diameter and nodule weight of garden pea (pooled data of two years)

Treatment	No. of nodules plant^{-1} after 30 days	No. of nodules plant^{-1} after 42 days	No. of nodules plant^{-1} after 54 days	No. of nodules plant^{-1} after 66 days	Nodule length (mm)	Nodule diameter (mm)	Nodule wt. (g)
T_1 = Control	6.44c	16.8d	20.6d	16.8c	3.39c	2.58d	0.0041c
T_2= 30 kg K ha^{-1}	6.59b	19.6c	22.4c	17.3bc	3.48b	2.61cd	0.0047c
T_3= 40 kg K ha^{-1}	6.63b	20.4b	22.9b	18.3ab	3.52b	2.64bc	0.0056b
T_4= 50 kg K ha^{-1}	6.84a	21.6a	23.3a	18.9a	3.64a	2.69a	0.0069a
T_5= 60 kg K ha^{-1}	6.79a	21.4a	23.2ab	19.4a	3.61a	2.66ab	0.0064a
CV (%)	0.67	1.29	0.90	3.85	1.17	0.89	7.05
LSD (0.05)	0.08	0.48	0.38	1.31	0.08	0.04	0.001

Values within the same column with a common letter do not differ significantly at 5% level by LSD test

Effect of potassium on N, P, K, S, Zn and B contents in seed and straw of garden pea

Different rates of K demonstrated remarkable influence on the content of N, P, K, S, Zn and B in seed and straw of garden pea (Table 4). The results of N content was exhibited highest (3.58% in seed and 1.38% in straw) in T_4 treatment, comparable with T_5 and T_3 treatment, while the minimum N content (3.25% in seed and 1.21% in straw) in K control (T_1) treatment. Soil of experimental field indicated the K deficiency might have increased the N and P availability to legume plant which facilitated biological N_2 fixation through nodulation process, causing higher N content in seed and straw of garden pea. This result is in close similarity with the findings of Asgar *et al.* (2006) in mungbean. Significantly the increased P content (0.87%) in seed was observed in T_4 followed by T_5 treatment. Similarly, the highest P content in straw (0.43%) was also found similar but lowest in control treatment (Table 4). Similar findings were reported by Pranav et al. (2014) in mungbean. However, the highest content of K (1.50%) in seed was recorded from T_5 treatment while lowest K content (0.66%) control (T_1) treatment. The highest

K content in straw of garden pea (1.65%) was also recorded from T_5 comparable with T_4 treatment, although minimum K content in control (T_1) treatment (Table 4). Jamil *et al*. (2018) reported that highest K content (1.86%) in mungbean was observed in the plot receiving 125 kg K ha^{-1}. The maximum S content in garden pea (0.41% in seed and 0.28% in straw) was observed in T_4 closely followed by T_5 treatment, while the lowest in K control (T_1) treatment. Potassium contributed to accumulate Zn and B by garden pea plant. The maximum Zn content in garden pea (41.0 ppm in seed and 41.3 ppm in straw) was found in T_4 treatment followed by T_3 and T_5 treatment for straw while lowest Zn content (28.6 ppm in seed and 33.9 ppm in straw) control (T_1) treatment. The maximum B content in garden pea (40.3 ppm in seed and 33.4 ppm in straw) was noted from the T_4 treatment, which was statistically similar to T_5 treatment. Potassium might be involved in Zn and B accumulation by garden pea plant outlined by Chaudhari *et al*. (2018).

Table 4. Effect of K on N, P, K, S, Zn and B contents in seed and straw of garden pea (pooled data of two years)

Treatment	N	P	K	S	Zn	B
	%				ppm	
Seed						
T_1 = Control	3.25b	0.63b	0.66d	0.25c	28.6d	30.1c
T_2= 30 kg K ha^{-1}	3.38ab	0.69b	0.92c	0.30bc	33.1c	32.8bc
T_3= 40 kg K ha^{-1}	3.52ab	0.68b	1.10c	0.35ab	36.5bc	35.2b
T_4= 50 kg K ha^{-1}	3.58a	0.87a	1.29b	0.41a	41.0a	40.3a
T_5= 60 kg K ha^{-1}	3.55ab	0.86a	1.50a	0.38a	37.5b	38.9a
CV (%)	4.98	6.39	8.96	9.9	5.2	5.33
LSD (0.05)	0.33	0.09	0.18	0.06	3.46	3.56
Straw						
T_1 = Control	1.21c	0.33b	1.09c	0.15c	33.9c	28.7cd
T_2= 30 kg K ha^{-1}	1.25bc	0.38ab	1.33b	0.23ab	36.4bc	29.6bc
T_3= 40 kg K ha^{-1}	1.34ab	0.39ab	1.42b	0.20bc	39.2ab	26.9d
T_4= 50 kg K ha^{-1}	1.38a	0.43a	1.55a	0.28a	41.3a	33.4a
T_5= 60 kg K ha^{-1}	1.36ab	0.42a	1.65a	0.26a	38.7ab	31.5ab
CV (%)	5.17	9.94	4.33	13.9	4.52	4.43
LSD (0.05)	0.13	0.07	0.12	0.06	3.22	2.5

Values within the same column with a common letter do not differ significantly at 5% level as per LSD test

Effect of K on quality attributes of garden pea

Quality attributes like TSS, vitamin C and protein content in garden pea were influenced significantly by the application of Potassium (Figure 2). The highest total soluble solid (TSS) content (^{0}Brix 13.0) was found in T_4 comparable with T_5, T_3 and T_2 treatments, while the lowest value (^{0}Brix 11.1) in T_1 treatment (Figure

2). Different K rates exhibited significant effect on vitamin-C content. The maximum vitamin-C content (42.0 mg/100g) was recorded from T_4 followed by T_2 treatment, although lowest vitamin C value (39.0 mg/100g) in T_1 treatment (Figure 2). The K is an activator of dozens of important enzymes for biochemical and physiological process that are responsible to the quality improvement (Oosterhuis *et al*., 2014). The maximum protein content (22.4) in dry seed of garden pea was found in T_4 treatment while minimum protein value (20.3%) was noted in T_1 treatment (Figure 2). Potassium might take part in protein synthesis, carbohydrate metabolism, and enzyme activation responsible for improving nitrogen use efficiency which leads to increase the protein content of the crop (Wang *et al*., 2013).

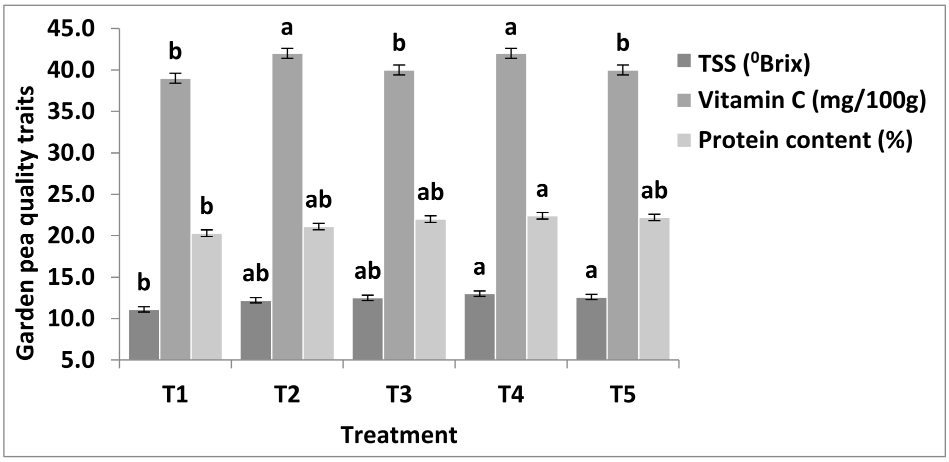

Fig. 2. Effect of K on TSS, vitamin C and protein content of garden pea (pooled data of two years). Mean values followed by uncommon letter (s) are significantly different from each other at 5% level of significance by LSD test, T_1 = Control, T_2= 30 kg K ha^{-1}, T_3= 40 kg K ha^{-1}, T_4= 50 kg K ha^{-1}, T_5= 60 kg K ha^{-1}.

Effect of potassium on K uptake by seed and straw of garden pea

The uptake of K by seed and straw of garden pea as well as total K uptake was influenced significantly by the application of potassium (Figure 3). The highest uptake of K (22.0 kg ha^{-1}) by seed was recorded in T_5 treatment, although the lowest value (7.05 kg ha^{-1}) in T_1 treatment (Figure 3). The K uptake by straw was also higher (25.9 kg ha^{-1}) in T_5 treatment which was statistically similar with T_4 and T_3 treatment, while lower in T_1 treatment (Figure 3). In case of total K uptake (seed + straw), the maximum total K uptake (42.4 kg ha^{-1}) by garden pea was found in T_5 (application of 60 kg K ha^{-1}) treatment closely followed by T_4 (application of 50 kg K ha^{-1}). The lowest total K uptake (23.0 kg ha^{-1}) was from (T_1 treatment (Figure 3). Higher K content and higher yield of garden pea in T_4 and T_5 treatments have led to attaining higher K uptake in these treatments. Similar observation was documented by Kumawat *et al*. (2009).

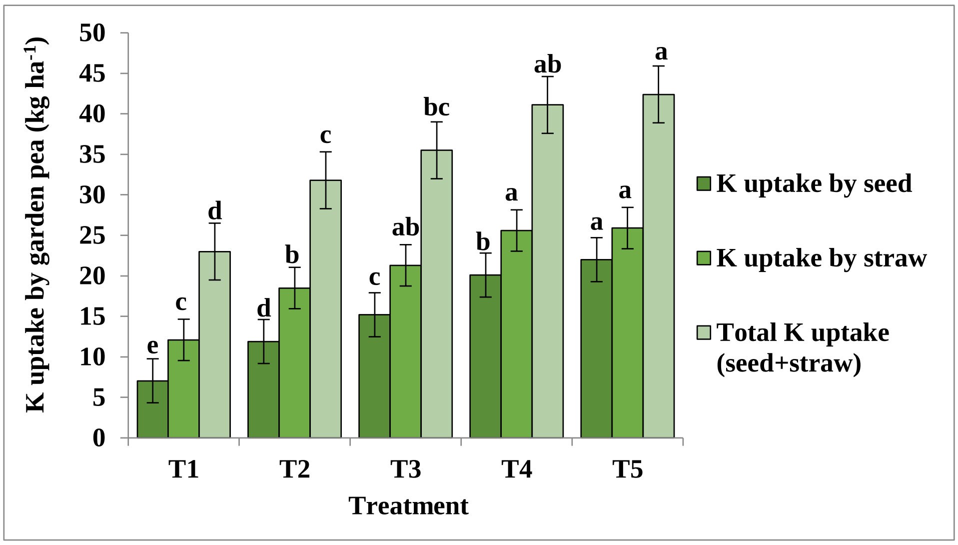

Fig.3. Effect of K application on K uptake by seed and straw and total K uptake (seed+straw) by garden pea (pooled data of two years). Mean values followed by the uncommon letter are significantly different according to the least significant difference (LSD) test at $p \leq 0.05$. T_1 = Control, T_2= 30 kg K ha^{-1}, T_3= 40 kg K ha^{-1}, T_4= 50 kg K ha^{-1}, T_5= 60 kg K ha^{-1}.

Potassium use efficiency and apparent balance

Potassium application created significant influence on PE of K and ANR in garden pea except AE of K which was insignificant (Figure 4a, b, c). However, the AE of K in garden pea varied from 7.60 to 10.1 kg kg^{-1} among the treatments, although the most AE of K (10.1 kg kg^{-1}) was recorded in T_4 (50 kg K ha^{-1}) while minimum AE in T_5 treatment (Figure 4a). The PE of K in garden pea ranged from 20.4 to 27.0 kg kg^{-1} among the different rates of K application. Result showed that the increased PE of K (27.0 kg kg^{-1}) was noted from the treatment T_4 comparable with T_3 and T_2 treatments, while the lowest PE of K (20.4 kg kg^{-1}) from T_5 treatment (Figure 4b). Application of K in soil exhibited significant effect on ANR of garden pea (Figure 4c). The maximum ANR (26.2%) was achieved in T_4 treatment which was statistically similar to T_5 treatment. The lowest ANR (16.3%) was recorded in T_2 treatment (Figure 4c). The variability of K use efficiency might be attributed to the variation of growing environment, seasonal variability and fertilizer management that affect crop yield. Similar observation was documented by Salam *et al*. (2014) in rice based cropping system.

Nutrient harvest index of K in garden pea responded significantly due to the application of different rates of potassium (Figure 4d). The increased potassium harvest index (51.9%) was progressively attained with increasing rate of K application up to 60 kg ha^{-1} which was followed by 49.1% at 50 kg K ha^{-1}. The minimum K harvest index (30.5%) was found from K control (T_1) treatment (Figure 4d).

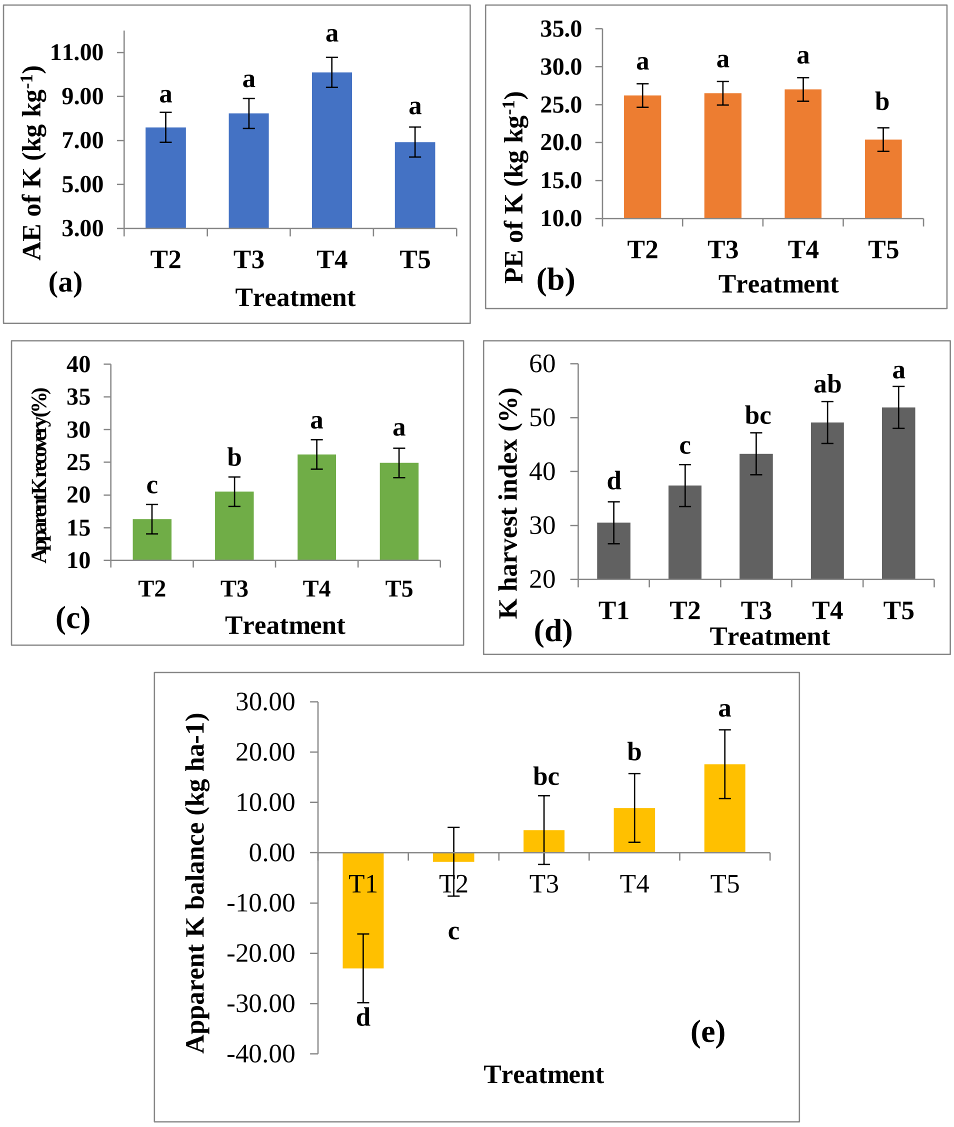

Fig.4. Effect of K on (a) agronomic efficiency of K, (b) physiological efficiency of K, (c) apparent K recovery efficiency, (d) K harvest index and (e) apparent K balance (pooled data of two years). Mean values followed by the same letter are not significantly different according to the least significant difference (LSD) test at $p \leq 0.05$. T_1 = Control, T_2= 30 kg K ha^{-1}, T_3= 40 kg K ha^{-1}, T_4= 50 kg K ha^{-1}, T_5= 60 kg K ha^{-1}.

The apparent K balance responded significantly due to application of different rates of potassium (Figure 4e). Results revealed that the negative apparent K balance observed in T_1 and T_2 treatment ranged between minus 1.8 and minus 23.0 kg ha^{-1}. In the study, the highest K depletion (23.0 kg ha^{-1}) was recorded in K control plot, while the lowest K depletion (1.8 kg ha^{-1}) in T_2 plot (Figure 4e). The variation of negative apparent K balance in garden pea might be associated with K control or lower K application rate. Quddus *et al*. (2019) reported similarly that negative apparent K balance in mungbean was related to the lower rate of K application. On the other hand, the positive apparent K balance was found in T_3, T_4 and T_5 treatment which varied from 4.5 to 17.6 kg ha^{-1}, although the highest positive K balance (17.6 kg ha^{-1}) was recorded from T_5 (application of 60 kg K ha^{-1}) treatment. The least positive apparent K balance (4.5 kg ha^{-1}) was registered in T_3 (use of 40 kg K ha^{-1}) treatment (Figure 4e). It reveals from the observation that the magnitude of apparent K balance might have depended on soil type and fertility, crop duration and amount of K application.

Effect of potassium on postharvest soil properties

The post-harvest soil properties were significantly influenced by the application of different rates of potassium (Table 5). The soil pH of all treatment was found almost static or slightly increased with the initial reference status (Table 5). The organic matter (OM) and total N content in soil varied significantly due to application of potassium. The maximum OM (1.28%) was noted in T_4 and T_5 followed by T_3. Similarly the total N content was maximum (0.065%) in T_4 and T_5 treatment being statistically similar to T_3 treatment (Table 5). The OM and total N content of all treatments were found slightly increased over the initial status. The K content in postharvest soil varied significantly among the treatment but static or increasing trend of exchangeable K content was exhibited compared to the initial soil K status. The highest K content (0.14 meq. 100 g^{-1}) was recorded from T_5 comparable with T_4 treatment (Table 5). The variation of post-harvest soil P and S was non-significant. The Zn and B content in postharvest soil were recorded higher in T_4 treatment but statistically similar to T_5 treatment. The Zn and B content were slightly improved in all treatments as compared to the initial soil (Table 5). Results of post-harvest soil properties, pulse crop like garden pea may facilitate to enrich the soil quality for next crop. Musinguzi *et al.* (2010) was verified the similar view.

Table 5. Effects of potassium on chemical properties of postharvest soil

Treatment	pH	OM	Total N	K	P	S	Zn	B
		%		meq. 100 g^{-1}	ppm			
Initial soil	6.4	1.20	0.062	0.10	13.5	14.4	0.78	0.16
T_1 = Control	6.4a	1.20c	0.061c	0.10b	13.0a	14.8a	0.79c	0.17a
T_2= 30 kg ha^{-1}	6.4a	1.24b	0.063b	0.10b	13.5a	15.3a	0.80c	0.18a
T_3= 40 kg ha^{-1}	6.5a	1.27a	0.064ab	0.11b	13.7a	15.4a	0.83b	0.17a
T_4= 50 kg ha^{-1}	6.5a	1.28a	0.065a	0.13a	14.0a	15.5a	0.85a	0.17a
T_5= 60 kg ha^{-1}	6.5a	1.28a	0.065a	0.14a	13.4a	15.3a	0.84ab	0.17a
CV (%)	1.38	1.04	1.57	8.62	4.16	3.69	1.09	5.27

Values within the same column with a common letter do not differ significantly ($P \leq 0.05$).

Cost and return analysis

Regarding the cost and return analysis, the maximum gross return Tk. 214080 ha^{-1} for green pod and T. 109760 ha^{-1} for dry seed of garden pea was recorded in T_4 treatment followed by T_5. The minimum gross returns were calculated from K control treatment. The higher gross margin also noted in T_4 treatment. The highest benefit cost ratio (BCR) of 5.67 for green pod and 2.91 for dry seed was registered in T_4 treatment. The lowest BCR was recorded from the T_2 treatment (Table 6). Similar results were observed by Ali *et al.* (2007) in chickpea.

Table 6. Cost, return and benefit for garden pea production as influenced by potassium application (pooled data of two years)

Treatment	Total variable cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})		Gross margin (Tk. ha^{-1})		BCR	
		Green pod	Seed	Green pod	Seed	Green pod	Seed
T_1 = Control	36276	175040	74340	138764	38064	4.82	2.05
T_2= 30 kg ha^{-1}	36776	188680	90300	151904	53524	5.13	2.26
T_3= 40 kg ha^{-1}	37276	197280	97370	160004	60024	5.29	2.61
T_4= 50 kg ha^{-1}	37778	214080	109760	176302	71982	5.67	2.91
T_5= 60 kg ha^{-1}	38265	206000	103460	167735	65195	5.38	2.70

Input prices: Urea= Tk. 16 kg^{-1}, T.S.P= Tk. 24 kg^{-1}, MoP= Tk. 17 kg^{-1}, Gypsum= Tk. 15 kg^{-1}, Zinc sulphate= Tk. 1400 kg^{-1}, Boric acid= Tk. 1400 kg^{-1}, Provex= Tk. 400 100^{-g}, Bavistin= Tk. 200 100^{-g}, Ribcord= Tk. 120 100^{-ml}, Karate= Tk. 450 500^{-ml}, Garden pea seed= Tk. 80 kg^{-1}, Plowing= Tk. 1400 ha^{-1}(one pass), Wage rate= Tk. 400 day^{-1}

Output price: Garden pea green pod @ Tk. 40 kg^{-1} and Garden pea seed @ k.T 70 kg^{-1}.

Conclusion

Aforesaid results and discussion clearly indicated that application of 50 kg ha^{-1} K performed better based on yield and yield contributing characters, nodulation, nutrient content, protein and vitamin C content of garden pea. The same treatment exhibited better profitability and K use efficiency. Application of 50 kg ha^{-1} K had the potential in improving soil fertility. Hence, recommendation can be made for application of 50 kg ha^{-1} K obtains maximum yield and quality of garden pea in K deficient terrace soil.

References

Akter, N., M. M. Ali, M. M. Akter, M. M. Hossain, M. S. Hossan and M. A. Khan. 2020. Effects of Potassium on the Growth, Yield and Physico-chemical Properties of Three Garden Pea (*Pisum sativum*) Varieties. *Asian Journal of Agricultural and Horticultural Research,* **5(3):** 22-31.

Ali, A., M. A. Nadeem, A.T.M. Tahir and M. Hussain. 2007. Effect of different potash levels on the growth, yield and protein contents of chickpea (*Cicer arietinum* L.). *Pak. J. Bot*. **39(2):** 523-527.

Anonymous. 2018. Fertilizer recommendation guide. Bangladesh Agricultural Research Council, Farmgate, Dhaka, Bangladesh.

Asgar, A., M.A. Nadeem, M. Muddassar and M. Ejaz. 2006. Effect of different levels of potash on growth, yield and protein contents of mungbean varieties. *Journal of Agricultural Research,* **44(2):** 121-126.

Baligar, V.C., N.K. Fageria, and Z.L. He. 2001. Nutrient use efficiency in plants. *Commun. Soil Sci. Plant Anal.* **32:** 921-950.

Chaudhari, A. V., S.S. Mane and B.R. Chadar. 2018. Effect of graded levels of potassium on growth, yield and quality of black gram. *International Journal of Current Microbiology and Applied Sciences*, Special Issue-*6*, 1607-1612.

Hiller, A., J. Plazin and D.D. Vanslyke.1948. A study of conditions of Kjeldhal determination of nitrogen inproteins. *J. Bio. Chem.* **176(3):** 1401-1420.

Hu, W., N. Jiang, J. Yang, Y. Meng, Y. Wang, B. Chen, W. Zhao, D.M. Oosterhuis and Z. Zhou. 2016. Potassium (K) supply affects K accumulation and photosynthetic physiology in two cotton (*Gossypium hirsutum* L.) cultivars with different K sensitivities. *Field Crop. Res*. **196:** 51-63.

Kumar S., S.J. Dan and S. Rajesh. 2018. Growth and Yield Response of Mung Bean (*Vigna radiata* L.) in Different Levels of Potassium. *Acta Scientific Agriculture,* **2(6):** 23-25.

Kumawat, N., R. Kumar and O.P. Sharma. 2009. Nutrient uptake and yield of mungbean *Vigna radiata* (L.) Wilczek as influenced by organic manures, PSB and phosphorus fertilization. *Environment & Ecology,* **27(4B):** 2002-2005.

Laghari U.A., A.N. Shah, M.N. Kandhro, Ziaul-Hassan, G.M. Jamro and K.H. Talpur. 2016. Growth and yield response of five elite grass pea (*Lathyrus sativus* L.) genotypes to varying levels of potassium. *Sarhad Journal of Agriculture*, **32(3):**218-222.

Mazed, H.E.M.K., J.F. Moonmoon, M.N. Haque, M.A.I. Pulok and M.H. Rahman. 2015. Growth and yield of mungbean as influenced by potassium and sulphur. *Ann. Biol. Res.* **6 (1):** 6-10.

Musinguzi, P., J.S. Tenywa and M.A. Bekunda. 2010. Strategic Nutrient Management of Field pea In Southwestern Uganda. *African Journal of Food Agriculture Nutrition and Development* (AJFAND online), *10* (6), Published by ASSCAT, Kenya.

Oosterhuis, D., D. Loka, E. Kawakami and W. Pettigrew. 2014. The physiology of potassium in crop production. *Adv. Agron*. **126:** 203–234.

Page, A. L., R.H. Miller and D.R. Keeney. 1982. Methods of soil analysis.Part 2, Chemical and microbial properties. *American Society of Agronomy, No. 9* (Part 2), Agronomy Series. Soil Science Society of America, Madison, WI.

Paul F., F. Brentrup, T. BruuIsema, F. Garcia, R. Norton and S. Zingore. 2014. *Nutrient/fertilizer use efficiency: measurement, current situation and trends*. IFA, IWMI, IPNI and IPI.

Piper, C. S. (1964). *Soil and plant analysis*. Adelaide University Press, Adelaide, Australia.

Pranav, K., K. Pravesh, S. Tarkeshwar S., Anil K.S. and I.Y. Ram. 2014. Effect of different potassium levels on mungbean under custard apple based agri-horti system. *African Journal of Agricultural Research*, **9(8):** 728-734.

Quddus, M. A., M. A. Hossain, H. M. Naser, B. Anwar, M. A. Siddiky and M. R. Ali. 2019. Influence of Potassium Addition on Productivity, Quality and Nutrient Uptake of Mungbean (*Vigna radiata* L.). *Journal of Agricultural Studies*, **7 (1):** 21-40.

Sadaf, A. and M. Tahir. 2017. Effect of Potassium on Growth, Yield and Quality of Mungbean under Different Irrigation Regimes. *Bulletin of Biological and Allied Sciences Research*, **2(4):**1-10.

Salam, M.A., A.R.M. Solaiman, A.J.M.S Karim and M. Saleque. 2014. System productivity, nutrient use efficiency and apparent nutrient balance in rice-based cropping systems. *Archives of Agronomy and Soil Science,* **60(6):** 747-764.

Sharma, N.K., R. J. Singh and K. Kumar. 2012. Dry matter accumulation and nutrient uptake by wheat (*Triticum aestivum* L.) under poplar (populus deltoides) based agroforestry system. *International Scholarly Research Network ISRN Agronomy*, Vol. 2012, Article ID 359673:1-7.

Shil, N.C., M. A. Saleque, M. R. Islam, and M. Jahiruddin. 2016. Soil fertility status of some of the intensive crop growing areas under major agro-ecological zones of Bangladesh. *Bangladesh J. Agril. Res.* **41(4):** 735-757.

Statistix 10. 1985. An Anlytical Software, Po Box 12185, Tallahassee, FL 32317, Copy right © 1985-2013.

Sustr, M, A. Soukup and E. Tylova. 2019. Potassium in Root Growth and Development. *Plants*, 8, 435; doi: 10.3390/plants8100435

Wang, M., Q. Zheng, Q. Shenand S. Guo. 2013. The critical role of potassium in plant stress response. *Int. J. Mol. Sci.*, **14:** 7370-7390.

Wang, Y., Y.F. Chen and W.H. Wu. 2021. Potassium and phosphorus transport and signaling in plants. *Journal of Integrative Plant Biology,* **63:** 34-52.

Xu X, X. Du, F. Wang, J. Sha, Q. Chen, G. Tian, Z. Zhu, S. Ge and Y. Jiang. 2020. Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings. *Front. Plant Sci*. **11:**904.

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BIO-EFFICACY OF INSECT GROWTH REGULATORS AGAINST BEAN POD BORER, *MARUCA VITRATA* F. INFESTING COUNTRY BEAN

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Abstract

The Bean pod borer, *Maruca vitrata* F. (Lepidoptera: Crambidae) is a key pest of country bean causing severe yield loss. The present study was conducted to evaluate the efficacy of four insect growth regulators (IGRs) for managing the bean pod borer, on country bean. Four IGRs as T_1 = Lufenuron (Hayron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG) and T_4 = Buprofezin (Award 40 SC) were used with three doses against *M. vitrata*. All the treatments were found significantly effective against the pod borer over untreated control. The highest efficacy was found in the Emamectin benzoate @ 1.0 g L^{-1} water treated plots followed by Buprofezin @ 0.50 ml L^{-1} water at 1st, 3rd and 7th days after treatments (DATs). The highest number of healthy flowers per ten inflorescences (126.56) were recorded in Emamectin benzoate at 1.0 g L^{-1} water treated plots but the lowest in the untreated control (68.11). The highest number of healthy pods were also observed in Emamectin Benzoate @ 1.0 g L^{-1} water treated plots. The highest pods plant^{-1} (760.33 g) were found from Emamectin benzoate at 1.0 g L^{-1} water treated plots followed by Buprofezin at 0.50 ml L^{-1}. Conversely, the lowest weight of healthy pods per plant (478.33g) was recorded in the untreated control. So, based on bio-efficacy, among the IGRs studied, Emamectin benzoate may be used for better management of bean pod borer *M. vitrata*.

Keywords: Efficacy, IGRs, Damage, Bean pod borer, Country bean.

Introduction

Country bean, *Lablab purpureus* L. (Papilionaceae) is a self-pollinated winter legume vegetable in Bangladesh (Salim *et al*., 2013). Recently, farmers are cultivating this crop year round in large scale due to high demand, high profit and tremendous nutritional value (Khan *et al*., 2020). However, this crop is threatened by many insect pests during cultivation, resulting huge economic losses (Oliveira *et al.*, 2014). Among them, the legume pod borer, *Maruca vitrata* F. (Lepdoptera: Crambidae) is a key pest of bean causing up to 80% yield loss (Aktar *et al*., 2020). It is a genetically complex species (Margam *et al*., 2010 and Periasamy *et al*., 2015) due to an extensive host range, high damage potential and cosmopolitan distribution (Margam *et al*., 2010).

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This destructive pest is controlled by synthetic insecticides for quick knockdown (Pavela *et al*., 2009). But chemical protection measures suffer so many serious drawbacks (Lee *et al*., 2001 and Ambethar, 2009). The indiscriminate use of chemicals causes the natural enemies destruction, adverse effects on the environment, creates phytotoxicity, residues in foods and feeds, triggers pest resistance and resurgence and is hazardous to producers and consumers as well (Azad *et al*., 2010 and Hossain *et al*., 2013; Yule and Srinivasan, 2013; Srinivasan *et al*., 2015). Hence, globally researchers are trying to adopt alternatives to protect crop from insect pest infestation (Ahmed *et al*., 2020).

The new generation insecticides such as insect growth regulators (IGRs) offer several advantages over conventional pesticides like high selectivity, excellent efficacy at low dosage, least harmful to beneficial insects, biodegradable and safe (Kodandaram *et al*., 2010). Besides, IGRs are bio-rational compound, disrupts the normal growth, development, moulting and metamorphosis of insects eventually causing the death. IGRs as pesticide are relatively safe, available and fit well for sustainable agriculture. Again, reports on the IGRs against the bean pod borer are scanty in Bangladesh (Ahmed *et al*., 2020). Therefore, the present study was undertaken to evaluate the efficacy of four IGRs viz., Lufenuron, Emamectin benzoate, Lufenuron + Emamectin benzoate and Buprofezin against the bean pod borer, *M. vitrata* infesting country bean.

Materials and Methods

The experiment was conducted in the research field of the Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur. The experimental site was a medium high land belonging the AEZ-1 of Old Himalayan Piedmont Plain soil (p^H 5.52, EC 2.0 mS m^{-1}, contains medium organic matter).

Seeds of BARI Sheem-2 variety was collected from the BADC of Sadar Upazila in Dinajpur. The land was ploughed and cross-ploughed several times with a power tiller to obtain a good tilth followed by laddering and spading. The stubbles of the crops and uprooted weeds were removed from the field and the land was then leveled prior to seed sowing. Five seeds were sown in each prepared pit followed by a light irrigation to ensure soil moisture for germination. After 15 days of sowing, one healthy plants in each pit were kept by thinning. Each plant was stacking with bamboo stick to save the plant from lodging. Irrigation, weeding and other intercultural operations were done as and when needed. Fertilizers were applied according to the recommended doses (FRG, 2012). The whole field was divided into 39 plots.

The study was arranged in randomized complete block design (RCBD) with 3 replications. The unit plot size was 3.0 m × 2.0 m accommodating with a single pit. Plot to plot distance was maintained 1.0 m.

Treatments: The treatments were T_1 = Lufenuron (Hayron 5 EC) @ 0.50, 0.75 and 1 ml/L of water, T_2 = Emamectin Benzoate (Noclaim 5 SG) @ 0.50, 0.75 and 1.0 g/L of water, T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG) @ 0.50, 0.75 and 1 g/L of water, T_4 = Buprofezin (Award 40 SC) @ 0.30, 0.40 and 0.50 ml/L of water. Besides, an untreated control was also maintained by applying water only. Treatments were applied 3 times with the help of knapsack sprayer at 15 days intervals at 4 pm for safety of pollinators. Data were recorded on number of healthy and infested flowers, number of healthy and infested pods and pod yield at 1st, 3rd and 7th days after treatment.

Statistical analyses: All the collected data of different parameters were compiled and arranged for statistical analysis. Then the data were statistically analyzed using Statistix 10 software to test the significance of variance among the treatments and means were separated using Tukey's HSD test ($p<0.05$).

Results

Effect of IGRs on the number of healthy and infested flowers: The tested IGRs had profound effects on the number of healthy and infested flowers of country bean after 1st, 2nd and 3rd spray as compared to untreated control (Tables 1-2). Significantly (1st: $P < 0.05$, $df = 12$, $F = 4.41$; 2nd: $P < 0.05$, $df = 12$, $F = 5.96$; 3rd: $P < 0.05$, $df = 12$, $F = 5.37$) the highest number of healthy flowers were recorded as 119.67, 125.33 and 134.67 in Emamectin Benzoate treated plants @ 1.0 g L^{-1} of water followed by Buprofezin (as 96.67, 114.67and 125.33) @ 0.50 ml L^{-1} of water at 1st, 3rd and 7th days after treatments, respectively (Table 1). Conversely, the lowest number of healthy flower was recorded in the untreated control at 1st, 3rd and 7th days after treatments. The pooled mean highest number of healthy flowers were counted as 126.56 in Emamectin Benzoate treated plots @ 1.0 g/L but the lowest (68.11) in the untreated control. Similarly, among the treatments significantly (1st: $P < 0.05$, $df = 12$, $F = 16.05$; 2nd: $P < 0.05$, $df = 12$, $F = 17.58$; 3rd: $P < 0.05$, $df = 12$, $F = 31.31$) the lowest number of infested flowers (13.0, 8.67 and 6.33) were observed at 1st, 3rd and 7th DATs, respectively in Emamectin Benzoate treated plot @ 1.0 g/L of water (Table 2). Conversely, the highest number of infested flowers was recorded as 36.67, 36.67 and 36.33 in the untreated control treatments at 1st, 3rd and 7th DATs, respectively. The lowest (9.33) pooled mean number of infested flowers were counted in Emamectin benzoate treated plots @ 1.0 g/L while the highest (34.78) from the untreated control.

Table 1. Effect of IGRs on the number of healthy flowers of country bean against by *M. vitrata*

Treatments	Doses (g/ml) L^{-1} water	Mean number of healthy flowers per ten inflorescences			Cumulative mean
		1st DATs	3rd DATs	7th DATs	
T_1	0.50	75.67 bc	87.33 bc	97.67 bc	86.89
	0.75	78.33 bc	88.67 bc	104.00 a-c	90.33
	1.00	83.67 bc	94.33 a-c	103.33 a-c	93.78
T_2	0.50	89.00 a-c	100.67 ab	113.33 bc	101.00
	0.75	92.33 a-c	112.67 ab	130.67 ab	111.89
	1.00	119.67 a	125.33 a	134.67 a	126.56
T_3	0.50	81.67 bc	95.00 a-c	104.00 a-c	93.56
	0.75	85.00 bc	98.00 a-c	112.00 ab	98.33
	1.00	92.67 a-c	113.67 ab	121.67 ab	109.34
T_4	0.30	82.33 bc	96.67 a-c	105.33 a-c	94.78
	0.40	88.00 a-c	98.67 a-c	113.33 ab	100.00
	0.50	96.67 ab	114.67 ab	125.33 ab	112.22
Untreated control	-	61.33 c	68.00 c	75.00 c	68.11
CV (%)		12.75	10.47	10.56	-

Within column values followed by different letter(s) are significantly different at 5% level of probability by Tukey's HSD test. T_1 = Lufenuron (Hayron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG), T_4 = Buprofezin (Award 40 SC).

Table 2: Effect of IGRs on the number of infested flowers of country bean against *M. vitrata*

Treatments	Doses (g/ml) L^{-1} water	Mean number of infested flowers per ten inflorescences			Cumulative mean
		1st DATs	3rd DATs	7th DATs	
T_1	0.50	35.67 a	26.33 b	23.67 b	28.56
	0.75	35.33 a	23.33 bc	17.33 b-d	25.33
	1.00	20.00 b-d	17.33 b-f	11.00 d-g	16.11
T_2	0.50	26.00 a-d	15.00 c-f	12.00 d-g	17.67
	0.75	18.33 cd	13.67 d-f	10.33 d-g	14.11
	1.00	13.00 d	8.67 f	6.33 g	9.33
T_3	0.50	33.67 a	24.00 bc	20.67 bc	26.11
	0.75	28.33 a-c	21.67 b-d	16.33 c-e	22.11
	1.00	19.33 b-d	13.00 d-f	9.00 fg	13.78
T_4	0.30	29.33 ab	20.00 b-d	16.00 c-f	21.78
	0.40	26.67 a-c	18.33 b-e	15.33 c-f	20.11
	0.50	13.67 d	10.67 ef	10.00 e-g	11.44
Untreated control	-	36.67 a	36.67 a	36.33 a	34.78
CV (%)		13.91	16.23	15.54	-

Within column values followed by different letter(s) are significantly different at 5% level of probability by Tukey's HSD test. T_1 = Lufenuron (Hayron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG), T_4 = Buprofezin (Award 40 SC).

Effect of IGRs on the number of healthy and infested pods: The treated different IGRs had potential effects on number of healthy and infested pods of country bean (Tables 3-4). Significantly (1st: $P < 0.05$, $df = 12$, $F = 4.76$; 2nd: $P < 0.05$, $df = 12$, $F = 8.91$; 3rd: $P < 0.05$, $df = 12$, $F = 6.41$) the highest number of healthy pods were recorded as 81.67, 92.33 and 106.67 when the plots were treated with Emamectin Benzoate @ 1.0 g L^{-1} followed by Buprofezin (80.67, 90.00 and 103.00) @ 0.50 ml L^{-1} water at 1st, 3rd and 7th DATs, respectively (Table 3). Conversely, the highest numbers of infested pods were observed in the untreated control (39.67, 49.67 and 55.00) at 1st, 3rd and 7th DATs, respectively. The polled mean highest number healthy pods were counted as 93.56 in Emamectin Benzoate treated plots @ 1.0 g L^{-1} while the highest (48.11) from the untreated control. Likewise, significantly (1st: $P < 0.05$, $df = 12$, $F = 25.95$; 2nd: $P < 0.05$, $df = 12$, $F = 22.48$; 3rd: $P < 0.05$, $df = 12$, $F = 25.38$) the lowest number of infested pods were found as 6.67, 6.67 and 8.33 in Emamectin Benzoate treated plot @ 1.0 g L^{-1} water followed by Buprofezin @ 0.50 ml L^{-1} water (10.0, 8.67 and 8.67) at 1st, 3rd and 7th DATs, respectively (Table 4). But the highest numbers of infested pods were counted in the untreated control as 29.67, 31.00 and 27.00 at 1st, 3rd and 7th DATs, respectively. The cumulative lowest infested pods were recorded as 7.22 in Emamectin Benzoate treated plots @ 1.0 g L^{-1} water followed by Buprofezin @ 0.50 ml L^{-1} water treated plots as 9.11. However, the highest (29.22) infested pods were detected in the untreated control.

Table 3. Effect of IGRs on the number of healthy pods of country bean against *M. vitrata*

Treatments	Doses (g/ml) L^{-1} water	Mean number of healthy pods per ten inflorescences			Polled mean healthy pods
		1st DATs	3rd DATs	7th DATs	
T_1	0.50	51.00 ab	58.33 cd	71.67 bc	60.33
	0.75	56.33 ab	69.33 a-d	79.67 abc	68.44
	1.00	77.33 a	88.33 ab	94.33 ab	86.66
T_2	0.50	58.67 ab	91.00 a	98.67 ab	82.78
	0.75	75.00 a	85.00 ab	102.67 a	87.56
	1.00	81.67 a	92.33 a	106.67 a	93.56
T_3	0.50	56.00 ab	64.67 bcd	80.67 abc	67.11
	0.75	64.67 ab	70.33 a-d	86.00 ab	73.67
	1.00	79.00 a	89.67 a	99.00 ab	89.22
T_4	0.30	58.33 ab	70.67 a-d	89.00 ab	72.67
	0.40	66.00 ab	77.00 abc	101.33 ab	81.44
	0.50	80.67 a	90.00 a	103.00 a	91.22
Untreated control	-	39.67 b	49.67 d	55.00 c	48.11
CV (%)		15.98	10.58	11.39	-

Within column values followed by different letter(s) are significantly different at 5% level of probability by Tukey's HSD test. T_1 = Lufenuron (Hayron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG), T_4 = Buprofezin (Award 40 SC).

Table 4: Effect of IGRs on the number of infested pods of country bean caused by *M. vitrata*

Treatments	Doses (g/ml) L^{-1} water	Mean number of infested pods per ten inflorescences			Polled mean infested pods
		1st DATs	3rd DATs	7th DATs	
T_1	0.50	21.67 b	19.33 b	18.33 b	19.78
	0.75	21.00 bc	18.00 b	15.67 bc	18.22
	1.00	17.33 bcd	14.33 bcd	13.33 b-e	15.00
T_2	0.50	18.33 bcd	15.00 bcd	12.00 cde	15.11
	0.75	13.00 def	10.67 cde	10.33 def	11.33
	1.00	8.33 f	6.67 e	6.67 f	7.22
T_3	0.50	21.33 b	18.67 b	17.67 b	19.22
	0.75	18.33 bcd	15.67 bc	14.33 bcd	16.00
	1.00	13.00 def	10.00 cde	10.00 def	11.00
T_4	0.30	21.00 bc	16.00 bc	15.00 bcd	17.33
	0.40	15.33 cde	14.67 bcd	14.00 bcd	14.78
	0.50	10.00 ef	8.67 de	8.67 ef	9.11
Untreated control	-	29.67 a	31.00 a	27.00 a	29.22
CV (%)		11.06	14.66	12.57	-

Within column values followed by different letter(s) are significantly different at 5% level of probability by Tukey's HSD test. T_1 = Lufenuron (Hayron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG), T_4 = Buprofezin (Award 40 SC).

Table 5. Effect of IGRs on pod yield of country bean against *M. vitrata*

Treatments	Doses (g/ml) L^{-1} water	Yield (g) in weight of pods/plant
T_1	0.50	552.00 bc
	0.75	581.33 abc
	1.00	641.33 abc
T_2	0.50	655.00 abc
	0.75	714.67 ab
	1.00	760.33 a
T_3	0.50	602.67 abc
	0.75	651.33 abc
	1.00	672.67 abc
T_4	0.30	639.00 abc
	0.40	678.33 ab
	0.50	716.33 ab
Untreated control	-	478.33 c
CV (%)		10.17

Within column values followed by different letter(s) are significantly different at 5% level of probability by Tukey's HSD test. T_1 = Lufenuron (Haron 5 EC), T_2 = Emamectin Benzoate (Noclaim 5 SG), T_3 = Emamectin Benzoate + Lufenuron (Himam 50 WDG), T_4 = Buprofezin (Award 40 SC).

Effect of IGRs on the yield: The yield of healthy pods of treated country bean varied with different IGRs in the assigned plots (Table 5). The effects of various IGRs and their doses and varied significantly ($P < 0.05$, $df = 12$, $F = 3.96$) among the treatments. The highest (760.33 g) of healthy pods were recorded in Emamectin Benzoate @ 0.10 g L^{-1} of water treated plants followed by Buprofezin @ 0.50 ml L^{-1} (716.33 g) which is statistically different. Conversely, the lowest (478.33 g) weight of healthy pods was found in the untreated control.

Discussions

In this study, four insect growth regulators (IGRs) were evaluated against the pod borer infestation in country bean with three doses. The outcome revealed that all treatments were found potential in reducing the pod borer infestation as compared to the untreated control. In the first, second, and third sprayings, all the IGRs reduced the flower and pod damages against the *M. vitrata*.

Results revealed that the tested IGRs had profound effects on healthy and infested flowers against the bean pod borer. Efficacy of the tested IGRs was observed as doses and time exposure dependent (Table 1-2). The highest number of healthy flowers were observed in Emamectin benzoate treated plots @ 1.0 g L^{-1} water at 1^{st}, 3^{rd} and 7^{th} DATs as compared to the untreated control (Tables 1-2). Present findings are similar with the result of Patel *et al*. (2012). They observed that Emamectin benzoate 5% SG @ 0.3 g L^{-1} were found to be the most effective insecticides against the *M. vitrata* in Nepal, which provided lowering flower damage with the highest benefit cost ratio. The present results also could be supported by the Ahmed *et al*. (2020) where they claimed that Emamectin benzoate @ 1.0 g L^{-1} water showed a superior performance in comparison to spinosad- a widely used insecticide in respect of benefit cost ratio. Aryal *et al.* (2021) also experienced similar results with the same insecticides at equal doses.

The applied IGRs had promising effects on healthy pods and consequently offered lowest infested pods against the bean pod borer (Tables 3-4). Novel innovative research illustrated that the diverse IGRs have been tried by several researchers with a good degree of success against the pod borer, *M. vitrata* (Haritha, 2008; Ahmed *et al*., 2020). Tested IGRs provided the highest number of healthy pods from Emamectin benzoate treated plots @ 1.0 g L^{-1} water followed by Buprofezin @ 0.50 ml/L at 1^{st}, 3^{rd} and 7^{th} DATs while the lowest in the untreated control (Table 3). Our findings are also comparable with the observations as stated by Kolarath *et al*. (2015) and Aktar *et al*. (2020). They found the highest healthy bean pods in Emamectin benzoate treated plots. This results are also similar with the report of Regmi *et al.* (2014) where they found the highest weight of healthy yardlong bean pods $plot^{-1}$ from the Emamectin treated plants.

IGRs as the novel insecticides showed their significant effect in reducing the infested pods as compared to the control (Table 5). This findings are in close proximity with Aktar *et al*. (2020) where they found that the lowest number of infested pod plot^{-1} (2.88) from Emamectin benzoate treated plots. Parallel findings were also obtained by Patel *et al*. (2012) who observed that Emamectin benzoate 5% SG @ 0.3 g/L was the most effective insecticide in lowering cowpea pod damage with highest benefit cost ratio. Similarly, Haripriya *et al.* (2019) reported that due to sequential application of Emamectin benzoate only 8.87% pod was infested by *M. vitrata* on lablab bean. Aktar *et al.* (2020) also reported the highest increase of healthy pod (63.29%) over control from Emamectin benzoate treated plots against the *M. vitrata* infesting country bean.

The results revealed that all treatments significantly could increase marketable pod yield of country bean as compared to control (Table 5). However, the highest yield was obtained from Emamectin benzoate @ 1.0 g L^{-1} water treated plot while the lowest in untreated control plots. Aktar *et al.* (2020) also found the highest yield (7.1 t ha^{-1}) and yield increase 32.58% over control from Emamectin benzoate 5 SG (1g L^{-1} water) treated plots against country bean pod borer.

The used IGRs in the present study had direct effect against *M. vitrata* which reduced the infestation on flowers and pods. Use of these IGRs have a great economic and environmental importance in comparison to detrimental chemical pesticides. Hence, farmers can use IGRs especially Emamectin benzoate @ 1.0 g L^{-1} for effective management of *M. vitrata* in country bean.

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References

Ahmed, R. N., M. M. Uddin, M. A. Haque and K. S. Ahmed. 2020. Field evaluation of microbial derivatives for management of legume pod borer, *Maruca vitrata* F. in yard long bean. *J. Entomol. Zool. Studies*. **8(3):** 162-166.

Aktar, S., M. M. Uddin and K. S. Ahmed. 2020. Bio-efficacy of some novel insecticides and biopesticides for managing bean pod borer, *Maruca vitrata* G. *J. Bangladesh Agril. Univ.* **18(2):** 221-226.

Ambethar, V. 2009. Potential of entomopathogenic fungi in insecticide resistance management (IRM): a review. *J. Biopest*. **2(2):** 177-193.

Aryal, L. N., R. Regmi, S. Lohani and Y. Bhusal. 2021. Efficacy of commercial insecticides for cowpea pod borer (*Maruca vitrata* F.) management in Pokhara, Nepal. *J. Agric. Nat. Res*. **4(1):** 165-175.

Azad, H. M. S., M. R. Amin, S. M. A. Hossain and D. A. Tithi. 2010. Field abundance and incidence of predator associated with different cotton varieties at Dinajpur in Bangladesh. *J. Env. Sci. Nat. Res*. **3**: 127-130.

FRG (Fertilizer Recommendation Guide). 2012. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

Haripriya, K., S. Jeyarani, S. Mohankumar and R. P. Soundararajan. 2019. Field evaluation of biocontrol agents and biopesticides against spotted pod borer, *Maruca vitrata* G. on lablab. *Indian J. Agric. Res*. **53(5):** 599-603.

Haritha, B. 2008. Biology and Management of *Maruca vitrata* G. in pigeonpea. MSc Thesis, Department of Entomology, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad, India.

Hossain, S. M. A., M. A. Baque and M. R. Amin. 2013. Comparative effectiveness of seed treating and foliar insecticides against sucking pests of cotton and impact on their natural enemies. *Bangladesh J. Agric. Res*. **38**: 61-70.

Khan, S. A. R., Z. Yu, A. Belhadi and A. Mardani. 2020. Investigating the effects of renewable energy on international trade and environmental quality. *J. Environ. Manage*. **272(3):** 213-221.

Kodandaram, M. H., A. B. Rai and J. Halder. 2010. Novel insecticides for management of insect pests in vegetable crops: A review. *J. Veg. Sci*. **37**(2): 109-123.

Kolarath, R., S. Rappa, R. A. Balikai, B. S. Nandihalli and Y. N. Havaldar. 2015. Evaluation of newer insecticides for the management of pod borers of field bean, *Lablab purpureus* (L.). *Karnataka J. Agric. Sci*. **28(1):** 107-109.

Lee, P. and D. Y. H. Tai. 2001. Clinical features of patients with acute organophosphate poisoning requiring intensive care. *Int. Care Med*. **27**(4): 694-699.

Margam, V. M., B. S. Coates, M. N. Ba, W. Sun, C. L. Binso-Dabire, I. Baoua, M. F. Ishiyaku, J. Shukle, T. Hellmich, R. L. Covas, F. G. Ramasamy, S. Armstrong, J. B. R. Pittendrigh and L. L. Murdock. 2010. Geographic distribution of phylogenetically-distinct legume pod borer, *Maruca vitrata* (Lepidoptera: Pyraloidea: Crambidae). *Mol. Biol. Rep*. **38**: 893-903.

Oliveira, C. M., A. M. Auad, S. M. Mendes and M. R. Frizzas. 2014. Crop losses and the economic impacts of insect pests on Brazilian. *Crop Prot*. **56**: 50-54.

Patel, P. S., I. S. Patel, B. Panickar and Y. Ravindrababu. 2012. Management of spotted pod borer, *Maruca vitrata* in cowpea through newer insecticides. *Trends Biosci*. **5**(2): 149-151.

Pavela, R., V. Nadezda and S. Bozena. 2009. Repellency and toxicity of three Impatiens species (Balsaminaceae) extracts on *Myzus persicae* Sulzer (Homoptera: Aphididae). *J. Biopest*. **2(1):** 48-51.

Periasamy, M., R. Schafleitner, K. Muthukalingan and S. Ramasamy. 2015. Phylogeographical structure in mitochondrial DNA of legume pod borer (*Maruca vitrata*) population in Tropical Asia and Sub-Saharan Africa. *PLoS ONE*. **10(4):** e0124057.

Regmi, R., S. Tiwari, R. B. Thapa and G. B. K. C. Fashions. 2014. Eco-friendly management of spotted pod borer, *Maruca vitrata* on yardlong bean in Chitwan, Nepal. *Int. J. Res*. **1(6):** 386-394.

Salim, M., S. Hossain, S. Alam, J. A. Rashid and S. Islam. 2013. Estimation of genetic divergence in lablab bean (*Lablab purpureus* L.) genotypes. *Bangladesh J. Agril Res*. **38(1):** 105-114.

Srinivasan, R., M. Y. Lin, F. C. Su, S. Yule, C. Khumsuwan, T. Hien, V. M. Hai, L. D. Khanh and K. R. M. Bhanu. 2015. Use of insect pheromones in vegetable pest management: Successes and struggles. In: Chakravarthy, A. K. (ed.). "New horizons in insect science: Towards sustainable pest management". Springer. pp. 231-237.

Yule, S. and R. Srinivasan. 2013. Evaluation of biopesticides against legume pod borer, *Maruca vitrata* F. (Lepidoptera: Pyralidae), in laboratory and field conditions in Thailand. *J. Asia-Pacific Ent*. **16**: 357-360.

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SUPPLEMENTAL IRRIGATION AND FERTILIZATION TO MITIGATE THE ADVERSE EFFECT OF TERMINAL DROUGHT STRESS ON TRANSPLANTED AMAN RICE

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Abstract

An experiment was conducted at Crop Physiology and Ecology Research Field, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during July to December 2021 to assess the impact of terminal drought stress on T. Aman rice and evaluate the efficacy of supplemental irrigation and additional fertilizer application for sustainable production. The study was arranged in split-plot design with three replications. Main plot treatment consisted of three water management options such as I_0- Rain-fed (Control), I_1- One supplemental irrigation (6 cm) at flowering stage, I_2- Two supplemental irrigations (6 cm) at panicle initiation and flowering stage. Sub plot treatment consisted of four nutrient management as, F_1- Recommended doses of inorganic fertilizer (RDF), F_2- 150% of RDF, F_3- 15 t ha^{-1} Farmyard manure + RDF and F_4- 10 t ha^{-1}Biochar + RDF. Rice variety BRRIdhan-94 was used as planting material. Results indicated that T. Aman rice suffered from terminal drought stress affecting growth, physiology and yield attributes. The impact of supplemental irrigation on plant height, tillers hill^{-1}, grains panicle^{-1}, thousand grains weight and grain yield of T. Aman was found significantly positive but there was no significant variation between one and two supplemental irrigations. Additional fertilization, particularly with cattle manure, effectively mitigated the adverse effects of terminal drought stress on T. Aman rice yield. Overall, the study suggests that either one supplemental irrigation or additional fertilization is sufficient to sustain yield under terminal drought stress condition in T. Aman rice cultivation.

Keywords: Irrigation, fertilization, terminal drought stress and T. Aman rice.

Introduction

Aman rice is one of the major crops of Bangladesh contributing approximately 38.8 % of the nation's total rice production (BBS, 2021). The changing climate pattern have disrupted traditional rainfall schedule leading to water stress during critical growth stage of rice cultivation with around 90% of the total rainfall occurring between April to October, the abrupt cessation of monsoon in September can create severe water stress in T. Aman season. After October, rainfall is not sufficient for potential yield of rice and most of the Aman rice remains at the flowering and grain filling stages (Sattar *et al*., 2009). A rice crop can not be sustained during this period

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form rainfall alone (Rashid *et al*., 2005). In response to these challenges, the adoption of drought-tolerant rice cultivars and complementary crop management practices becomes important to mitigate risks and enhance productivity and profitability. Haefele *et al*. (2016) reviewed a wide range of studies have highlighted various management options, including water management, cropping systems, improved nutrient management and soil ameliorate strategies, for rain-fed lowland rice cultivation in drought-prone environments. The problem of yield reduction in paddy due to dry spell is overcome by providing supplementary irrigation(s) during this period (Pawar and Dongarwar, 2007). Research indicates that timely supplementary irrigation during the T. Aman season significantly enhance rice yields ranging from 8 to 71 percent over rain-fed condition (Saleh, 1987; BRRI, 1991). Moreover, balanced fertilizer application has been reported to enhance crop resistance to adverse soil conditions, including moisture deficits. (Tisdale *et al*.,1985; Wade *et al*.,1999; Karim and Rahman, 2015). Additionally, the application of biochar has demonstrated positive effects on plant growth, biomass, and yield under drought through increased photosynthesis, nutrient uptake, and modified gas exchange characteristics in moisture stressed plants by improving the physical, chemical and biological properties of soil (Rani *et al*., 2019; Hadiawati *et al*., 2019). Similarly the combined application of poultry litter based compost and inorganic fertilizers increased the rice production and yield through enhanced tiller number, panicle length, 1000-grain weight presumably by increasing nutrient uptake and utilization (Chowdhury *et al*., 2020).

Despite these advancements, limited information exists on the effect of supplemental irrigation, improved nutrient management and soil organic amendments in alleviating the adverse effect of terminal drought stress on Transplanted aman in Bangladesh condition is scanty. Thus, this study aims to investigate the effect of terminal drought on physiology, yield attributes and yield of T. Aman rice, to determine the number of supplemental irrigation during dry spells for sustaining yield of T. Aman rice and also to evaluate the efficacy of additional fertilizer, cattle manure and biochar in alleviating the adverse effect of terminal drought stress on T. Aman rice production.

Materials and Methods

The experiment was conducted at Crop Physiology and Ecology Research Field, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during July 2021 to June 2022. The experimental field was a medium high land belonging to the non-calcareous dark gray floodplain soil under the agro-ecological zone (AEZ-1) of Old Himalayan Piedmont Plain. The soil is sandy loam under the Order Inceptisol. The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from May to September and scantly rainfall in the rest of the year. The meteorological data pattern in respect to temperature and rainfall during the growing period of the experimental site are presented in Figure 1 and 2.

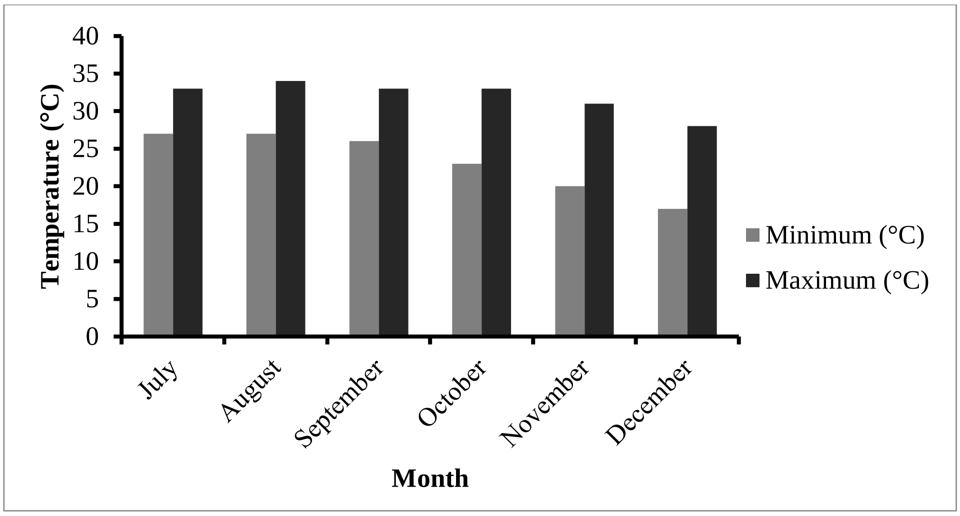

Fig. 1: Temperature (°C) of growing season of T. aman during July to December.

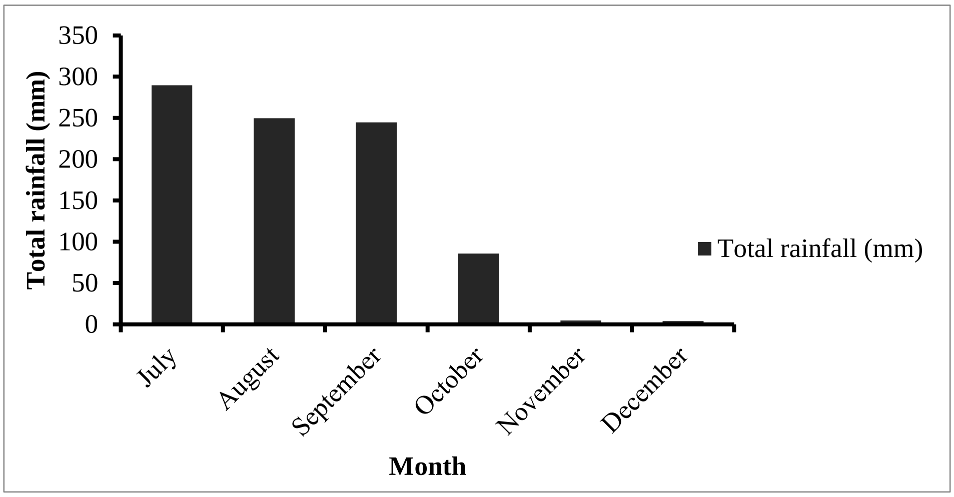

Fig. 2: Total rainfall (mm) of growing season of T. aman during July to December.

The experiment consisted three levels of water management viz. I_0- Rainfed (Control), I_1- One supplemental irrigation (6 cm) at flowering stage and I_2- Two supplemental irrigations (6 cm) at panicle initiation and flowering stage along with four levels of nutrient management viz. F_1- Recommended doses of inorganic fertilizer (RDF), F_2- 150% of RDF, F_3- 15 t ha^{-1} cattle manure + RDF and F_4- 10 t ha^{-1}Biochar + RDF (Dhaliwal *et al.*, 2023; Zohora *et al.*, 2023; Shashi *et al.*, 2018). The experiment was laid out in a split-plot design with three replications assigning water management in the main plots and nutrient management in the sub-plots. Rice variety BRRI dhan-94 was used as planting material.

Seedbed was prepared on 1st July 2021 and seeds were sown uniformly on 5 July 2021.The main land preparation was commenced on last week of July 2021 for cultivation of T. aman rice.

Farmyard manure (15 t/ha), Biochar (10 t/ha), Triple super phosphate (TSP), Muriate of potash (MOP), Gypsum and Zinc Sulfate ($ZnSO_4.7H_2O$) were applied as basal dose during final land preparation as per experimental treatments. Urea was applied in three equal splits. The first dose of urea was applied at l5 days after transplanting of rice seedlings. The rest doses of urea were top dressed at 30 days after transplanting (active tillering stage) and 45 days after transplanting (panicle initiation stage). The recommended doses of fertilizers are N 85, P 14.5, K 70, S 11 and Zn = 1.8kg/ha (BARC, 2005).

Thirty days old seedlings were uprooted carefully and transplanted on the same day on August 6, 2021. The spacing was 20 cm × 20 cm and three healthy seedlings were transplanted in each hill. Rice in control plot was cultivated under rainfed condition. Supplemental irrigated plots were irrigated up to 6 cm on soil surface as par treatments. Weeding, gap filling and other intercultural operations were done as when necessary. Data were recorded on plant parameters such as plant height (cm), number of tillers hill^{-1}, number of panicles hill^{-1}, shoot and root dry weight (g hill^{-1}), panicle length (cm), 1000-grain weight and grain yield (g/m^2). SPAD value was taken from middle portion of five flag leaf at 50, 65 and 80 days after transplanting using SPAD meter (Model: MINOLTA, CHLOROPHYLL METER, SPAD-502, JAPAN). Relative leaf water content was determined at 100 days after transplanting according to Barrs and Weatherly (1962). Water retention capacity was determined at 100 days after transplanting according to Bars and Weatherly (1962). Proline content of the fully expanded flag leaf at 100 days after transplanting from all experimental plots was estimated according to Bates (1973).

Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer using Statistics 10 program. The treatment means were compared using Tukey's test at $p \leq 5\%$ level.

Results and Discussion

Growth parameters

Plant height at different days after transplanting

Plant height recorded at 50, 65 and 80 days after transplanting (DAT) was significantly influenced by the combined effect of supplemental irrigation and fertilization treatments (Table 1). Supplemental irrigation alone or in combination with additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) favored the height of T. aman rice plant. But the influence was greater at the later growth stages. Chowdhury *et al.* (2020) showed that plant height significantly varies with the applications of poultry compost, biochar and supplemental irrigation. Era *et al.* (2021) also reported similar results.

Table 1. Effect of supplemental irrigation and fertilization on plant height of BRRIdhan- 94 at different days after transplanting in aman season

Supplemental irrigation	Fertilization	Plant height (cm)		
		At 50 DAT	At 65 DAT	At 80 DAT
I_0	F_1	95.6 b	111.0 b	115.0 e
	F_2	100.2 ab	122.2 a	123.7 bcde
	F_3	96.5 b	120.6 a	120.7 cde
	F_4	101.9 ab	121.7 a	130.0 abc
I_1	F_1	95.9 b	119.4 a	122.7 cde
	F_2	102.2 ab	121.6 a	123.3 bcde
	F_3	98.9 ab	120.3 a	133.7 ab
	F_4	99.3 ab	120.2 a	130.2 abc
I_2	F_1	99.1 ab	120.7 a	125.3 abcde
	F_2	101.9 ab	123.6 a	135.0 a
	F_3	103.9 a	123.6 a	130.0 abc
	F_4	99.2 ab	119.2 ab	129.7 abcd
CV (%)		2.23	2.30	2.10
Significance level		*	*	**

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

N.B.: DAT indicates days after transplanting, CV indicates co-efficient of variance, * indicates significant at 5% level of probability,** indicates significant at 1% level of probability, I_0- Rainfed (No supplemental irrigation), I_1- One supplemental irrigation (6 cm) at flowering stage,I_2- Two supplemental irrigations (6 cm) at panicle initiation and flowering stage, F_1- Recommended doses of inorganic fertilizer (RDF),F_2- 150% of RDF,F_3- 15 t ha^{-1} Farmyard manure + RDF and F_4- 10 t ha^{-1}Biochar + RDF.

Tillers $hill^{-1}$ at different days after transplanting

Tillers $hill^{-1}$ recorded at 50 and 80 days after transplanting (DAT) was significantly influenced by the combined effect of supplemental irrigation and fertilization treatments except at 65 DAT (Table 2). Supplemental irrigation alone or in combination with additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) favored the number of tillers hill^{-1} of T. Aman rice. Era *et al.* (2021) reported similar results.

Table 2. Effect of supplemental irrigation and fertilization on tillers hill^{-1} of BRRIdhan- 94 at different days after transplanting in aman season

Supplemental irrigation	Fertilization	Tillers hill^{-1}		
		At 50 DAT	At 65DAT	At 80 DAT
I_0	F_1	10.0 j	14.2 a	14.6 g
	F_2	13.6 c-g	18.7 a	17.7 b-f
	F_3	13.3 c-h	20.9 a	18.7 a-d
	F_4	14.0 c-e	20.6 a	18.9 a-c
I_1	F_1	12.9 c-i	18.7 a	17.9 b-f
	F_2	14.8 b-d	21.1 a	18.9 a-c
	F_3	16.9 ab	21.8 a	20.3 ab
	F_4	13.8 c-f	22.3 a	21.7 a
I_2	F_1	13.2 c-i	19.8 a	17.4 b-f
	F_2	15.3 a-c	21.3 a	18.7 a-d
	F_3	17.8 a	22.7 a	18.4 b-f
	F_4	14.4 b-d	22.8 a	18.5 b-e
CV (%)		7.06	5.49	4.02
Significance level		**	NS	**

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

Shoot and root dry weight at different days after transplanting

Shoot dry weight hill^{-1} at 50, 65 and 80 days after transplanting (DAT) was significantly influenced by the combined effect of supplemental irrigation and fertilization treatments but root dry weight hill^{-1} was not significantly influenced at 50 and 65 DAT but significant at 80 DAT (Table 3). In that case, supplemental irrigation alone had no effect but additional fertilization alone or in combination with supplemental had remarkable influence on shoot and root dry weight. These results are in agreement with the research findings of Mohanty *et al.* (2018) and Era *et al.* (2021).

Table 3. Effect of supplemental irrigation and fertilization on shoot and root dry weight hill^{-1} of BRRIdhan- 94 at 50, 65 and 80 days after transplanting in aman season

Supplemental irrigation	Fertilization	Dry weight at 50 DAT		Dry weight at 65 DAT		Dry weight at 80 DAT	
		Shoot (g hill^{-1})	Root (g hill^{-1})	Shoot (g hill^{-1})	Root (g hill^{-1})	Shoot (g hill^{-1})	Root (g hill^{-1})
I_0	F_1	19.6 bc	3.4 a	24.8 e	3.57 a	35.0 c	5.02 abc
	F_2	19.9 bc	3.17 a	30.5 d	4.60 a	42.7 ab	5.97 ab
	F_3	20.8 bc	3.10 a	33.1 cd	3.77 a	43.3 a	5.90 ab
	F_4	22.5 abc	3.43 a	33.4 cd	4.03 a	48.0 a	5.10 abc
I_1	F_1	18.9 c	3.13 a	30.7 d	4.20 a	34.3 c	4.47 bc
	F_2	22.6 abc	3.63 a	35.7 bc	4.53 a	48.7 a	5.77 abc
	F_3	20.2 bc	3.37 a	37.7 bc	4.13 a	46.4 a	4.83 abc
	F_4	20.3 bc	2.83 a	39.2 ab	3.70 a	44.0 a	5.07 abc
I_2	F_1	19.5 bc	3.53 a	33.9 cd	4.73 a	35.7 bc	3.27 c
	F_2	20.5 bc	3.07 a	43.3 a	5.50 a	47.0 a	5.73 abc
	F_3	23.3 ab	4.30 a	38.7 ab	4.07 a	48.7 a	5.63 abc
	F_4	25.7 a	4.53 a	39.0 ab	5.70 a	49.0 a	6.97 a
CV (%)		6.24	13.18	4.39	14.89	4.18	13.83
Significance level		**	NS	**	NS	**	*

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

Physiological attributes

SPAD value at different days after transplanting

The SPAD value which indicated the greenness of leaf recorded at 65 and 80 days after transplanting (DAT) was significantly influenced by the combined effect of supplemental irrigation and fertilization treatments but it was not significantly influenced at 50 DAT (Table 4). Supplemental irrigation alone or in combination with additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) improved the SPAD value of leaves. The influence was found greater when one supplemental irrigation was applied than two supplemental irrigation. Mohanty *et al.* (2018) and Era *et al.* (2021) also recorded similar results.

Table 4. Effect of supplemental irrigation and fertilization on SPAD value of leaf of BRRIdhan- 94 at different days after transplanting in aman season

Supplemental irrigation	Fertilization	SPAD value		
		At 50 DAT	At 65DAT	At 80 DAT
I_0	F_1	39.1 a	37.3 b	39.0 b
	F_2	39.9 a	43.7 ab	44.6 a
	F_3	37.0 a	38.6 b	41.2 ab
	F_4	37.6 a	45.6 a	40.4 ab
I_1	F_1	40.4 a	41.8 ab	41.0 ab
	F_2	39.9 a	38.4 b	42.2 ab
	F_3	36.9 a	40.1 ab	42.0 ab
	F_4	39.8 a	39.6 ab	44.9 a
I_2	F_1	39.8 a	39.4 ab	41.3 ab
	F_2	38.8 a	41.4 ab	40.2 ab
	F_3	39.5 a	39.3 ab	40.2 ab
	F_4	40.2 a	39.4 ab	39.2 b
CV (%)		6.78	2.38	4.09
Significance level		NS	**	*

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

Water retention capacity

Water retention capacity at 100 days after transplanting (DAT) was significantly influenced by the combined effect of supplemental irrigation and fertilization treatments (Table 5 Supplemental irrigation alone or in combination with additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) improved the water retention capacity of leaves. The influence was found greater in two supplemental irrigated plots than one supplemental irrigated plots. Rani *et al*. (2019) reported similar results.

Relative leaf water content

The relative leaf water content at 100 days after transplanting (DAT) was significantly increased by the combined effect of supplemental irrigation and fertilization (Table 5). Supplemental irrigations either alone or in combination with additional fertilization treatments (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) improved the relative leaf water content. This findings aligns with the results reported by Chowdhury *et al*. (2020).

Proline content

The proline content of flag leaf at 100 DAT was significantly affected by the combined effect of supplemental irrigation and fertilization (Table 5). The maximum proline content (1.89 µ mole/ g fresh weight) was recorded when 150% of recommended doses of inorganic fertilizer were applied in rain-fed condition (I_0F_2), but statistically similar to that observed with RDF under rain-fed condition (1.85 µ mole/ g fresh weight). However, supplemental irrigation alone or in combination with additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) reduced the proline level. These results suggested that T. Aman rice suffered from terminal drought stress which supplemental irrigation, either alone or combined with additional fertilization, helped to alleviate. Karim and Rahman (2015) underscored the importance of balanced fertilization in managing drought risk for increased cereal production. Studies revealed that irrigation alone is not sufficient to obtain satisfactory grain yield without balanced fertilization. Additionally balanced fertilization can improve photosynthetic activity by stabilizing superoxide dismutase (SOD) activity, improve proline, abscisic acid (ABA) levels, thereby enhancing crop drought tolerant and yield.

Table 5. Effect of supplemental irrigation and fertilization on water retention capacity, relative leaf water content and proline content of flag leaf of BRRIdhan- 94 at 100 days after transplanting in aman season

Supplemental irrigation	Fertilization	Water retention capacity (% of initial water content after 24 hours)	Relative leaf water content (%)	Proline content (µ mole/ g fresh weight)
I_0	F_1	5.14 b	82.3 e	1.85 a
	F_2	6.01 ab	84.3 de	1.89 a
	F_3	6.09 ab	91.1 ab	1.70 ab
	F_4	6.34 a	93.1 a	1.35 cd
I_1	F_1	5.89 ab	86.8 cd	1.49 bc
	F_2	6.97 a	93.2 a	1.40 cd
	F_3	6.03 ab	90.8 ab	1.43 c
	F_4	6.36 a	91.3 ab	1.29 cd
I_2	F_1	6.41 a	87.5 bcd	1.38 cd
	F_2	6.49 a	91.8 a	1.20 d
	F_3	6.63 a	92.3 a	1.32 cd
	F_4	6.51 a	90.2 abc	1.34 cd
CV (%)		3.26	1.28	5.45
Significance level		**	**	**

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test

Yield and yield attributes

Grain yield was significantly increased but the straw yield was not significantly influenced by the combined use of supplemental irrigation and fertilizer application (Table 6). The lowest grain yield (583 g m^{-2}) was recorded when recommended doses of inorganic fertilizer (RDF) were applied in rain-fed condition (I_0F_1) which was followed by one supplemental irrigation with RDF (662 g m^{-2}), two supplemental irrigation with RDF (680 g m^{-2}) and two supplemental irrigation with 15 t ha^{-1} farmyard manure + RDF (688 g m^{-2}). The maximum grain yield was obtained from one supplemental irrigation with 10 t ha^{-1} biochar + RDF (756 g m^{-2}) followed by one supplemental irrigation with 150% of RDF (740 g m^{-2}), one supplemental irrigation with 15 t ha^{-1} farmyard manure + RDF (746 g m^{-2}) and rain-fed condition with 10 t ha^{-1} biochar + RDF (722 g m^{-2}). Other treatments provided moderate yield. The result indicated that supplemental irrigation and additional fertilization (50% of RDF, 15 t ha^{-1} cattle manure and 10 t ha^{-1} biochar) alone or combination of both significantly increased the grain yield (662 to 756 g m^{-2}). The increase in grain yield was contributed by increase in number of panicles $hill^{-1}$, grains $panicle^{-1}$ and thousand grain weight in the respective treatment combinations (Table 7). The performance of grain yield indicates that one supplemental irrigation performed better than two supplemental irrigations. One supplemental irrigation or additional fertilization was found suitable in alleviating the adverse effect of terminal drought stress. Similar results were obtained by Rahman *et al*. (2002), Shamsuzzaman (2007), Kabir (2011) and Mohanty *et al.* (2018).

Soil nutrient status

Organic carbon (%), organic matter (%) and total N (%) were significantly influenced by the combined effect of supplemental irrigation and fertilizer application treatments, but available P, exchangeable K and available S content were not significantly influenced by the combined effect of supplemental irrigation and fertilization treatments (Table 7). Significantly the highest organic carbon (0.613%), organic matter (1.053%) and total N (0.053%) were recorded when cattle manure @ 15 t ha^{-1} was applied in rain-fed condition (I_0F_3). Similar results are reported by Wade *et al*. (1999) and Rouf *et al.* (2018).

Conclusion

Results of the present study indicated that one supplemental irrigation or additional fertilization (150% of RDF, 15 t ha^{-1} farmyard manure + RDF and 10 t ha^{-1} biochar + RDF) can alleviate the adverse effect of terminal drought stress effectively.

Table 6. Effect of supplemental irrigation and fertilization on growth and yield of BRRIdhan- 94 at harvest in aman season

Supplemental irrigation	Fertilization	Tillers hill^{-1}	Panicles hill^{-1}	Plant height (cm)	Panicles length (cm)	Grains panicle^{-1}	Thousand grain weight (g)	Grain yield hill^{-1} (g)	Grain yield m^{-2} (g)	Straw yield m^{-2} (g)
I_0	F_1	13.9 c	12.2 c	117.7 d	25.3 a	187.4 e	18.6 b	42.9 c	583 f	920 a
	F_2	15.9bc	14.2ab	126.4 c	27.8 a	233.3 abcd	20.26 ab	54.1ab	710 abcde	1050 a
	F_3	17.5ab	15.1ab	127.3bc	26.9 a	210.3 bcde	20.1ab	52.7 b	686 cde	1170 a
	F_4	18.1 a	15.6ab	131.8abc	26.4 a	227.7 abcd	20.6 a	55.5ab	722 abcd	1100 a
I_1	F_1	16.3abc	14.6ab	124.7 cd	26.4 a	202.9 de	20.3 a	52.1 b	662 e	1090 a
	F_2	16.6ab	14.9ab	131.9ab	26.5 a	212.9 bcde	20.9 a	54.7ab	740 abc	1220 a
	F_3	17.4ab	15.1ab	135.1ab	27.3 a	230.9 abcd	21.28 a	59.7 a	746 ab	1130 a
	F_4	17.6ab	15.3ab	131.6abc	26.3 a	205.1 cde	21.0 a	58.1ab	756 a	1087 a
I_2	F_1	16.3abc	13.9 b	129.8bc	26.9 a	233.7 abcd	20.6 a	55.1ab	680 de	1100 a
	F_2	17.9ab	14.7ab	138.9 a	27.7 a	242.0 ab	20.0ab	56.4ab	703 abcde	1180 a
	F_3	16.2abc	15.7 a	132.4ab	28.7 a	235.0 acb	20.2ab	58.9ab	688 cde	1100 a
	F_4	17.8ab	15.3ab	135.7ab	28.9 a	249.0 a	20.7 a	58.2ab	698 bcde	1240 a
CV (%)		4.28	3.90	1.40	3.19	3.97	2.75	3.63	2.75	8.35
Significance level		**	*	**	NS	**	*	**	*	NS

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

N.B.: DAT indicates days after transplanting, CV indicates co-efficient of variance, NS indicates not significant, * indicates significant at 5% level of probability, ** indicates significant at 1% level of probability, I_0- Rainfed (No supplemental irrigation), I_1- One supplemental irrigation (6 cm) at flowering stage,I_2- Two supplemental irrigations (6 cm) at panicle initiation and flowering stage, F_1- Recommended doses of inorganic fertilizer (RDF),F_2- 150% of RDF,F_3- 15 t ha^{-1} Farmyard manure + RDF and F_4- 10 t ha^{-1}Biochar + RDF.

Table 7. Nutrient status of soil as influenced by supplemental irrigation and fertilization on BRRIdhan- 94 rice field in aman season

Supplemental Irrigation	Fertilization	Organic carbon (%)	Organic matter (%)	Total Nitrogen (%)	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)
I_0	F_1	0.400 b	0.690 bc	0.039 bc	14.70 a	0.167 a	5.04 a
	F_2	0.400 b	0.690 bc	0.040 b	15.51 a	0.167 a	5.51 a
	F_3	0.613 a	1.053 a	0.053 a	15.99 a	0.180 a	5.94 a
	F_4	0.280 b	0.480 cd	0.024 de	15.45 a	0.190 a	7.84 a
I_1	F_1	0.280 b	0.480 cd	0.024 de	13.34 a	0.227 a	6.09 a
	F_2	0.307 b	0.527 bcd	0.027 cde	12.94 a	0.203 a	6.87 a
	F_3	0.427 b	0.733 b	0.036 bcd	13.90 a	0.230 a	3.93 a
	F_4	0.333 b	0.573 bcd	0.029 bcde	14.31 a	0.250 a	5.19 a
I_2	F_1	0.267 b	0.457 d	0.023 e	13.02 a	0.180 a	6.81 a
	F_2	0.293 b	0.503 bcd	0.027 cde	12.94 a	0.203 a	6.20 a
	F_3	0.427 b	0.733 b	0.037 bcd	13.90 a	0.230 a	3.93 a
	F_4	0.320 b	0.550 bcd	0.028 bcde	13.42 a	0.240 a	5.19 a
CV (%)		16.70	12.87	12.66	13.09	15.45	28.34
Significance level		*	*	**	NS	NS	NS

In a column, means followed by similar letter(s) did not differ significantly by Tukey's test.

N.B.: DAT indicates days after transplanting, CV indicates co-efficient of variance, NS indicates not significant, * indicates significant at 5% level of probability, ** indicates significant at 1% level of probability, I_0- Rainfed (No supplemental irrigation), I_1- One supplemental irrigation (6 cm) at flowering stage, I_2- Two supplemental irrigations (6 cm) at panicle initiation and flowering stage, F_1- Recommended doses of inorganic fertilizer (RDF), F_2- 150% of RDF, F_3- 15 t ha^{-1} Farmyard manure + RDF and F_4- 10 t ha^{-1}Biochar + RDF.

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References

BARC (Bangladesh Agricultural Research Council). 2005. Fertilizer Recommendation Guide. BARC Soils Publication No. 45. BARC, Dhaka. Pp. 1-254.

Barrs, H.D. and P.E. Weatherley. 1962. A re-examination of the relative turgidity technique forestimating water deficits in leaves. *Aust.J. Biol. Sci.* **24:** 519-570.

Bates, L.S. 1973. Rapid determination of free proline for water-stress studies. *Plant Soil.* **39:**205-207.

BBS. 2021. Bangladesh Bureau of Statistics, Statistical Yearbook of Bangladesh, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka. p. 144.

BRRI. 1991. Internal Review Report. Irrigation and Water Management Division, Bangladesh Rice Research Institute, Gazipur. Pp. 149-155.

Chowdhury, A.K.M.M.B, T.S. Tudu, M.A. Shohag, M.A. Hossain and M.Z. Islam. 2020. Performance of Poultry Litter Based Compost on Morpho-Physiological Characters and Yield of T. Aman Rice and Soil Fertility. *Bangladesh Agron. J.* **23(1):** 13-27.

Chowdhury, A.K.M.M.B, M.A. Hossain, J. Alam, M.A. Hasan and M.Z. Islam. 2020. Amelioration of adverse effect of drought on rice (*Oryza sativa* L.) variety BRRI Dhan28 through application of poultry litter based compost.*The Agriculturists.* **18(1):** 42-55.

Dhaliwal S.S., V. Sharma, V. Verma, M. Kaur and P. Singh. 2023. Impact of manures and fertilizers on yield and soil properties in a rice-wheat cropping system. *PLoS One*. **18(11):** e0292602. https://doi.org/10.1371/journal.pone.0292602

Era, M.A., M.A. Hasan, A.K.M.M.B. Chowdhury, M.R. Islam and S.K. Pramanik. 2021. Effect of supplemental irrigation to alleviate the adverse impact of terminal drought stress on aman rice. *Int. J. Agric. Med. Plants.* **2(2):** 8-15.

Hadiawati, L., T. Sugianti and Y. Triguna. 2019. Rice-husk Biochar for Better Yield of Lowland Rainfed Rice in Lombok, Indonesia. AIP Conference Proceedings 2199, 040001.https://doi.org/10.1063/1.5141288

Haefele, S. M., Y. Kato and S. Singh. 2016. Climate ready rice: Augmenting drought tolerance with best management practices. *Field Crops Res.* **190:** 60-69.

Kabir, S.M. 2011. Effect of supplemental irrigation on the yield and yield contributing component of BINA Dhan 7, MS Thesis, Department of Soil Science, Bangladesh Agricultural University, Mymensingh. Pp. 32-34.

Karim, M.R. and M.A. Rahman. 2015. Drought risk management for increased cereal production in Asian Least Developed Countries. *Weather.Clim. Extremes.* **7:** 24-35.

Mohanty, S., S.K. Rautaray and D.K. Panda.2018. Effect of fertilizer levels and supplementary irrigation on late maturing transplanted paddy under rainfed medium land situations. *Oryza.* **55(1):** 179-184.

Pawar, W.S. and U.R. Dongarwar. 2007. Effect of protective irrigation on early and mid-late transplanted paddy. *Oryza.* **44(2):** 172-173.

Rahman,M.T., M.T. Islam and M.O. Islam. 2002. Effect of water stress at different growth stages on yield and yield contributing characters of Transplanted aman rice. *Pak. J. Biol. Sci.* **5**(2): 169-172.

Rani, P., H. Nayar, S. Rai, S.K. Prasad and R.K. Singh. 2019. Biochar: Moisture stress mitigation. *J.Pharmacogn. Phytochem.* **SP5:** 299-307.

Rashid, M. A., A. F. M. Saleh and L. R. Khan.2005. Water Saving and Economics of Alternate Wetting and Drying Irrigation for Rice. *Bangladesh J. Water Resour. Res.* **20:** 81-93.

Rouf, M.A., M.A. Khan, M. H. Rabin, A. Barman and M. N. H. Mehedi. 2018. Effect Of Fertilizer And Manure On the Change Of Nutrient Availability Of T. Aman Rice In Different Soil. *J. Agric. Vet. Sci*. **11(5):** 17-21.

Saleh, A.F.M. 1987. The effect of supplementary irrigation on rice yield in Bangladesh. International Rice Research Newsletter. **2(1):** 25-26.

Sattar, M.A. and M.I. Parvin. 2009. Assessment of vulnerability of drought and its remedial measures for sustainable T. Aman rice production in the selected locations of Bangladesh. Proc. of 2nd International Conference on Water and Flood Management (ICWFM 2009), Dhaka, Bangladesh. p.509.

Shamsuzzaman, A.K.M. 2007. Comparative study on the yield performance of transplanted Aman rice under rainfed and supplemental irrigated condition. Department of Soil Science, Bangladesh Agricultural University (BAU), Mymensingh.

Shashi M.A., M.A. Mannan, M.M. Islam and M.M. Rahman. 2018. Impact of Rice Husk Biochar on Growth, Water Relations and Yield of Maize (*Zea mays* L.) under Drought Condition. *The Agriculturists*. **16(2):** 93-101.

Tisdale, S.L., W.L. Nelson and J.D. Beaton. 1985. Soil Fertility and Fertilizers. Macmillan Publishing Company, New York. p.754

Wade, L.J, S.T. Amarante, A. Olea, D. Harnpichitvitaya, K. Naklang, A. Wihhardjaka, S.S. Sengar, M.A. Mazid, G. Singh and C.G. McLarel. 1999. Nutrient requirements in rainfed lowland rice. *Field Crops Res.* **64(1-2):** 91-107.

Zohora F., S.K. Paul, R.A. Rahman, N.C. Paul, M.M. Rahman, T. Javed, C. Barutçular, F. Çiğ , S. soysal and A.E. Sabagh. 2023. Effect of planting and nutrient management on the growth, yield and protein content of aromatic fine rice. *J. Aridland Agric*. **9:** 22-30. doi: 10.25081/jaa.2023.v9.7209 https://updatepublishing.com/journal/index.php/jaa

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INSECTICIDE USE PATTERN ON SUMMER TOMATO PRODUCTION IN JASHORE AND SATKHIRA DISTRICTS OF BANGLADESH

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Abstract

The study was conducted at summer tomato growing areas in Jashore and Satkhira districts of Bangladesh to describe the insecticide use pattern on summer tomato production. Ninety farmers were selected randomly and an interview schedule was developed according to the objective of the study. Farmers of the study area used 16 different types of pesticides and most of them were toxic. In the study area 77.77% of the farmers sprayed insecticides on summer tomato one or more than one times in a week, 82.2% of the farmers harvested their crop at 0-5 days after spraying, 31.1% of the farmers depended on pesticide dealer for insecticide related knowledge, maximum farmers (84.4%) mixed different types of insecticides during spraying, most of the farmers (65.6%) measured insecticides approximately, 73.3% of the farmers started 1st spray without observing any insect in the field and 51.1% of the farmers didn't use any safety measures during spraying insecticides. Farmer's education, farm size annual income, training experience had negative relationship with the schedule of insecticide spray and positive relationship with the harvesting time after insecticide spray, use of tools for measuring pesticide, use of safety method where most of the relationships were significant.

Keywords**:** Summer tomato, Insecticides, Spraying frequency, Pre harvest interval, Safety method, Correlation.

Introduction

Agricultural production in Bangladesh is diversifying with high-value crops rather than solely focusing on rice to provide food security (FAO, 2011). Tomato (*Solanum Lycopersicum*) is the world's fourth most valuable food crop in terms of production, yield, commercial use, and consumption (Schreinemachers *et al.*, 2018). After eggplant and potatoes, tomatoes are the most significant vegetable in Bangladesh (Schreinemachers *et al.,* 2016). But tomato plant is highly susceptible to many insect pests and plant pathogens which cause large amount of economic losses and lead to the excessive use of pesticides. In the world, over 385 million people per year suffer from acute pesticide poisonings (Boedeker *et al*., 2020).

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Although tomato plants may thrive in a variety of climates, they are particularly vulnerable to the hot, humid conditions that characterize Bangladesh's summer and rainy seasons (Karim *et al.,* 2009). The optimum time to plant tomatoes in Bangladesh is in the early part of November when the climate remains favorable for their growth during the cold winter months (Hossain *et al.,* 1999). Tomatoes require a nighttime temperature of 15 to 20 ^{0}C for fruit setting, according to Charles and Harris (1972), but this temperature is not present in any location in Bangladesh from May to September. Seasonality and a variety of insect and disease issues are the two key factors that limit the ability of Bangladesh to produce tomato throughout the year. Due to tomatoes' superior nutritional and processing features, demand for them has greatly expanded in both domestic and international markets (Hossain *et al.,* 1999). Bangladesh Agricultural Research Institute (BARI) has taken the initiative to develop off-season summer and rainy season tomatoes due to the rising demand and significance of the tomato. Three hybrid tomato varieties that can be cultivated during the summer and rainy season have been introduced by BARI so far e.g., BARI Hybrid Tomato-3, BARI Hybrid Tomato-4, and BARI Hybrid Tomato-8 (Haque *et al.,* 2017). The farmers of Bagharpara upazila under Jashore district started to adopt this technology as pioneer farmer since 2005 (Karim *et al.,* 2009). Summer tomato is profitable in Jashore and Satkhira districts but insect attack is one of the major constraint there (Pradip *et al*, 2018). In tomato 100 to 200 insect pest attack occurs from seedling to harvesting stage (Lange and Bronson, 1981). In Jashore, average tomato yield losses from insect pests and diseases is 3.1tha^{-1} and tomato farmers are mostly depends on chemical pesticides to control the pest (Depenbusch *et al*., 2023). There is a possibility of indiscriminate use of pesticides on summer tomato as it is off season and high valued crop. The effect of off-season vegetable cultivation on income and pesticide use in developing countries has not been the subject of many researches (Kang *et al*., 2013, Nair and Barche, 2014). For this reason the present study was designed to find out the type of insecticides used on summer tomato and to investigate the insecticide use pattern on summer tomato production followed by summer tomato growers.

Materials and method

The study was a descriptive survey and for that reason an interview schedule was developed considering the objective of the study. Summer tomato growing areas were selected for data collection. Three upazila namely Bagherpara from Jashore, Kalaroa and Tala from Satkhira were selected as the study area on the basis of availability of the farmer involved in summer tomato cultivation. Thirty farmers involved in summer tomato cultivation were selected randomly from each of the selected Upazila and a total of ninety farmers were considered as the sample of the study.

The interview schedule was divided into two parts viz., (1) Personal and professional characteristics of the farmers and (2) their viewpoint (Name of insecticides used by the farmer, schedule of insecticide spray, harvesting time after insecticide spray, pesticide chosen by decision maker, mixing pesticide, decision for spraying and safety measures followed during pesticide spray) . Data were collected from the selected farmers by face to face interview method.

Age of a farmer was measured by counting the years from the time of his/her birth to the time of the interview. The level of education was measured by the number of years of schooling. Farm size refers to the area of land under the respondent's possession including share cropping and leased which was measured in terms of hectare. Annual income of a farmer was determined on the basis of his total earnings from agriculture, service, business, and other sources. Training experience was measured by respondent's training experience on summer tomato cultivation in his entire life from different organizations. The assigned score for having training experience was 1 and for not having training experience was 0.

Schedule of insecticide spray, harvesting time after insecticide spray, pesticide chosen by decision maker, mixing pesticide, decision for spraying and safety measures followed during pesticide spray data were collected by asking the farmer's opinion towards a prepared questionnaire. Information regarding used pesticides by the farmer was written on the data collection sheet.

Statistical Package for Social Science (SPSS) version 21 and descriptive statistical tools such as mean, percentage and frequency were used for analyzing the data of this study.

Results and discussion

Total 16 insecticides belong to 12 group were used by the farmer at study area. The highest number of farmers used nitro (50%), movento (46.66%), belt expert (42.22%), imitaf (34.4%) and voliam flexi (31.11) (Table 1). Among the insecticides only tracer and success were considered as bio-pesticides and the rests of them were toxic chemical. Different bio-pesticides viz., azadirachtin, D-limonene, sodium lauryl ether sulphate, matrine, abamectin, SNPV (Spodoptera nuclear polyhedrosis virus), HNPV (Helicoverpa nuclear polyhedrosis virus) etc. were found effective against tomato and other vegetable insects (Rahman *et al*., 2016; Mohammad *et al.*, 2018 and Rashid *et al.*, 2022), but farmers of the study area did not familiar with these. Depenbusch *et al*., 2023 also observed the similar situation where they found bio-pesticide made up less than 1% of the quantity of pesticides applied in Jashore area. So, there is a scope to disseminate bio-pesticide based management strategies among the summer tomato growers considering environmental and health issues.

Table 1. Type of pesticide used for summer tomato production by farmers in the study area

Group name	Name of insecticide	% Farmer used
Cypermethrin	Relothrin 10EC	22.2
	Ripcord 10EC	16.6
Imidacloprid	Imitaf 20SL	38.8
	Confidor 70 WG	27.7
Chlorpyrifos+ Cypermethrin	Nitro	50
Chlorantraniliprole+Thiamethoxam	Voliam Flexi	31.11
Acetamiprid	Tundra 20 SP	22.22
Spirotetramat	Movento240SC	46.66
Abamectin + Emamectin benzoate	Sienna 6WG	16.66
Emamectin benzoate	Proclaim	24.44
	Dana double plus 10WG	8.88
Spinosad	Tracer 45SC	15.55
	Success 2.5 SC	8.88
Carbosulfan	Marshal 20EC	23.33
Flubendiamide+Thiacloprid	Belt expert	42.22
Spiromesifen	Oberon 240SC	28.88

Source: Surveyed data collected by the author's in this study.

*Multiple insecticides used by a farmer was considered for determining percent of farmer.

Result indicated that 41.1% farmers of the study area sprayed insecticide one times in a week, 34.4% farmers sprayed more than 1 times in a week, 1.1% farmers sprayed one time in a day, 1.1% farmers sprayed more than one time in a day where only 22.2% farmers sprayed less than 1 time in a week (Table 2). Tomato insects are possible to control by 3-4 times spraying at 7-15 days interval during the cropping period (Carson *et al*., 2012; Rahman *et al*., 2016 and Rashid *et al.,* 2022). Therefore, most of the farmer of study area sprayed insecticide unnecessarily in summer tomato.

It was observed that the highest 36.7% farmers of the study area harvested summer tomato after 1-2 days of insecticide spraying, 34.4% farmers harvested after 3-5 days of insecticide spraying and 11.1% farmers harvested same day after insecticide spraying through 12.2% farmers harvested tomato after 6-8 days of insecticide spraying and 5.56% farmers harvested tomato more than 8 days after spraying (Table 2). Prodhan *et al*., 2018 and Kabir *et al*., 2008 determined 3-12 days pre harvest interval (PHI) for different insecticides in different vegetables including tomato. Considering this, a large number of farmers didn't follow the safe PHI during summer tomato harvesting.

Result revealed that, for insecticide related knowledge, the highest 31.1% farmers of the study area were depend on pesticide dealer, followed by 25.6% farmers were depend on neighbor, 22.2 % farmers were depend on Government officials, 17.8%

farmers were depend on NGO officials and 3.3 % farmers were depend on own knowledge (Table 2). Involvement of more government and NGO officials are needed to reduce pesticide dealer dependency of the farmer.

Present study was also indicated that 84.4% farmers of the study area mixed different type of insecticides during spray, 65.6% farmers measured insecticide approximately, 73.3% farmers sprayed in their field without observing any insect in the field and 51.1% farmers didn't use any kind of safety measure during insecticides spraying (Table 2). That means majority of the farmers had lack of knowledge on insecticide application, use and handling. So, training on judicial insecticide applications, its uses and handling should provide among the summer tomato growers.

Table 2. Insecticide use pattern on summer tomato production of the farmers in Jashore and Satkhira districts

Schedule of insecticide spray (n=90)	Frequencies	Percent of farmers
More than one times in a day	1	1.1
one times in a day	1	1.1
More than one times in a week	31	34.4
one times in a week	37	41.1
More than one times in a month	15	16.7
one time in a month	4	4.4
less than one time in a month	1	1.1
Harvesting time after insecticide spray(n=90)		
Same day after spray	10	11.1
1-2 days after spray	33	36.7
3-5 days after spray day	31	34.4
6-8 days after spray day	11	12.2
more than 8 days after spray	5	5.6
How farmer made decision about insect pest management like pesticide chosen, application dose fixation etc. (n=90)		
Own knowledge	3	3.3
Consulting with neighbor	23	25.6
Pesticide dealer	28	31.1
NGO workers	16	17.8
Government worker	20	22.2
Do farmer mix different pesticide(n=90)		
Yes	76	84.4
No	14	15.6

Schedule of insecticide spray (n=90)	Frequencies	Percent of farmers
How farmer measure pesticide(n=90)		
Using measuring tools	31	34.4
Approximately	59	65.6
When farmer take decision for spraying(n=90)		
Without observing any insect	66	73.3
After initial symptoms	24	26.7
Above ETL	0	0
Safety method followed by the farmer(n=90)		
No use of safety method	46	51.1
Use of partial safety method	40	44.4
Use of full safety method	4	4.4

Source: Surveyed data collected by the author's in this study.

Table 3. Demographic characteristics profile of the farmers (n= 90)

Variable	Categories	Frequencies	%
Farmer's age (Mean = 45.83, SD±9.26)	30 years and less	7	7.8
	31 to 40	22	24.4
	41 to 50	36	40
	51 to 60	22	24.4
	More than 60 years	3	3.3
Farmer's education(Mean = 4.97, SD±3.87)	No education/illitarate	26	28.9
	Primary education	32	35.6
	Secondary (SSC level)	26	28.9
	Upper SSC level	6	6.7
Farmer's annual income [Mean = 188090 BDT (1791.33 USD)]	Less than 150000 BDT	20	22.22
	150000-250000 BDT	55	61.11
	More than 250000 BDT	15	16.67
Farm size (Mean = 0.914, SD±0.723)	Less than 1.01 ha	61	67.8
	1.01 to 3.03 ha	27	30.0
	More than 0.03 ha	2	2.2
Training participation on Summer tomato cultivation	No training	50	55.6
	Training	40	44.4

Source: Surveyed data collected by the author's in this study

Socio-demographic information of the farmers like age, educational qualification, annual income, farm size and training experience are presented in Table 3. The

Table provided categories, frequencies, and percentage for all these demographic variables and indicated that the highest 40% farmers were within 41 to 50 years of age, most of the farmers (71.1%) of the study area were educated either in primary, secondary or tertiary level but 28.9% of them had no education. The average income of the farmers of the study area was Tk.188090.00 which was near to the national average of Tk.187397.7 (1784.74 USD) (Trading Economics, 2022). In the study area, 44.4% farmers had training exposure related to summer tomato cultivation and this percentage was comparatively higher than other technology adopted by farmers (Hasan *et al*., 2017 and Mohammad *et al.*, 2020). The reasons of higher training received by farmers of the study area may be due to farmer's early adoption behavior, high price of summer tomato and reputation of the study area for summer tomato cultivation (Karim *et al.*, 2009).

Pearsons Correlation Co-efficient "r" was used to determine the relationships between the selected demographic characteristics of the farmer and their behavior of insecticide use. Farmer's education, farm size, annual income and training experience had negative relationship with schedule of insecticide spray and positive relationship with harvesting time after insecticide spray, use of tools for measuring pesticide, safety method followed by the farmer where most of the relationships were significant (Table 4).

Table 4. Relationship between demographic characteristics of the farmer and their behavior of insecticide use

Personal and professional characteristics of the farmers	Coefficient correlation value of 'r'			
	Schedule of insecticide spray	Harvesting time after insecticide spray	Use of tools for measuring pesticide	Safety method followed by the farmers
Age	0.088	-0.074	-0.143	0.060
Education	-0.195	0.299**	0.225*	0.177
Farm size	-0.229*	0.353**	0.10	0.275*
Annual income	-0.298**	0.260*	0.259*	0.368**
Training experience	-0.476**	0.490**	0.507**	0.256*

** Correlation is significant at 1% level. * Correlation is significant at 5% level.

Conclusions

The study was conducted in two summer tomato growing regions of Bangladesh. Results indicated that most of the summer tomato growers depended on chemical insecticides and followed frequent spraying. Very minimum numbers of the farmers (17.7%) maintained 6 or more days of pre-harvest interval period. Majority of the farmers (65.6%) did not use any kind of measuring tools for pesticide measurement, 73.3% of farmers sprayed insecticide without observing any insect in the field, 51.1 % of farmers did not use any kind of safety measure during pesticide spraying and only 22.2 % of the farmers were depended on government officials for insecticide related knowledge. Education, farm size annual income, training experience of the farmers had significant relationship with their insecticide use pattern.

References

Boedeker, W., M. Watts, P. Clausing, and E. Marquez. 2020. The global distribution of acute unintentional pesticide poisoning: estimations based on a systematic review. *BMC public health* **20 (1):** 1875.

Carson W. G., G. S. Kund and J. T. Trumble. 2012. Effect of insecticides on tomato insects. *Arthropod management tests*. **37(1):** E69.

Charles, W. B. and R. E. Harries. 1972. Tomato fruit set at high temperatures. *Canadian J. Plant. Sci.*. **52**: 497-507.

Depenbusch, L., T. Sequeros, P. Schreinemachers, M. Sharif, K. Mannamparambath, N. Uddin and P. Hanson. 2023. Tomato pests and diseases in Bangladesh and India: farmers' management and potential economic gains from insect resistant varieties and integrated pest management. *International Journal of Pest Management*. https://doi.org/10.1080/09670874.2023.2252760

FAO. 2011. Plant breeding and seed systems for rice, vegetables, maize and pulses in Bangladesh. FAO plant production and protection paper 207. Food and agriculture organization of the united nations, Rome.

Hajong, P., B. Sikder, S. Mondal and M. A. Islam. 2018. Adoption and profitability of summer tomato cultivation in Jashore district of Bangladesh. *Bangladesh J. Agril. Res.* **43(4):** 575-585.

Haque, M. A., M. Y.Ali, K. A. Kana, M. A. H. Sheikh, &A. Nahar. 2017. Assessment of farmers' indigenous knowledge and attitude towards summer tomato cultivation in Mymensingh region of Bangladesh. *Fundam. Appl. Agric.* 2(1): 212–217.

Hasan, S. S., A. Mohammad, M. K. Ghosh and M. I. Khalil. 2017. Assessing of farmers' opinion towards floating agriculture as a means of cleaner production: a case of Barisal district, Bangladesh. *BJAST*, **20***(6): 1-14.*

Hossain, M.A., M. A. Goffer, J. C. S. Chowdhury, M. S. Rahman and M. I. Hossain. 1999. A study on postharvest practices and loss of tomato in some selected areas of Bangladesh. *Bangladesh J. Agril. Res.* **24(2):** 299.

Kabir, K. H., M. A. Rahman, M. S. Ahmed, M. D. H. Prodhan and M. W. Akon. 2008. Determination of residue of diazinon and carbosulfan in brinjal and quinalphos in yard long bean under supervised field trial. *Bangladesh J. Agril. Res.* **33(3):** 503-513.

Kang, Y., Y. C. A. Chang, H. S.Choi, & M. Gu. 2013. Current and future status of protected cultivation techniques in Asia. *Acta Hortic*. ***987***: 33-40.

Karim, M. A., M. S. Rahman and M .S. Alam. 2009. Profitability of summer tomato cultivation in Jessore District of Bangladesh. *J. Agric. Rural Dev*. **7(1&2):** 73-79.

Lange, W. H., Bronson, L. 1981. Insect pests of tomatoes. *Annu rev entomol* **26:** 345-371.

Mohammad, A., M. M. Rahman, J. C. Barman, M. I. Kaysar and N. Sakib. 2020. Analysis of farmers' knowledge and attitude towards lac cultivation in Bangladesh. *Bangladesh J. Agril. Res*. **45**(4): 409-417.

Mohammad. A., S. N. Alam, M. R. U. Miah, M. R. Amin and H. B. Saif. 2018. Bio-rational management packages of jassid and shoot and fruit borer of okra. *Bangladesh J. Agril. Res.* **43(2):** 323-332.

Nair, R., & S. Barche. 2014. Protected cultivation of vegetables-present status and future prospects in India. *Indian J. Appl. Res.* **4(6):** 245-247.

Prodhan, M. D. H., M. W. Akon and S. N. Alam. 2016. Determination of pre-harvest interval for quinalphos, malathion, diazinon and cypermethrin in Major Vegetables. *J. Environ. Anal. Toxicol.* **8:(1).** http://dx.doi.org/10.4172/2161-0525.1000553

Rahman, A. K. M. Z., M. A. Haque, S. N. Alam, K. Begum and D. Sarker. 2016. Development of integrated pest management approaches against *Helicoverpa armigera* (Hubner) in tomato. *Bangladesh J. Agril. Res.* **41(2):** 195-205.

Rashid, M. H., N. K. Dutta, M. A. Sarkar, M. A. Zahid, A. K. Saha, M. M. E. Rahman. 2022. Integrated Management of Thrips-Mite And Borer Complex Attacking Chilli. *J Entomol. Zool. Stud.* **10(5):**216-220.

Schreinemachers, P., E. B. Simmons, and M. C. S. Wopereis. 2018. Tapping the Economic and Nutritional Power of Vegetables. *Global Food Security* **16**: 36–45.

Schreinemachers, P., M. Wu, M. N. Uddin, S. Ahmed, & P. Hanson. 2016. Farmer training in off-season vegetables: Effects on income and pesticide use in Bangladesh. *Food Policy*, **61**: 132-140.

Trading Economics. 2022. Available:http://www.tradingeconomics.com/bangladesh/gdpper-capita.

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GENOTYPE-ENVIRONMENT INTERACTION OF MAIZE HYBRIDS THROUGH AMMI MODEL AT DIFFERENT LOCATION IN BANGLADESH

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Abstract

Eighteen promising single crosses of maize and two check varieties (BHM-9 and 981) were assessed for genotype environment interaction (GEI) and stability for the selection of promising one(s) in three agro-ecological zones of Bangladesh. The AMMI (additive main effects and multiplicative interaction) model was used to analyze the GEI over three locations to select desired hybrid having higher yield and other potential attributes. Both genotypes (G) and environment (E) exhibited significant variation for all the characters studied. The environment of Gazipur and Ishwardi were poor but Dinajpur was favorable for the tested maize hybrids. Considering the mean, bi and S^2di value, all the genotypes showed differential response of adaptability under different environmental conditions. Hybrids E12 (BIL28 × BIL96) and E15 (BIL95 × BIL79) showed the higher yield as well as stable across locations regarding response and stability parameters.

Keywords: Stability, maize hybrids, heterosis, different locations

Introduction

Maize is one of the most important food grains in the world. It is the highest yielding grain crop having various uses. A great combination of high market demand with relatively low production cost, ready market and high yield has generated great interest among the farmers in maize cultivation. Day by day it is gaining popularity in the country due to vast demand, particularly for poultry industry. In 2020-21, maize was cultivated in 11.86 lac acre of land in Bangladesh and production was 41.16 lac mtons (BBS, 2022).

Multi-environment yield trials are commonly conducted to study the stability of the superior genotypes before releasing a variety. (Genotype × environment Interaction) is usually used when different genotypes are tested in a number of environments. The large GEI variation usually impairs the accuracy of yield estimation and reduces the relationship between genotypic and phenotypic values (Nachit *et al*., 1992). Numerous methods for multi-environment trials data have been developed to reveal the patterns of G×E interaction (Yamada, 1962), joint

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regression (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966) and currently AMMI ((additive main-effects and multiplicative interaction) (Gauch, 1992) and GGE biplot (genotype main effect plus genotype by environment interaction). AMMI model combines the analysis of variance of genotypes and the environment main effects with principal component analysis of the GEI into a unified approach (Gauch and Zobel, 1996). Crossa *et al.*, (1990) indicated that the AMMI model can be used to analyze the GEI to identify the superior hybrid maize genotypes and to select the best test environments for hybrid maize genotype evaluation. More precise GEI estimates can be obtained with the AMMI model which makes easier to interpret the results (Durate and Vencovsky, 1999). The objective of this study was to use the AMMI analysis model to assess the stability of some maize hybrids and verify the influence of a sample of environments at different locations of Bangladesh (Gazipur, Dinajpur and Ishwardi) in the productive performance of these hybrids.

Materials and Method

The experiment was conducted at three locations namely Gazipur, Dinajpur and Ishurdi during rabi 2017-18. Eighteen hybrids viz., E1 (CML551 × CLO2450), E2 (CLG1831 × CML223), E3 (BIL121 × BIL95), E4 (CML451 × CML285), E5 (CML429 × CML170), E6 (BIL153 × BIL95), E7 (CML191 × CML162), E8 (CML491 × CML502), E9 (BIL72 × BIL95), E10 (CML491 × CML502), E11 (CML431 × CML451), E12 (BIL28 × BIL96), E13 (CML285 × CML429), E14 (CML551× CML431), E15 (BIL95 × BIL79), E16 (CML170 × CML192), E17 (CML154 × CML502), E18 (BIL72 × BIL28) and two check varieties BHM-9 and 981 were evaluated in this study. The experiment was laid out in alpha lattice design with 2 replications. Seeds of each entry were sown in two rows, 4m long plots with 60 cm and 25 cm spacing between rows and hills, respectively. Seeds were sown at Gazipur on 27 November, Dinajpur on 23 November and Ishurdi on 12 December, 2017. One healthy seedling per hill was kept after thinning. Fertilizers were applied @ 250, 55, 110 40, 5 and 1.5 kg/ha of N, P, K, S, Zn and B respectively (FRG, 2018). Two border rows at both end of each replication was used for minimize the border effect. Data on days to pollen shedding, days to silking was recorded on whole plot basis. Ten randomly selected plants were used for recording observations on plant and ear height. All the plants in two rows were considered for plot yield and converted to t/ha.

The analysis of variance (ANOVA) was used and the GE interaction was estimated by the AMMI model (Zobel et al., 1988). In this procedure, the contribution of each genotype and each environment to the GE interaction is assessed by use of the biplot graph display in which yield means are plotted against the scores of the first principal component of the interaction (IPCA1). The computational program for AMMI analyses was developed by Duarte and Vencovsky (1999). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russel (1966). Significance of differences among bi value and unity was tested by t-test while between S^2di and zero by F-test. All the data were processed and analyzed using Crop Stat and PBTools (1.2) program.

Results and Discussion

Results of combined analysis of variance for five characters of twenty hybrids at three environments are presented in Table 1. The mean sum of squares for the genotypes were highly significant for all the traits which revealed the presence of genetic variability in the studied materials. Environments mean sum of squares were highly significant for all of the characters. The highly significant effects of environment indicated high differential genotypic response across the different environments. The variation in soil structure and moisture across the environments were considered as a major underlying causal factor for the G×E interaction. Environment relative magnitude was much higher than genotypic effect, suggesting that performance of each genotype was influenced more by environmental factors. Stability analysis for days to pollen shedding, days to silking, plant height, ear height and yields were presented in Table 2-6.

Table 1. Full joint analysis of variance including the partitioning of the G×E interaction of maize hybrids over three locations during 2017-18

Source of variation	Df	Mean sum of squares				
		Days to pollen shedding	Days to silking	Plant height (cm)	Ear height (cm)	Grain yield (t/ha)
Genotypes (G)	19	8.58**	8.85**	273.75**	189.92**	2.07**
Environment (E)	2	1312.18**	1350.24**	8076.71**	5302.88**	10.19**
Interaction G × E	38	4.00	3.75	137.53	108.90	1.51
AMMI Component 1	20	4.96**	4.80**	180.52**	126.34**	1.62**
AMMI Component 2	18	2.93**	2.58**	89.76**	89.52**	1.38*
G×E (Linear)	19	4.78**	2.86**	181.69**	127.51**	1.44**
Pool deviation	19	4.78	4.64	93.37	90.29	1.58
Pooled error	78	6.29	6.32	342.71	260.62	1.88

*P<0.05, **P<0.01.

Days to pollen shedding along with the value of phenotypic index (Pi,) regression coefficient (bi), deviation from regression (S^2di) are presented in Table 2. The genotypic mean for pollen shedding ranged from 94 to 99 days (BHM-9). Positive and negative Pi index observed in ten hybrids each. The hybrids which showed negative Pi index represent earliness. Talukder et al., (2016) found positive and negative Pi in their studied materials of maize hybrids. The hybrids E13, E14 and E5 exhibited comparatively a higher value for days to pollen shedding and E9 and E6 were for earliness. The bi and S^2di values for days to pollen shedding ranged from 0.73 to 1.28 and 0.06 to 17.96, respectively. Negative Pi index, non-significant regression coefficient (bi) and deviation from regression (S^2di), indicating the stability of these genotypes over all the environments with earliness.

Table 2. Stability analysis for days to 50% pollen shedding of maize hybrids over three environments

Genotype	Locations			Overall mean	Pi	bi	S^2di
	Gazipur	Dinajpur	Ishwardi				
E1	90	108	96	98	0.78	1.12	0.4
E2	92	104	97	97	0.45	0.73	1.84
E3	91	108	98	99	-0.21	1.05	1.66
E4	92	105	98	98	1.11	0.79	3.61
E5	92	106	99	99	1.95	0.87	5.38
E6	87	102	93	94	-2.88	0.93	0.99
E7	92	105	97	98	0.95	0.83	0.95
E8	92	104	91	96	-1.83	0.84	17.96
E9	88	103	91	94	-3.05	0.98	3.25
E10	88	106	91	95	-2.05	1.18	6.56
E11	92	105	95	97	-0.05	0.84	0.80
E12	90	108	93	97	-0.21	1.15	5.93
E13	91	110	97	99	2.83	1.23	0.06
E14	91	108	98	99	1.95	1.02	2.0
E15	90	107	97	98	0.93	1.05	1.66
E16	87	105	95	95	-1.71	1.10	3.36
E17	93	107	96	99	1.61	0.87	1.05
E18	91	107	95	98	0.95	1.05	0.34
E19 (BHM-9)	86	105	97	96	-1.21	1.10	13.71
E20 (981)	89	108	89	98	-1.88	1.28	0.40
Mean	90	106	95	97	-	-	-
E. Index (Ij)	-6.95	8.89	-1.93	-	-	-	-
LSD (0.05)	3.93	5.04	4.63	-	-	-	-

Pi= phenotypic indices, bi= regression co-efficient and S^2di=deviation from regression

Days to silking along with the value of phenotypic index (Pi), regression co-efficient (bi), deviation from regression (S^2di) is presented in Table 3. The regression co-efficient ranged from 0.73 to 1.28. The genotypic mean for days to silking ranged from 97 to 102 days. Eight hybrids showed positive Pi index while the rest twelve including checks showed negative Pi index for days to silking. The hybrids which exhibited negative Pi index represent earliness. The bi and S^2di values for days to silking ranged from 0.73 to 1.28 and 0.06 to 19.47, respectively. Negative phenotypic index (Pi), a non-significant regression coefficient (bi) and a non-significant deviation from regression (S^2di) value of hybrids considered to be stable across the environment.

Table 3. Stability analysis for days to 50% silking of maize hybrids over three environments

Genotype	Locations			Overall mean	Pi	bi	S^2di
	Gazipur	Dinajpur	Ishwardi				
E1	92	110	97	100	-0.02	1.12	0.4
E2	94	111	98	101	1.30	0.73	1.84
E3	94	110	99	101	1.30	1.05	1.66
E4	93	107	99	100	-0.02	0.79	3.61
E5	95	109	101	102	2.14	0.87	5.38
E6	92	103	95	97	-3.02	0.93	0.99
E7	94	109	98	100	0.47	0.83	0.95
E8	96	107	93	99	-1.19	0.84	17.96
E9	90	106	93	96	-3.52	0.98	3.25
E10	95	109	92	99	-1.02	1.18	6.56
E11	94	108	95	99	-0.69	0.84	0.80
E12	95	110	95	100	-1.90	1.15	5.93
E13	94	114	98	102	2.47	1.23	0.06
E14	95	111	99	102	0.92	1.02	2.00
E15	96	110	98	101	-0.07	1.05	1.66
E16	92	108	96	98	-1.35	1.10	3.36
E17	96	109	98	101	0.97	0.87	1.05
E18	96	112	96	101	1.64	1.05	0.34
E19 (BHM-9)	91	108	97	98	-1.92	1.10	13.71
E20 (981)	92	110	91	98	-2.02	1.28	19.47
Mean	94	109	96	100	-	-	-
E. Index (Ij)	-5.95	9.37	-3.42	-	-	-	-
LSD (0.05)	3.51	6.20	4.35	-	-	-	-

Plant height along with the value of phenotypic index (Pi), regression coefficient (bi), deviation from regression (S^2di) is presented in Table 4. The genotypic mean for plant height ranged from 182 (E7) to 223 cm (E17). Twelve hybrids showed positive Pi index while rest eight showed negative Pi index in plant height. The hybrids which showed positive Pi index represent taller and negative Pi index showing genotypes represent dwarf plant. Hybrid E13exhibited a negative phenotypic index (Pi), significant regression coefficient (bi) value and non-significant S^2di value, indicating a semi-dwarf plant type, and were highly responsive to the favorable environment of Gazipur and Ishwardi locations. The bi and S^2di values for plant height ranged from 0.31 to 1.80 and 0.22 to 443.07, respectively.

Table 4. Stability analysis for plant height (cm) of maize hybrids over three environments

Genotype	Locations			Overall mean	Pi	bi	S^2di
	Gazipur	Dinajpur	Ishwardi				
E1	215	220	184	206	5.00	0.63	443.07
E2	184	245	200	209	8.06	1.49	172.03
E3	187	242	173	201	-0.15	1.80	53.82
E4	190	230	200	207	5.67	0.98	71.93
E5	190	247	191	210	8.34	1.63	11.52
E6	178	230	191	200	-1.32	1.28	121.7
E7	193	262	213	223	21.67	1.67	286.1
E8	177	195	190	187	-13.99	0.31	93.2
E9	188	205	184	192	-8.82	0.54	2.89
E10	191	227	189	202	1.34	1.07	0.22
E11	201	220	190	204	2.50	0.71	50.75
E12	205	235	186	209	7.67	1.14	139.56
E13	178	237	173	196	-4.82	1.77*	1.00
E14	192	220	180	198	-3.65	0.98	50.36
E15	200	222	185	202	1.34	0.87	94.52
E16	180	197	183	187	-14.16	0.44	7.60
E17	182	197	168	182	-18.66	0.66	86.95
E18	188	202	193	195	21.67	0.33	13.41
E19 (BHM9)	195	232	205	211	9.50	0.92	70.54
E20 (981)	195	220	191	202	0.67	0.78	2.94
Mean	191	224	189	201	-	-	-
E. Index (Ij)	-10.57	23.17	-12.6	-	-	-	-
LSD (0.05)	29.73	44.75	24.66	-	-	-	-

Ear height along with the value of phenotypic index (Pi), regression coefficient (bi), deviation from regression (S^2di) is presented in Table 5. The genotypic mean for ear height ranged from 83 cm to 107 cm. Twelve hybrids showed positive Pi index while the rest eight showed negative Pi index for ear height. The hybrids which showed positive Pi index represent taller and negative Pi index signify dwarfness of plant. The bi and S^2di values for ear height ranged from 0.24 to 1.97 and 0.01 to 367.19, respectively.

Table 5. Stability analysis for ear height (cm) of maize hybrids over three environments

Genotype	Locations			Overall mean	Pi	bi	S^2di
	Gazipur	Dinajpur	Ishwardi				
E1	107	135	79	107	5.00	1.53	291.42
E2	83	140	90	104	8.50	1.86	62.33
E3	90	140	79	103	-0.15	1.97	18.71
E4	81	107	92	93	5.67	0.70	79.27
E5	95	115	84	98	8.34	0.91	44.95
E6	74	117	98	96	-1.32	1.04	348.2
E7	80	132	104	105	21.67	1.36	367.19
E8	86	100	95	93	-13.99	0.30	42.41
E9	77	97	75	83	8.82	0.74*	0.06
E10	84	117	86	96	1.34	1.12	10.21
E11	86	100	85	90	2.50	0.51*	0.01
E12	97	112	87	99	7.67	0.73	31.05
E13	92	130	77	99	-4.82	1.63	59.37
E14	98	122	82	101	-3.65	1.17	96.84
E15	102	127	86	105	1.34	1.21	88.71
E16	73	95	79	82	-14.16	0.64	27.72
E17	79	90	68	79	-18.66	0.58	47.16
E18	92	97	89	93	-6.65	0.24	4.38
E19 (BHM9)	93	115	101	103	9.50	0.61	48.81
E20 (981)	89	112	77	93	1.34	1.05	46.89
Mean	88	115	89	86	-	-	-
E. Index (Ij)	-10.57	23.17	-12.60	-	-	-	-
LSD (0.05)	25.58	41.23	25.28	-	-	-	-

Yield along with the value of phenotypic index (Pi), regression coefficient (bi), deviation from regression (S^2di) are presented in Table 6. The environmental mean and genotypic mean ranged from 9.51 t/ha to 10.88 t/ha and 8.28 t/ha to 11.82 t/ha, respectively. Among the hybrids, E2 (CLG1831 × CML223) produced the highest yield (11.82 t/ha). Ten genotypes showed positive phenotypic index while the other genotypes had negative phenotypic index for yield. Thus, positive phenotypic index represents the higher and negative represents the lower yield among the genotypes. The regression coefficient (bi) values of these genotypes ranged from -0.13 to 3.82. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering three stability parameters viz. mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The regression coefficient should be better considered as an indicator for genotypic responses to varying environments said by Solomon et al., (2008). Dinajpur was favourable environments for maize cultivation as they showed positive environmental index (Ij).

Table 6. Stability analysis for grain yield (t/ha) of maize hybrids over three environments

Genotype	Locations			Overall mean	Pi	bi	S^2di
	Gazipur	Dinajpur	Ishwardi				
E1	13.07	9.24	11.09	11.13	1.05	1.99	3.33
E2	11.56	12.04	11.85	11.82	1.73	-0.28	0.04
E3	11.78	9.28	9.44	10.17	0.09	1.87	0.32
E4	10.38	11.06	8.81	10.08	0.02	0.71	2.12
E5	10.69	8.58	9.01	9.43	-0.64	1.42	0.44
E6	11.72	10.05	6.67	9.48	-0.59	3.19	2.83
E7	10.51	11.07	8.27	9.95	-0.12	1.11	3.11
E8	11.62	9.75	9.41	10.26	0.18	1.66	0.02
E9	11.23	8.80	10.84	10.30	0.21	0.78	2.79
E10	11.93	8.58	13.26	11.26	1.17	0.03	11.58
E11	10.39	10.16	8.64	9.73	-0.34	1.02	0.74
E12	11.98	10.75	10.89	11.20	0.05	0.84	0.16
E13	12.66	8.98	7.32	9.65	-0.42	3.82	0.08
E14	10.15	10.44	9.39	9.99	-0.08	0.35	0.46
E15	11.89	10.88	10.36	11.04	0.69	1.26	0.16
E16	7.71	8.45	8.67	8.28	-1.79	-0.70*	0
E17	9.97	8.94	7.61	8.84	-1.23	1.55	0.35
E18	9.07	10.2	10.3	9.85	-0.22	-0.94*	0.02
E19 (BHM-9)	10.64	10.24	9.58	10.15	-0.58	0.45	1.21
E20 (981)	13.07	11.31	10.78	11.72	0.87	-0.13	0.17
Mean	10.88	9.84	9.51	10.08	-	-	-
E. Index (Ij)	-0.23	0.80	-0.56	-	-	-	-
LSD (0.05)	1.74	1.81	1.90	-	-	-	-

The biplot (Gabriel, 1971) has become a popular data conception tool in many scientific research areas, including psychology, medicine, business, sociology, ecology, and agricultural sciences. All types of biplots are useful conditional on the research objectives (Yan and Tinker, 2005). The AMMI biplot provide a visual expression of the relationship between the first interaction principal component axis (AMMI component 1) and mean of genotypes and environment (Fig. 1) as well as relationship of IPCA1 and IPCA 2. Genotypes with an IPCA1 score near zero displayed little interaction across the environments while genotypes with very high IPCA1 values showed considerable interactions across environments. From the Fig. 1 it was observed that hybrids E15 and E20 were high yielder as well as stable across locations because they had low interaction effects and suitable for all environments. Entry E5 and E18 had high interaction effects. The entries E1, E2 and E10 had high mean value and negative interactions which were suitable for unfavorable environment.

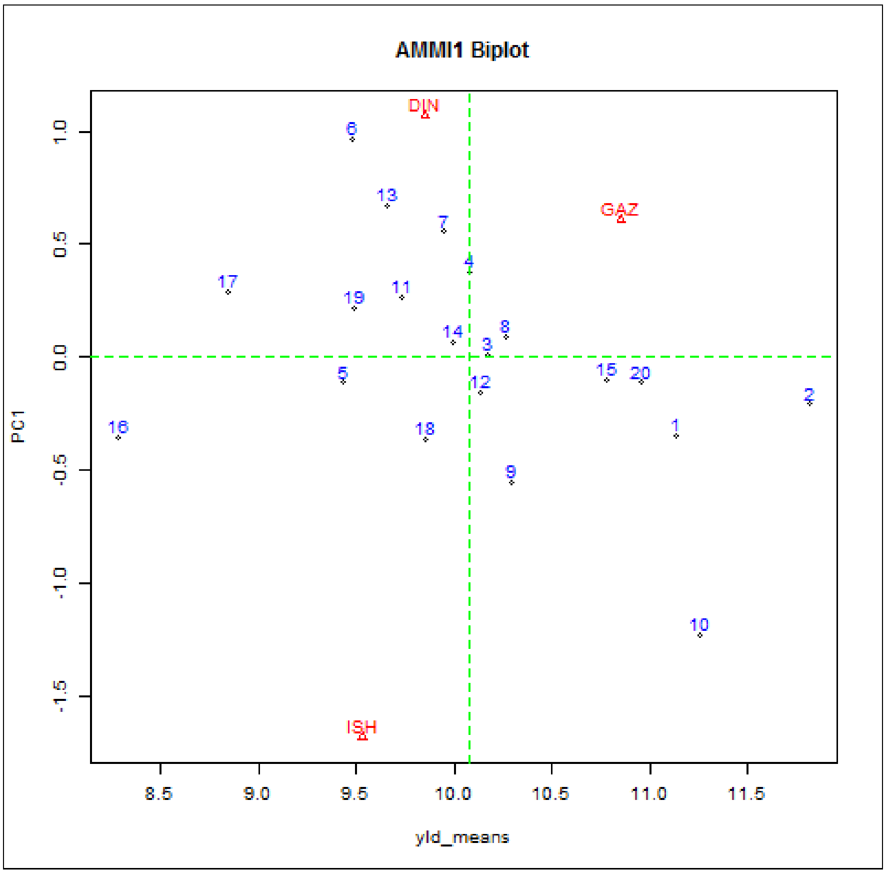

Fig.1. Biplot of the first AMMI interaction (IPCA1) score (Y –axis) plotted against mean yield (X- Axis) of twenty maize hybrids and three environments

Since IPCA2, scores also play a significant role in explaining the GEI; the IPCA1 scores were plotted against the IPCA2 score for further explanation of adaptation (Fig 2). The hybrid E12 and E15 were stable over locations for yield as located within the circle. This result can be observed directly in Figure 2 by the genotypes with high values in relation to “average mean coordination” (Yan et al., 2007). The performances of other hybrid were unstable due to their dispersed position.

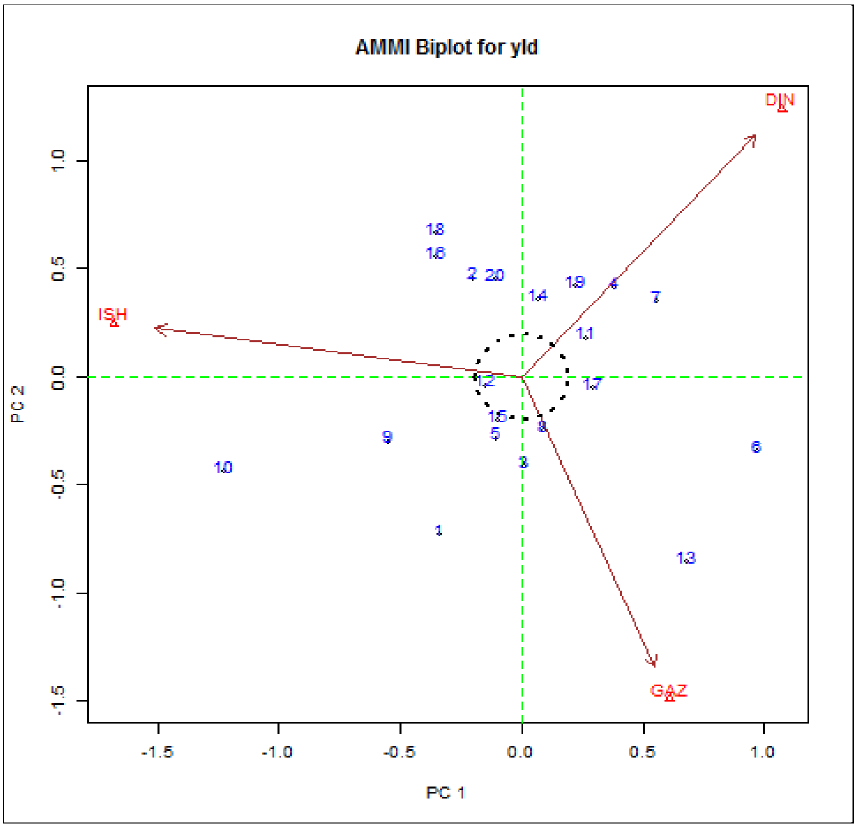

Fig. 2 Biplot of the first AMMI interaction (IPCA2) score (Y –axis) plotted against AMMI interaction (IPCA1) (X-Axis) of twenty maize hybrids and three environments.

The graph “which-won-where” enables to identify potential mega-environments (Yan et al., 2000 and Yan and Hunt, 2001). The genotypes that are utmost from the origin are connected with a straight line forming a polygon. The lines starting from the origin divide the polygon into several sectors. The genotype at the vertex of the polygon performs best in the environment falling within the sectors (Yan 2002; Yan and Tinker, 2006). The locations within one sector are the ones where the certain genotype had the best yield and can be considered as mega-environments only for that genotype where biplots for yields were shown in Fig 3. The hybrid E1 was high yielder and suitable only at Gazipur location. On the other hand, the genotype E10 was found high yielder and stable at Ishwardi and Dinajpur locations.

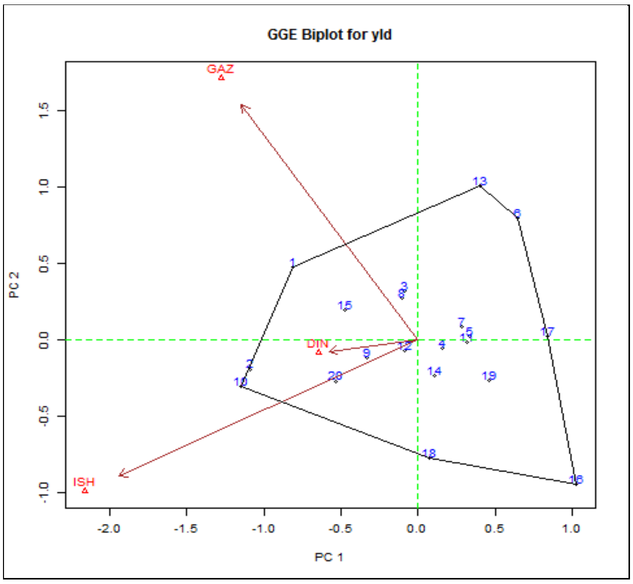

Fig. 3. GGE biplot showing "which won where" for yield of twenty maize hybrids and three environments

Conclusion

The AMMI statistical model has been used to determine the G×E interaction outline of grain yield of 20 promising hybrid maize varieties. The genotypes and environments had exhibited strong interaction. Considering the yield potentially and stability parameters, two tested hybrids viz. E12 (BIL28 × BIL96) and E15 (BIL95 × BIL79) showed the highest grain yield as well as stable for overall environments and need to be further evaluated in large plots before release as commercial hybrids across ecological zones in Bangladesh.

References

Bangladesh Bureau of Statistics (BBS). 2022. Statistics & Information Division (SID), Ministry of Planning, Government of The People's Republic of Bangladesh. p 133.

Crossa, J. 1990. Statistical analysis of multilocation trails. Advances in Agronomy. **44:** 55-85.

Duarte, J.B. and R. Vencovsky. 1999. Interação Genótipos x Ambientes: Uma introdução à análise .AMMI. Funpec,Ribeirão Preto, 60p. (sériemonografias, 9).

FAO. 2022. The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point. Main report. Rome.

https://doi.org/10.4060/cb9910en

Fertilizer Recommendation Guide (FRG). 2018. Bangladesh Agricultural Research Council. New Airport Road, Farmgate, Dhaka-1215. p79.

Eberhart, S.A. and W.A. Russel. 1966. Stability parameters for comparing varieties. *Crop Sci*. **6:** 36-40.

Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant breeding programme. *Australian J. Agric. Res.* **14(6):** 742-754.

Gauch, H.G. 1992. Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Elsevier, Amsterdam. p 278.

Gauch, H.G. and R.W. Zobel. 1996. AMMI analysis of yield trials. In: Genotype by Environment Interaction (Kang, M.S., Gauch, H.G., ed.). CRC Press, Boca Raton, FL. p 85122.

Gabriel, K.R. 1971. The biplot graphic display of matrices with application to principal component analysis. Biometrika **58:**453–467.

Talukder, M.Z.A., A.N.M.S. Karim, S. Ahmed and M. Amiruzzaman. 2016. Combining ability and heterosis on yield and its component traits in maize (Zea mays L.). *Bangladesh J. Agril. Res.* **41(3):** 565-577.

Nachit, M.N., M.E. Sorrells, R.W. Zobel, H.G. Gauch, R.A. Fischer and W.R. Coffman. 1992. Association of environmental variables with sites' mean grain yield and components of genotype environment interaction in durum wheat. *J. Genet. Breed.* **46:** 369-372.

Solomon, A., N. Mandefro and Z. Habtamu. 2008. Genotype-Environment Interaction and Stability Analysis for Grain Yield of Maize (Zea mays L.) in Ethiopia. *Asian J. Plant Sci.* **2:**163-169.

Yamada, Y. 1962. GEI and genetic correlation of the same trait under different environments. Japan J. Genet. **37:** 498-509.

Yan, W., L.A. Hunt, Q. Sheng and Z. Szlavnics. 2000. Cultivar evaluation and mega environment investigation based on the GGE biplot. *Crop Sci*. **40:** 597-605.

Yan, W. and L.A. Hunt. 2001. Interpretation of genotype× environment interaction for winter wheat yield in Ontario. Crop Sci. **41:** 19-25.

Yan, W. and N.A. Tinker. 2005. An integrated system of biplot analysis for displaying, interpreting, and exploring genotype-by-environment interactions. *Crop Sci*. **45:** 1004-1016.

Yan, W. and N.A. Tinker. 2006. Biplot analysis of multi-environment trial data: Principles and applications. Canadian *J. Plant Sci.* **86:** 623-645.

Yan W, M.S. Kang, B. Ma, S. Woods and P.L. Cornelious. 2007. GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Sci.* **47:** 643-653.

Zobel, R.W., M.J. Wright and H.G. Gauch. 1988. Statistical analysis of a yield trial. *J. Agron.,* **80:** 388-393.

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OVICIDAL AND LARVICIDAL EFFICACY OF FOUR BOTANICAL OILS AGAINST *SPODOPTERA FRUGIPERDA* (FAW) INFESTING MAIZE

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Abstract

The study was conducted to evaluate the efficacy of four botanical oils viz., neem, castor, black cumin and sesame against *Spodoptera frugiperda* in the laboratory during the period from November 2021 to March 2022. Tween-20 as an emulsifier was used with the tested oils at 5, 7.5 and 10% concentration along with an untreated control were evaluated for their toxic effect against *S. frugiperda.* The botanical oils gave profound toxic effect against eggs, first, second and third instar larvae of *S. frugiperda*. Each dose of different oils showed 100% inhibition of egg hatching and caused mortality of first instar larvae. Castor oil at 10% concentration gave the highest mortality (32.22 and 30.00%) while sesame oil at 5% showed the lowest (11.11 and 10.00%) against second and third instars larvae, respectively. Castor oil performed the highest toxicity of LD_{50} values against second (2015.8 mg kg^{-1}) and third (3525.5 mg kg^{-1}) instars larvae. Conversely, sesame oil performed the lowest toxicity of LD_{50} values against second (8391.3 mg kg^{-1}) and third (15222.3 mg kg^{-1}) instars larvae after 72 hours of exposure. Castor oil might be used as ovicidal and larvicidal ingredients against *S. frugiperda*.

Keywords: *Spodoptera frugiperda*, essential oils, mortality, maize.

Introduction

Maize (*Zea mays* L.) is the world's top-ranking cereals followed by wheat and rice due its higher importance as a staple food as well as animal feed and fuel (Abebe *et al.,* 2017). Globally it is called as a queen of cereals (Jeyaraman, 2017). Nutritionally grain contains 10% protein, 4% oil, 70% carbohydrate, 2-3% crude fibers, besides Vitamin A, E, nicotinic acid and riboflavin (Joshi, 2015). The farmers of Bangladesh are interested for maize cultivation for so many advantages such as suitable for cultivation, high demand, higher profit, cost effective, higher yield, feed for fish and livestock as well as soil fertility (Mottaleb *et al.,* 2018; Islam and Knan, 2021). But the production of maize is severely affected by a number of insect pests (Adhikari *et al.*, 2020; Azad *et al.*, 2020). Among them, *Spodoptera frujiperda* (Lepidoptera: Noctuidae) is commonly known as fall armyworm recognized as a highly invasive serious polyphagous pest of crops but regarded as major pest of maize (Hoy, 2013; Kandel and Poudel, 2020). *S. frugiperda* is native to tropical and subtropical regions of the America (Capinera,

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2017). It attacks more than 353 crops including maize, sorghum, soybean, cotton, potato, rice, millet, oat, barley, wheat, sugarcane, para grass and different types of vegetable crops (Bueno *et al.*, 2011). The caterpillars attack and feed on maize plants from seedling to cob formation, reducing photosynthetic activity, structural damages, plant lodging and slower reproduction causing enormous yield losses (Georgen *et al.*, 2016; Chimweta *et al.*, 2019).

At present farmers are solely relying on the use of synthetic pesticides against this pest for quick knockdown (Tumma and Chandrika, 2018). But the indiscriminate, overdoses and repeated use of chemicals against fall armyworm causes ecological imbalance, pest resurgence, residues, pests' outbreak, creates phytotoxicity, environmental risks, human health hazard and killing of beneficial organisms (Negrini *et al.*, 2019; Mweke *et al.*, 2020; Wan *et al.*, 2021). Therefore, researchers are globally now trying to adopt alternatives of chemicals to protect crop from insect infestation (Isman, 2006). It has been reported that essential plant oils viz., *Corymbia citriodora*, *Myrciaria dubi*a (Myrtaceae), *Lippia microphylla* (Verbenaceae), and *Piper umbelattum* as well as 1% oils of clove, lemon grass, basil, and rosemary demonstrated insecticidal activity against fall armyworm (Negrini *et al.*, 2019; Siddhartha *et al.*, 2019). Botanicals are safe, ecofriendly, economical, target-specific, varied modes of action, low toxicity, easily biodegradable, compatible with other low risk pesticides and no possibility of development of resistance with minimal adverse effects on agro ecosystems and human health as well (Abdelghany, 2015). So, an attempt was made to find out the ovicidal and larvicidal efficacy of four botanical oils such as black cumin, castor, neem and sesame against fall armyworm.

Materials and Methods

The experiment was carried out in the laboratory of the Department of Entomology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh from November 2021 to March 2022 following Completely Randomized Design (CRD).

Rearing of *S. frugiperda*

Mass culture of *S. frugiperda* was maintained in laboratory to obtain a large number of larvae for experimental use. Approximately 100 numbers of different instars healthy *S. frugiperda* larvae were collected from an infested maize field in Kornai and Sadipur village near the HSTU campus, Dinajpur. They were kept in plastic zipper bags (200 L × 175 W) (mm) and brought to the laboratory for rearing. The larvae were identified as the frons has white inverted "Y" line on the head, and four dark warts in a square form on the dorsal surface of the eighth abdominal segment (Prasanna *et al.*, 2018). The larvae were placed individually into ventilated plastic boxes (6 L × 6 W × 4 H) (cm) with 15-30 days old maize leaves (Hybrid Variety-Dalia 4455, Tista Seeds Company Private Ltd., Bangladesh). The rearing boxes were cleaned every day and supplied with new fresh maize leaves. The pre-pupal stage was transferred to a plastic box (6 L × 6 W × 4 H) (cm) one third filled with soil for pupation. The pupae were collected and kept into the oviposition cage (40 L × 40 W × 40 H) (cm). Sterile cotton soaked in sugar solution and honey (mixed with water) was placed on a Petri dish inside the cage as a food source for newly emerged adults. Male and female also verified as described by Ganiger *et al*., (2018) and allowed for mating. Forewing of male having gray brown with white triangular patch at the apical region and circular spot at the center of the wing while female has uniformly grayish brown forewings mottled with dark brown spots. The hind wings of both male and female with silvery white and a dark border.

Maize plants (8-10 days old) and piece of wax paper were introduced into rearing cage for oviposition. The eggs were collected every day after deposition. After 2-3 days, black-head-stage egg batches were collected and placed in sterile plastic box for hatching. Eggs were monitored daily up to hatching; as soon as the first instars emerged, they were introduced into several Petri dishes provided with tender and fresh maize leaves. Rearing was performed at ambient conditions (22 ± 5^0 C, 70 ± 10 RH) and repeated until a desired population was achieved for the experiment.

Treatments

The botanical oils of black cumin (*Nigella sativa*), castor (*Ricinus communis*), neem (*Azadirachta indica*) and sesame (*Sesamum indicum*) were collected from the local market. Three doses such as 10.0, 7.5, and 5.0% of each of the tested oils were prepared separately by diluting in water as solvent which emulsified by using one drop of tween-20 with the help of micro pipette (Dragon lap China, model: C40038142).

Ovicidal test

The eggs (1 to 2-days-old) of *S. frugiperda* were collected from the culture. A cohort of 26-33 eggs was separated under the Stereo Microscope by removing excess eggs with a camel hairbrush before applying treatments. The cohort of eggs was sprayed with each concentration of each oil separately by hand sprayer and air dried for 30 minutes then placed into ventilated plastic boxes (6 L × 6 W × 4 H) (cm). The distilled water was applied for untreated control. Three replications were maintained with 30 eggs for each concentration. The numbers of hatched and non-hatched eggs were recorded daily until 7 days after treatment with the help of magnifying glass.

Toxicity test against larva

First to third instars larvae were selected to determine the toxicity of the botanical oils against *S. frugiperda* by leaf dipping method. Freshly collected young (15-30-

days-old) maize leaves were treated separately with each concentration of each oil and air dried for 30 minutes. The treated leaves were placed into ventilated plastic boxes (6 L × 6 W × 4 H) (cm) and a larva of each of 1^{st}, 2^{nd} and 3^{rd} instars was placed separately with a fine camel hair brush. Three replications were maintained providing 10 larvae per replication for each concentration. Leaves treated with water only maintained for control treatments with equal number of larvae. Larval mortality was observed and recorded up to the 72 hours at 24 hours intervals after treatment. A larva was considered dead if it could not respond after being gently touched or itself after being placed on its dorsal surface with a camel hair brush. The percent mortality was corrected by the Abbott's (1987) formula.

$$P = \frac{P' - C}{100 - C} \times 100$$

Where, P = Corrected mortality (%), P′=Observed mortality (%), C=Mortality (%) at control

Statistical analysis

The data were analyzed statistically based on Completely Randomized Design (CRD) with the help of MSTAT-C, IBM SPSS Statistics version 25.0 and mean values were separated by Duncan's New Multiple Range Test (DMRT).

Results

Toxic effect of botanical oils on egg hatchability

Toxicity effects of botanical oils on egg hatchability of *S. frugiperda* were found similar among the treatments at different times after intervals. No neonate larva was hatched from treated eggs of *S. frugiperda* at different doses of botanical oils.

Toxic effect of botanical oils against the first instar larvae

Toxic effects of botanical oils on the mortality of first instar larvae of *S. frugiperda* were found similar among the treatments. Treated larvae of first instar were died at different doses of botanical oils.

Toxic effect of botanical oils against the second instar larvae

Mortality of second instar larvae of *S. frugiperda* in four botanical oils at three doses and their efficacy differed significantly at different time intervals (Tables 1-3). The highest mean mortality (29.26%) was recorded in castor oil ($p < 0.00$, $F = 214.42$, $df = 4$) as against the lowest (14.44%) in sesame oil having significant difference between them (Table 1). In case of dose effects, significantly ($p < 0.00$, $F = 29.35$, $df = 2$) the highest mean mortality (21.33%) was found at 10% concentration as against the lowest (14.67%) at 5% concentration (Table 2). In the interaction effects of oils and doses, significantly ($p < 0.01$, $F = 2.72$, $df = 12$) the highest mortality (32.22%) was observed at 10% concentration of castor oil while the lowest (11.11%) at 5% of sesame oil having significant difference between them (Table 3). But no mortality was recorded in the untreated control at 24, 48 and 72 hours after treatments (HATs).

Table 1. Toxic effect of botanical oils against the second instar larvae of *S. frugiperda* at different hours after treatment

Treatments (oils)	Mortality (%) at different HATs			Average mortality (%)
	24	48	72	
Neem	13.33 ab	21.11 a	45.56 a	26.67 b
Castor	16.67 a	23.33 a	47.78 a	29.26 a
Black cumin	11.11 b	16.67 b	31.11 b	19.63 c
Sesame	11.11 b	11.11 c	21.11 c	14.44 d
Untreated control	0.00 c	0.00 d	0.00 d	0.00 e
CV (%)	34.96	29.19	19.83	13.24

CV = Coefficient of variation, HATs = Hours after treatments, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Table 2. Toxic effect of different doses of botanical oils against second instar larvae of *S. frugiperda* at different hours after treatment (Interaction of doses and times)

Doses (%)	Mortality (%) at different HATs			Average mortality (%)
	24	48	72	
5	8.66 b	10.67 c	24.67 b	14.67 c
7.5	10.00 ab	14.67 b	29.33 a	18.00 b
10	12.67 a	18.00 a	33.33 a	21.33 a
CV (%)	34.96	29.19	19.83	13.24

CV = Coefficient of variation, HATs = Hours after treatment, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Toxic effect of botanical oils against the third instar larvae

Toxic effects of botanical oils, doses and their efficacy differed significantly among the treatments against the third instar larvae (Tables 4-6). Of tested oils, significantly ($p < 0.00$, $F = 209.64$, $df = 4$) the highest mean mortality (27.04%) was recorded in castor oil while the lowest (11.85%) in sesame oil (Table 4). Irrespective of oils among the doses, significantly ($p < 0.00$, $F = 33.33$, $df = 2$) the highest mean mortality (18.45%) was found at 10% concentration while the lowest (12.00%) at 5% concentration (Table 5). Due to the interaction effects of botanical oils, doses and times of intervals significantly ($p < 0.00$, $F = 3.58$, $df = 12$) the highest mean mortality (30.00%) was observed at 10% concentration of castor oil as against the lowest (10.00%) at 5% concentration of sesame oil (Table 6). Conversely, no mortality was recorded in the untreated control treatment at 24, 48 and 72 hours after water spraying.

Table 3. Interaction effect of botanical oils and doses on mortality of second instar larvae of *S. frugiperda* at different hours after treatment

Treatments (oils)	Doses (%)	Mortality (%) at different HATs			Average mortality (%)
		24	48	72	
Neem	5	10.00 b	13.33 de	43.33 ab	22.22 de
	7.5	13.33 b	23.33 abc	46.67 a	27.78 bc
	10	16.67 ab	26.67 ab	46.67 a	30.00 ab
Castor	5	13.33 b	16.67 cde	46.67 a	25.56 cd
	7.5	16.67 ab	23.33 abc	50.00 a	30.00 ab
	10	20.00 a	30.00 a	46.67 a	32.22 a
Black cumin	5	10.00 b	13.33 de	20.00 c	14.44 f
	7.5	10.00 b	16.67 cde	33.33 b	20.00 e
	10	13.33 b	20.00 bcd	40.00 ab	24.44 cd
Sesame	5	10.00 b	10.00 e	13.33 c	11.11 f
	7.5	10.00 b	10.00 e	16.67 c	12.22 f
	10	13.33 b	13.33 de	33.33 b	20.00 e
Untreated control	-	0.00 c	0.00 f	0.00 d	0.00 g
CV (%)	-	34.96	29.19	19.83	13.24

CV = Coefficient of variation, HATs = Hours after treatments, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Probit analysis for toxic effect of botanical oils

The results of the probit analysis for the estimation of LD_{50} values, χ^2 values and their 95% fiducial limits at 24, 48 and 72 HATs of FAW larvae are presented in Tables 7-8. The highest LD_{50} values were calculated as 1234092.3, 73896.8 and 8391.3 mg kg^{-1} for sesame oil but the lowest as 83841.1, 10180.0 and 2015.8 mg kg^{-1} at 24, 48 and 72 HATs, respectively for castor oil for 2^{nd} instar larvae (Table 7). Similarly, the highest LD_{50} values were calculated as 1234092.3 mg kg^{-1} at 24 HATs for neem, black cumin and sesame oil while 1265469.5 and 15222.3 mg kg^{-1} at 48 and 72 HATs, respectively for sesame oil for 3^{rd} instar larvae (Table 8). Conversely, the lowest LD_{50} values were calculated as 90495.0, 11829.4 and 3525.5 mg kg^{-1} at 24, 48 and 72 HATs, respectively for castor oil. The order of toxicity of oils was found as castor > neem > black cumin > sesame at 24, 48 and 72 HATs.

Table 4. Toxic effect of botanical oils against third instar larvae of *S. frugiperda* at different hours after treatment

Treatments (oils)	Mortality (%) at different HATs			Average mortality (%)
	24	48	72	
Neem	11.11 a	14.44 b	42.22 a	22.59 b
Castor	13.33 a	22.22 a	45.56 a	27.04 a
Black cumin	11.11 a	12.22 bc	22.22 b	15.19 c
Sesame	11.11 a	10.00 c	14.44 c	11.85 d
Untreated control	0.00 b	0.00 d	0.00 d	0.00 e
CV (%)	35.71	25.31	20.75	14.12

CV = Coefficient of variation, HATs = Hours after treatments, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Table 5. Toxic effect of doses of botanical oils against third instar larvae of *S. frugiperda* at different hours after treatment (Interaction of doses and times)

Doses (%)	Mortality (%) at different HATs			Average mortality (%)
	24	48	72	
5	8.00 b	9.33 b	18.67 b	12.00 c
7.5	8.66 b	11.33 b	26.67 a	15.55 b
10	11.33 a	14.67 a	29.33 a	18.45 a
CV (%)	35.71	25.31	20.75	14.12

CV = Coefficient of variation, HATs = Hours after treatments, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Table 6. Interaction effect of botanical oils and doses on mortality of third instar larvae of *S. frugiperda* at different hours after treatment

Treatments (oils)	Doses (%)	Mortality (%) at different HATs			Average mortality (%)
		24	48	72	
Neem	5	10.00 b	10.00 d	30.00 e	16.67 cd
	7.5	10.00 b	13.33 cd	46.67 abc	23.33 b
	10	13.33 ab	20.00 b	50.00 ab	27.78 a
Castor	5	10.00 b	16.67 bc	40.00 cd	22.22 b
	7.5	13.33 ab	20.00 b	53.33 a	28.89 a
	10	16.67 a	30.00 a	43.33 bc	30.00 a
Black cumin	5	10.00 b	10.00 d	13.33 fg	11.11 ef
	7.5	10.00 b	13.33 cd	20.00 f	14.44 de
	10	13.33 ab	13.33 cd	33.33 de	20.00 bc
Sesame	5	10.00 b	10.00 d	10.00 g	10.00 f
	7.5	10.00 b	10.00 d	13.33 fg	11.11 ef
	10	13.33 ab	10.00 d	20.00 f	14.44 de
Untreated control	-	0.00 c	0.00 e	0.00 h	0.00 g
CV (%)	-	35.71	25.31	20.75	14.12

CV = Coefficient of variation, HATs = Hours after treatments, within column mean values followed by different letter(s) are significantly different by DMRT at 5% level of probability

Table 7. Probit analysis of treated botanical oils against the second instar larvae of *S. frugiperda*

Treatments (oils)	No. of insects used	LD_{50} (mg/kg)	95% confidence limits lower	95% confidence limits upper	χ^2 values with 1 *df*
24 HATs					
Neem	30	90495.0	-		0.009
Castor	30	83841.1	-		0.003
Black cumin	30	105788.7	-		0.250
Sesame	30	1234092.3	-		0.069
48HATs					
Neem	30	11966.5	-		0.043
Castor	30	10180.0	-		0.016
Black cumin	30	20163.7	-		0.163
Sesame	30	73896.8	-		0.002
72HATs					
Neem	30	3535.1	79.9-5014.9		0.017
Castor	30	2015.8	-		0.890
Black cumin	30	5830.7	2849.8-7210.5		0.125
Sesame	30	8391.3	6027.6-5302395.1		0.607

Values were based on three concentrations, three replications of 10 insects of each, HATs = Hours after treatments, χ^2 = Goodness of fit, the tabulated value of χ^2 is 3.84 (*df* =1 at 5% level)

Table 8. Probit analysis of treated botanical oils against the third instar larvae of *S. frugiperda*

Treatments (oils)	No. of insects used	LD_{50} ($mgkg^{-1}$)	95% confidence limits lower	95% confidence limits upper	χ^2 values with 1 *df*
24 HATs					
Neem	30	1234092.3	-		0.069
Castor	30	90495.021	-		0.009
Black cumin	30	1234092.3	-		0.069
Sesame	30	1234092.3	-		0.069
48 HATs					
Neem	30	22415.4	-		0.169
Castor	30	11829.4	-		0.179
Black cumin	30	73896.8	-		0.002
Sesame	30	1265469.5	-		0.043
72HATs					
Neem	30	5035.0	2099.5-6241.9		0.190
Castor	30	3525.5	179.6-4952.5		0.280
Black cumin	30	7059.5	5248.4-9121.8		0.200
Sesame	30	15222.3	-		0.156

Values were based on three concentrations, three replications of 10 insects of each, HATs = Hours after treatments, χ^2 = Goodness of fit, the tabulated value of χ^2 is 3.84 (*df* =1 at 5% level).

Discussion

Present results revealed that the tested oils had profound toxic effects against the first, second and third instars larvae of *S. frugiperda*. Each doses of different oils showed 100% inhibition of eggs hatchability and caused mortality in case of first instar larvae. Parallel results were cited by Guedes *et al.*, (2020) who found that *azadirachtin* suppressed embryonic development of eggs, altered egg morphology, changed chorion structure and caused embryonic damage. Shu *et al.*, (2021) observed that azadirachtin also acted as growth inhibition and mortality against the larvae of *S. frugiperda*.

The second and third instars larval mortality by the tested oils were observed and found doses and time exposure dependent. The larval mortality percentages were increased proportionally with the increase of time intervals. Present results are in line with those of Silvestre *et al.*, (2021), Babendreier *et al.*, (2020), Lin *et al.*, (2020), Zhou *et al.*, (2020), Hruska (2019), Sisay *et al.*, (2019), Barbosa *et al.*, (2018), Lima *et al.*, (2010) and Farias-Rivera *et al.,* (2002). They experienced that neem oil, seed, and leaf powder caused 70% larval mortality of *S. frugiperda*. Parallel results were also obtained by Varella *et al.*, (2015). Present findings are also comparable with those of Farias- Rivera *et al.*, (2002). They mentioned that castor oil and vicinine extracts from the seeds and leaves of *Ricius communis* (L.) were effective, while methanol extract from residual fiber of *Zea diploperennis* caused high mortality and adversely affected the pupal size of *S. frugiperda*. Hruska (2019) observed another plant-based material as *Eucalyptus urograndis* oil and *Carica papaya* (L.) seeds and were found highly effective in inducing *S. frugiperda* mortality compared to the synthetic insecticide malathion. Again, Barbosa *et al.*, (2018) concluded that the oils extracted from *Corymbia citriodora, E. urograndis* had significant effects in protecting maize from *S. frugiperda* larvae, while oils extracted from turmeric, clove palmarosa, and neem were highly efficacious against first and second instars larvae of *S. frugiperda.*

The biological activities of tested oils can be attributed to several alkaloid contents as an insecticidal potency (Ghosal *et al*., 2005; Alice *et al*., 2007). The alkaloids like ricinin is present in castor oil (Prakash and Rao, 1996). The other phytochemicals as alkaloids, terpinoids, steroids, glycosides as morgason-O, nimbin, nimbidine, meliacins present in neem oil (Rejesus *et al.*, 1990) while sesamin in sesame oil (Prakash and Rao, 1996). Again, black cumin seeds characterized both qualitatively and quantitatively for phytochemicals, proved the secondary metabolites as bio-pesticide potentials against *D. maculatus* (Bob-Manuel and Ukoroije, 2020). It contains several phytoconstituents as phenols, alkaloid, flavonoid, terpenoid, saponin, tannin, cardiac glycoside, anthraquinone, steroid and oxalate in different proportion. All these chemical compounds might associate with insecticidal potency. The biological activity of oils interferes with normal respiration of insects resulting accelerate suffocation leading to death (Schoonhoven, 1978).

Novel innovative research illustrated that diverse plant products have been tried by several researchers with a good degree of success against *S. frugiperda* (Lin *et al.*, 2020; Zhou *et al.*, 2020). These findings are in line with that of Lima *et al.*, (2010). They found that leaves of *Ageratum conyzoides* potential against fall armyworm. Some scholars opined that botanical oils have also broad-spectrum insecticidal activity affecting insect nervous and defense systems (Hold *et al*., 2000; Isman, 2000; Ketoh, 2004). These chemical compounds might associate with deterrent, repellent and anti-feeding actions consequently leads to mortality against the tested caterpillars of *S. frugiperda*. The present findings are comparable with various researchers (Silvestre *et al.*, 2021; Babendreier *et al.*, 2020; Sisay*et al.*, 2019). They experienced those essential oils of neem, zinger, based products causing toxicity to larvae of *S. frugiperda* has induced larval growth inhibition under laboratory conditions might accelerate fatality.The present results are in parallel with those of Silvestre *et al.*, (2021). They cited that essential botanical oil of *Crocus speciosus* induced low larval mortality (33.2%) at 0.8% v/v while 86.6% at 1.0% v/v but caused 100% at 1.5% v/v at 72 hours of exposure in *S. frugiperda*.

The LD_{50} values of the tested botanicals oils have also been calculated to compare the efficacy. Probit results indicated that all the tested oils would more or less effective against the second and third instar larvae of *S. frugiperda*. But castor oil had the most effective followed by the neem oil. The present results are in line with the findings of Lima *et al.*, (2020). They opined those essential botanical oils from *Lippia sidoides*, and thymol showed LD50 values of 3.21 and 4.91 mg g^{-1}, respectively on *S. frugiperda*. Dutra *et al.*, (2020) also observed the insecticidal potency of three essential oils of *Piper corcovadensis*, *P. marginatu*, and *P. arboretum* on *S. frupigerda* and found LD_{50} values as 3.58, 4.18, and 10.91 mg g^{-1}, respectively. Outcome of the present findings are comparable with those of Tithi *et al.* (2021). They experienced that botanical oil of castor *R. communis* at 10% performed the highest toxicity of LD_{50} value as 6.4 mg kg^{-1} against the 3^{rd} instar grub of *Epilachna dodecastigma* after 72 hours of exposure.

Based on efficacy of the tested botanicals, castor oil was found the most effective against the eggs and 1^{st} to 3^{rd} instar larvae of *S. frugiperda*. However, further studies need to be conducted to isolate and evaluate the active compound of trialed oils with its mode of action.

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References

Abbott, W. S. 1987. A method of computing the effectiveness of an insecticide. *J. Am. Mosq. Control Assoc*. **3**: 302 - 303.

Abdelghany, T. M. 2015. Entomopathogenic Fungi and Their Role in Biological Control. OMICS Group e Books. pp. 1 - 41.

Abebe, Z., C. Dabala and T. Birhanu. 2017. System Productivity as Influenced by Varieties and Temporal Arrangement of Bean in Maize-climbing Bean Intercropping. *J. Agron*. **16**: 1 - 11.

Adhikari, K., S. Bhandari, L. Dhakal and J. Shrestha 2020. Fall armyworm (*Spodoptera frugiperda*): A threat in crop production in Africa and Asia. *Peruv. J. Agron*. **4(3):** 121 - 133.

Alice J., R. P. Sujeetha, N. Mathurani and L. Nadarajan. 2007. Effect of indigenous plant products and oils against the pulse beetle, *Callosobruchus chinensis* (L.) on stored blackgram. *Asian J. Biol. Sci*. **2(1&2):** 203 - 204.

Azad, A.B., M. Miaruddin, M. A. Ohab, M. H. R. Shak, B. L. Nagh and M. H. H. Rahman. 2020. KRISHI PROJUKTI HATBOI (Handbook on Agro-Technology). 9th edition Bangladesh Agricultural Research Institute. Gazipur-1701. Bangladesh.

Babendreier, D. L. K., P. Agboyi, M. Beseh, J. Osae, S. E. K. Nboyine, J. O. Ofori, V. A. Frimpong, M. Clottey and M. Kenis. 2020. The efficacy of alterna- tive, environmentally friendly plant protection measures for control of fall armyworm, *Spodoptera frugiperda,* in maize. *Insects*. **11**: 240.

Barbosa, M. S., B. B. Dias, M. S. Guerra and G. H. Costa Vieira. 2018. Applying plant oils to control fall armyworm (*Spodoptera frugiperda*) in corn. *Aust. J. Crop Sci*. **12**(4): 557 - 62.

Bob-Manuel, R. B. and R. Ukoroije. 2020. Insecticidal property of black seed (*Nigella sativa*) powder as an eco-friendly management of skin beetle *Dermestes maculatus* (Coleoptera: Dermestidae) in Atlantic codfish *Cadus morhua* (Gadiformes: Gadidae). *Asian J. Adv. Agric. Res.* **13(3):** 47 - 56. DOI:10.9734/ajaar/2020/v13i330108

Bueno, R. C. O. F., A. F. Bueno, F. Moscardi, J. R. Parra and C. B. Hoffmann-Campo. 2011. Lepidopteran larvae consumption of soybean foliage: basis for developing multiple-species economic thresholds for pest management decisions. *Pest Manag. Sci*. **67**: 170 -174.

Capinera, J. L. 2017. *Featured Creatures: Fall Armyworm*. Entomology and Nematology Circular, University of Florida IFAS. http://entnemdept.ufl.edu/creatures/field/ fall_army-worm.htm.

Chimweta, M., I. W. Nyakudya, L. Jimu and A. B. Mashingaidze. 2019. Fall armyworm [*Spodoptera frugiperda* (JE Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *Int. J. Pest Manag*. **66(2):** 1 - 13.

Dutra, K., V. Wanderley-Teixeira, C. Guedes, G. Cruz, D. Navarro, A. Monteiro, A. Agra, C. L. Neto, and A. Teixeira. 2020. Toxicity of essential oils of leaves of plants from the genus piper with influence on the nutritional parameters of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *J. Essent. Oil-Bear*. **23**: 213 - 229.

Farias-Rivera, L. A., J. L. Hernandez-Mendoza, J. Molina-Ochoa and A. Pescador-Rubio. 2002. Effect of leaf extracts of teosinte, *Zea diploperrennis* L. and a Mexican maize variety, Criollo "uruapeno" on the growth and survival of the Fall armyworm (Lepidoptera: Noctuidae). *Fl. Entomol*. **86**: 239 - 343.

Goergen, G., P. L. Kumar, B. Sagnia, Sankung, T. Abou and T. Manuele. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PLOS ONE*. **11(10):**1 - 9.

Ghosal, T. K., S. K. Senapati and D. C. Dev. 2005. Pesticidal effect of edible and non-edible oils on pulse beetle, *Callosobruchus chinensis* (Coleoptera: Bruchidae). *J. Ecobiol*. **17(4):** 321 - 327.Global

Guedes, C. A, V. W Teixeira, K. A. Dutra, D. M. A. Navarro, G. S. Cruz, C. J. C. L. Neto, A. A. Correia, J. M. Sandes, F. A. Brayner and L. C. Alves. 2020. Evaluation of *Piper marginatum* (Piperales: Piperaceae) oil on the embryonic development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in comparison to formulated products. *J. Econ. Entomol*. **13**: 239 - 248.

Hold, K. M., N. S. Sirisoma, T. Ikeda, T. Narahashi and J. E. Casida. 2000. Thujone (the bioactive component of absinthe): Aminobutyric acid type a receptor modulation and metabolic detoxification. *Proc. Nat. Academy Sci*. **97**: 3826 - 3831.

Hoy, M. 2013. Insect Population ecology and Molecular Geetics. In M. Hoy, Insect Molecular Genetics. 3rd Edn. pp. 591 - 659.

Hruska, A. J. 2019. Fall armyworm (*Spodoptera frugiperda*) management by smallholders. CABI Reviews. **14(43):** 1 - 11.

Islam, S. and M. R. I. Khan 2021. The Potentiality of major crops by products as livestock feed in Bangladesh, A Review. *Adv. Anim. Vet. Sci*. **9(12):** 2103 - 2115.

Isman, M. B. 2006. Botanical insecticides, Deterrents, and Repellents in Modern Agriculture and an Increasingly Regulated World. *Annu Rev. Entomol*. **51**: 45 - 66.

Isman, M. B. 2000. Plant essential oils for pest and disease management. *Crop Prot*. **19**: 603 -608. Jeyaraman, S. 2017. Field Crops Production and Management Vol I. New Delhi: Oxford and IBH Publishing Company Private Limited.

Oso, A. A. and A. O. Ashafa. 2021. Nutritional Composition of Grain and Seed Proteins. DOI:10.5772/intechopen.97878

Kandel, S. and R. Poudel. 2020. Fall Armyworm (*Spodoptera frugiperda*) in Maize: An emerging threat in Nepal and its management. *Int. J. Appl. Sci. Biotechnol*. **8(3):** 305 - 309.

Lima, A. P.S., E. D. R. Santana, A. C.C. Santos, J. E. Silva, G. T. Ribeiro, A. M. Pinheiro, I. T.B.F. Santos, A. F. Blank, A. P. A. Araújo and L. Bacci. 2020. Insecticide activity of botanical compounds against *Spodoptera frugiperda* and selectivity to the predatory bug *Podisus nigrispinus*. Crop Prot. **136**: 105230, https://doi.org/10.1016/j.cropro.2020.105230

Lima, R. K., M. D. Cardoso, J. C. Moraes, M. A. Andrade, B. A. Melo and V. G. Rodrigues. 2010. Chemical characterization and insecticidal activity of the essential oil leaves of *Ageratum conyzoides* L. on fall armyworm (*Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae). *J. Biosci*. **26**: 1 - 5.

Lin, S., K. Liu, R. Wang, B. Liu, Y. Zhang, J. Wu and Z. Zhang. 2020. Indoor toxicity of azadirachtin to *Spodoptera frugiperda* and its control effect in field. *J. South China Agric*. **41**: 22 - 27.

Mottaleb, M. A., G. Kruseman and O. Erenstein. 2018. Determinants of maize cultivation in a land-scarce rice-based economy: The case of Bangladesh. *J. Crop Improv*. **32**: 453 - 476.

Mweke, A., K. S. Akutse, C. Ulrichs, K. K. M. Fiaboe, N. K. Maniania and S. S. Ekesi. 2020. Integrated management of *Aphis craccivora* in cowpea using intercropping and entomopathogenic fungi under field conditions. *J. Fungi*. **60(6):** 1 - 20.

Negrini, M., E. Gomes, E. G. Fidelis, D. A. Schurt, F. Silva, R. S. Pereira,H. Ribeiro and H. R. Bizzo. 2019. Insecticidal activity of essential oils in controlling fall armyworm, *Spodoptera frugiperda*. *Arq. Inst. Biol.* **86**: 1 - 9.

Prakash, A. and J. Rao 1996. Botanical Pesticides in Agriculture, CRC Press, New Delhi, India, 480p.

Prasanna, B. M., J. E. Huesing, R. Eddy and V. M. Peschke. 2018. Fall armyworm in Africa: a guide for integrated pest management. USAID CIMMYT. **7**: 109.

Resjusus, B. M., H. A. Mani, K. Ohsawa and Yamamoto I. 1990. Insecticidal actions of several plants to *Callosobruchus chinensis* (L.) in Fujii. Bruchids and Legumes: Ecology and Co-evolution, Kluwer Publishers, Dordrecht, The Netherlands. pp. 53 - 62.

Schoonhoven, A.V. 1978. Use of vegetable oils to protect stored beans from bruchid attack. *J. Econ. Entmol.* **71**: 254 - 256.

Shu, B., H. Yu, Y. Li, H. Zhong, X. Li, L. Cao and J. Lin 2021. Identification of azadirachtin responsive genes in *Spodoptera frugiperda* larvae based on RNA-seq. *Pestic. Biochem. Phys*. **172**: 104 - 745.

Siddhartha, K., C. Chinniah and M. Shanthi. 2019. *In vitro* bioassay of certain botanical oils for their efficacy against maize fall army worm (J.E. Smith) *Spodoptera frugiperda* (Noctuidae: Lepidoptera). *J. Entomol. Zool. Stud*. **7**(5): 606 - 609.

Silvestre, W. P., C. B. Vicenço, R. A. Thomazoni and G. F. Pauletti. 2021. Insecticidal activity of *Callistemon speciosus* essential oil on *Anticarsia gemmatalis* and *Spodoptera frugiperda. Int. J. Trop. Insect Sci*. **42**: 1307 - 1314.

Sisay, B., T. Tefera, M. Wakgari, G. Ayalew and E. Mendesil. 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda* in maize. *Insects*. **10**: 45 - 58.

Tithi, D.A., M.A.Alim, H.F. El Taj, M.A. Hossain, and A.T.M.S. Islam, 2021. Potency of natural oils against the grub of epilachna beetle on bitter gourd. *Bangladesh J. Ecol*. **3(1):** 81 - 85.

Tumma, M., and K. Chandrika. 2018. Fall Armyworm [Web log post]. Retrieved from http://vikaspedia.in/agriculture/crop-production/integrated-pest-managment/fall-armyworm-faw

Varella, A. C., A. C. Menezes-Netto, J. D. S. Alonso, D. F. Caixeta, R. K. D. Peterson and O. A. Fernandes. 2015. Mortality dynamics of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) immature in maize. *PLOS ONE*. **10**. 1 - 12.

Wan, J. C. Huang , C. Y. Li , H. Zhou, Y. L. Ren, Z. Y. Li , L. S. Xing, , B. Zhang, X. Ao , C. H. Liu, Y. I. Xi, W. I. Liu, W. Wang, W. I. Qian, S. S. Mckirdy and F. Wan. 2021. Biology, invasion and management of the agricultural invader: Fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J. Integ. Agric*. **20(3):** 646 - 663.

Zhou, Y., D. Q. Qin, P. W. Zhang, B. J. Liu, X. T. Chen and Z. X. Zhang. 2020. The comparative metabolic response of *Bactrocera dorsalis* larvae to azadirachtin, pyriproxyfen and tebufenozide. *Ecotoxicol. Environ. Saf.* **189**. 110020. https://doi.org/10.1016/j.ecoenv.2019.110020.

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TEMPERATURE AND HOST DENSITY DEPENDENT FUNCTIONAL RESPONSE OF *DINARMUS BASALIS* (HYMENOPTERA: PTEROMALIDAE) ON *CALLOSOBRUCHUS CHINENSIS* (COLEOPTERA: BRUCHIDAE)

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Abstract

The functional response of *Dinarmus basalis* Rondani (Hymenoptera: Pteromalidae) were estimated on parasitizing late larval-pupal stages of *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) a major pest of stored legume over a range of temperatures and host densities. A functional response equation was used in which a quadratic component that included temperature was substituted for handling time. The instantaneous search rate was increased with increasing the temperatures. The searching rate was found the highest at 30°C but the lowest at 20°C. A linear relationship between the parasitization rate and prey density was observed with regression coefficient r^2 values lies between 0.951 and 0.997. The model predicts that the maximum number of *C. chinensis* (333.33) was parasitized per day by an individual *D. basalis* at 30°C. Handling time T_h was the lowest (0.003 minute or 4.32 day^{-1}) at 30°C while the highest (0.010 minute or 14.4 day^{-1}) at 20°C. Therefore, the ability of *D. basalis* to find and parasitized *C. chinensis* makes it as a good candidate for biological control in storage conditions.

Keywords: Parasitization; *Dinarmus basalis*; *Callosobruchus chinensis*; temperature; host density.

Introduction

Developmental temperature plays a pivotal role on the physiology, behaviour and biological attribute of insects (Irlich *et al*. 2009 and Jerbi-Elayed *et al*. 2021). It is one of the most important environmental factors that influence the distribution, abundance, immature development, adult emergence, fecundity, longevity, eficiency and fitness of parasitoids as well (Liu *et al*., 2012). The various symbol of this categories of an organism can roughly classified into three groups as reaction pattern, effect on stability, and daily cycles. So far, thermal intensity may contribute as a key factor which regulate seasonal rhythm and consequently compensate diverse aspects of insect biology (Danks, 2003). The thermo-rhythm strongly influences on parasitoid to facilitate on its position within the photoperiod (Reznik *et al.*, 2009). The thermo-period may be a very strong signal conjunction with the mean temperature. Response to a temperature of a prey-parasitiod interaction is a key component often dynamic as a stable critical effect.

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This study was done on a larval-pupal cosmopolitan ectoparasitoid *Dinarmus basalis* Rondani (Hymenoptera: Ptermalidae) hosted on *Callosobruchus chinensis* (Islam and Khan 2000 and Rojas *et al*., 2005). They were frequently presented in the natural conditions, and considerable check the pest population at certain time of the year in the granaries or stores infested by *C. chinensis* (Qumruzzaman, 2003). Now *D. basalis* is found in many wormer countries of the world as Egypt, Fiji, India, Nigeria, Peru South Africa, Sudan, Thailand, Togo and West Africa (Sanon *et al*., 2005) including Bangladesh (Qumruzzaman, 2003).

The relationship between prey density and a parasitism rate is known as the functional response (Abrams and Ginzburg, 2000 and Jeschke *et al*., 2002). A functional response per unit time is the change in prey-parasitization in relation to the change in prey density (Cogni *et al*., 2000) and is a behavioral response because it involves in host searching. Evaluation of optimum temperature for the development of a parasitoid is an important step in the mass production and a basic requirement of any biological pest control program (Meirelles *et al*., 2015). Such studies are important for predicting successful field releases of bio-control agents (Xiao and Fadamiro, 2010). Effects of temperature on the functional response of *D. basalis* have been limited studied. But some have proposed a general model of this parasitoid (Smith, 1994). Keeping these in view, the present research work was conducted to assess how *D. basalis* respond to changing prey density under simplified experimental conditions. In additional aimed, to determine the functional response of *D. basalis,* hosted on *C. chinensis* of four diverse intensive phases of temperatures.

Materials and Methods

The experiment was carried out at the Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during the period from June to October 2018 to investigate the functional response of *D. basalis* as biocontrol agents against *C. chinensis*. Stock cultures of *D. basalis* and *C. chinensis* on chickpea (*Cicer arietinum* L.) seeds were commenced at the laboratory in an incubator (BD 115 / 9010-0086, Germany) maintained 30 ± 1 °C, 75 ± 10 % RH, 12:12 (D: L) inside glass jars (47 H × 14 D cm).

Experimental protocol

Approximately 200 mated one-day old females of *C. chinensis* were taken from the stock culture and introduced in different Petri dishes (90 D × 20 H) containing fresh chickpea seeds. *C. chinensis* were removed from the Petri dishes after 3 hours of egg laying and the egg-bearing seeds were placed in the incubator for further development. The cycles were repeated for constant supply of different life stages of the host for this study. After 8, 10, 12, 14, 16 and 18 days, the egg-bearing seeds were checked for confirmation of the presence of different growth stages as stated by Islam (1997). It was found that after 8, 10, 12, 14, 16- and 18-days infested seeds contained first, second, third, fourth instar larvae, pre-pupae and pupae, respectively.

From the stock culture 12 to 15-day old single hosted seeds infested by *C. chinensis* that were collected and placed in plastic containers (14 H× 11 D). Host densities were used as 20, 40, 60 and 80 number in each Petri dish. From the stock culture one pair (♀: ♂) of newly hatched *D. basalis* was introduced in each Petri dish for parasitization and the mouths of the containers were covered with fine perforated lids and placed inside the chamber of incubator for 20, 25, 30 and 35ºC and 75 ± 10% RH. All treatments were replicated five times. The released parasitoids were removed from the containers after 7 days and parasitized host seeds were left undisturbed for their development. Emergence of the adult *D. basalis* and *C. chinensis* were observed and counted daily and collected with an aspirator from the containers, and recorded.

The type II response is the most common for insect predators and parasitoids. Holing curvilinear type II equation (Holling, 1959) was used for calculation of functional response. In this model, the number of prey parasitism (*Pe*) is a function of prey density (*N*) as follows:

$$Pe = (aTN)/(1 + aThN)$$

Where *a* is the rate of attack (discovery) of the prey, *T* is the total time available (1 d or 24 h in this experiment), and T_h is the handling time for one prey. The parameter of Holling curvilinear type II equation were the handling time (T_h) and the attack constant (a) were estimated using Holling's disc equation (1959) modified by reciprocal linear transformation (Livdahl and Stiven, 1983). The modified equation is as follows:

$$\frac{1}{Pe} = \frac{1}{a}.\frac{1}{NT} + \frac{Th}{T}$$

Where $\frac{1}{Pe}$ represents y, $\frac{1}{a}$ represents α,$\frac{1}{NT}$ represents x and $\frac{Th}{T}$ represents *ß*. The linear regression form becomes y = α x + β. The maximum number of parasitized prey per parasitoid (asymptote), $Ha_{max} = \frac{T}{Th}$was found.

Statistical analyses

The data on attack rate, handling time, prey consumption rates, parasitization and suppression were analyzed using linear regression procedures (Rstudio 3.1.3). All graphical works were done by Microsoft Excel.

Results

Functional response of *D. basalis*

The functional response parameters as attack rates, handling times, parasitization (asymptote) and regression coefficient (r^2) of *D. basalis* were assessed with tested densities of *C. chinensis* at different temperatures of 20, 25, 30 and 35 °C (Table 1). The type II Holling disc equation was fitted separately for each tested temperature level in order to compared the search rate a and handling times T_h for parasitization. The parasitization efficiency by the parasitoid was found to increase with increasing temperature. The instant search rate or handling time was found increasing as temperature increases. Among the temperatures, 30°C showed the highest rate of attack (0.975 d^{-1}) while 20°C exhibited the lowest (0.676 d^{-1}). Handling time decreased as temperature increasing except for 35°C temperature with all levels of parasitoid introduction. The predicted maximum numbers of prey parasitization (T/T_h) within 24 hours by an adult female of *D. basalis* were 100, 200, 333.33 and 142.86, respectively at four temperatures of 20, 25, 30 and 35 °C.

Table 1. Type II functional response parameters of *D. basalis* fed on different densities of *C. chinensis*

Temperature (°C)	a	T_h (day/min.)	T/T_h	r^2
20	0.676	0.010 (14.4)	100	0.997
25	0.894	0.005 (7.2)	200	0.969
30	0.975	0.003 (4.32)	333.33	0.951
35	0.798	0.007 (10.08)	142.86	0.996

Where: a = Rate of attack, T_h = Handling time, $\frac{T}{Th}$ =Prediction of maximum prey consumption, r^2 = Regression coefficient

Parasitization rates over temperatures and prey densities

The results suggest that parasitization of *D. basalis* to *C. chinensis* increases with temperature and offered prey densities up to 30 °C, but have declined by 35 °C, although parasitization at 35 °C is still greater than that seen at both 20 and 25 °C (Figure 1).The differences in prey parasitization rate at various prey densities within a developmental stage of *D. basalis* were detected significant at all levels of temperature (20°C: F = 234.02; df = 3 ; P = 0.0042; 25°C: F = 63.09; df = 3; P = 0.0155; 30°C: F = 38.82; df = 3 ; P = 0.0248; 35°C: F = 81.63; df= 3 ; P = 0.012).Also, relationships of parasitization are negatively correlated against prey density offered at all temperatures level. The highest parasitization (90.0%) was calculated at the lowest prey density (20) offered while the lowest (71.25%) in the highest (80) prey density at 30 °C temperature (Figure 1).

Parasitization of *D. basalis* was estimated by offering tested host densities of *C. chinensis* to evaluate the form of its efficient response and the linier model of functional response corresponds to Holling disc equation II (Figure 2). The result indicates that the parasitization rate all tested temperatures decreased with increasing host density and all the values of linear constant were negative (Figure 2). The highest parasitization (57.0) was found while offered 80 hosts at 30 °C. Conversely, the lowest (11.8) parasitization experienced on 20 host density at 20 °C temperature.

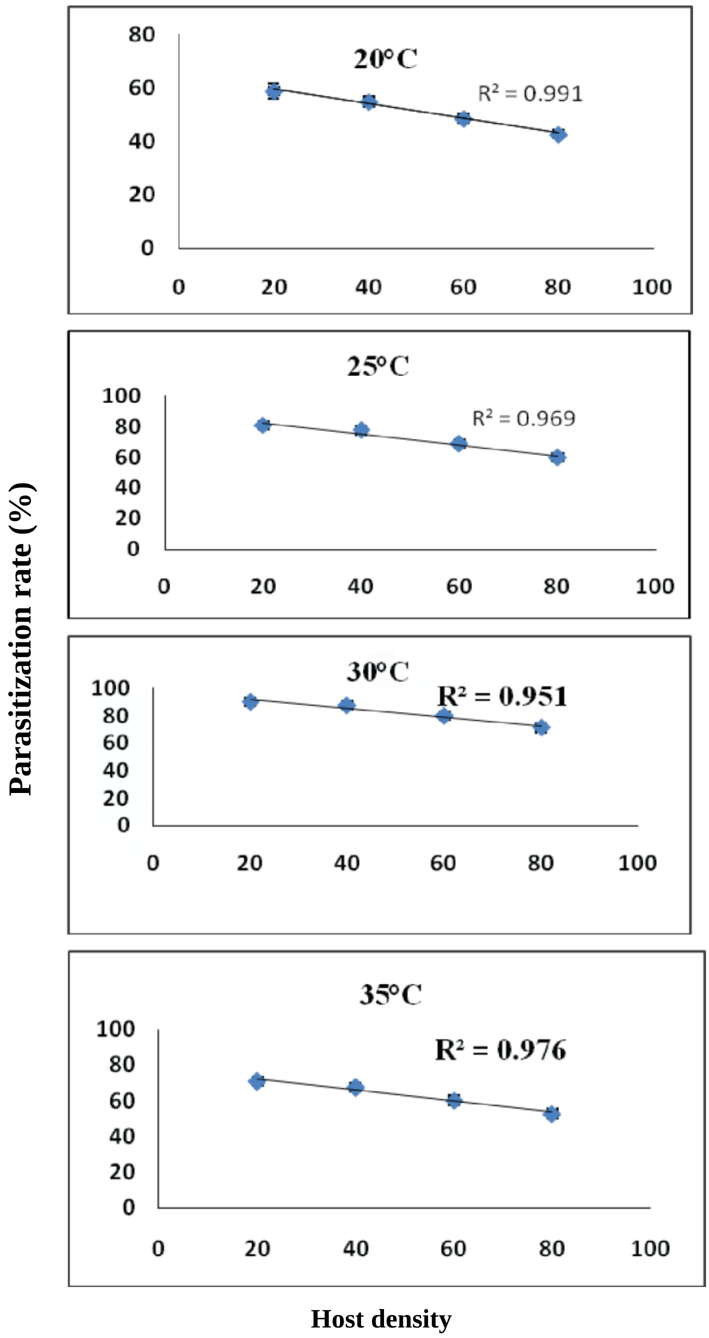

Fig. 1. Parasitization (%) of *D. basalis* to *C. chinensis* hosted on chickpea seed at tested temperatures and host density. Error bars show standard errors.

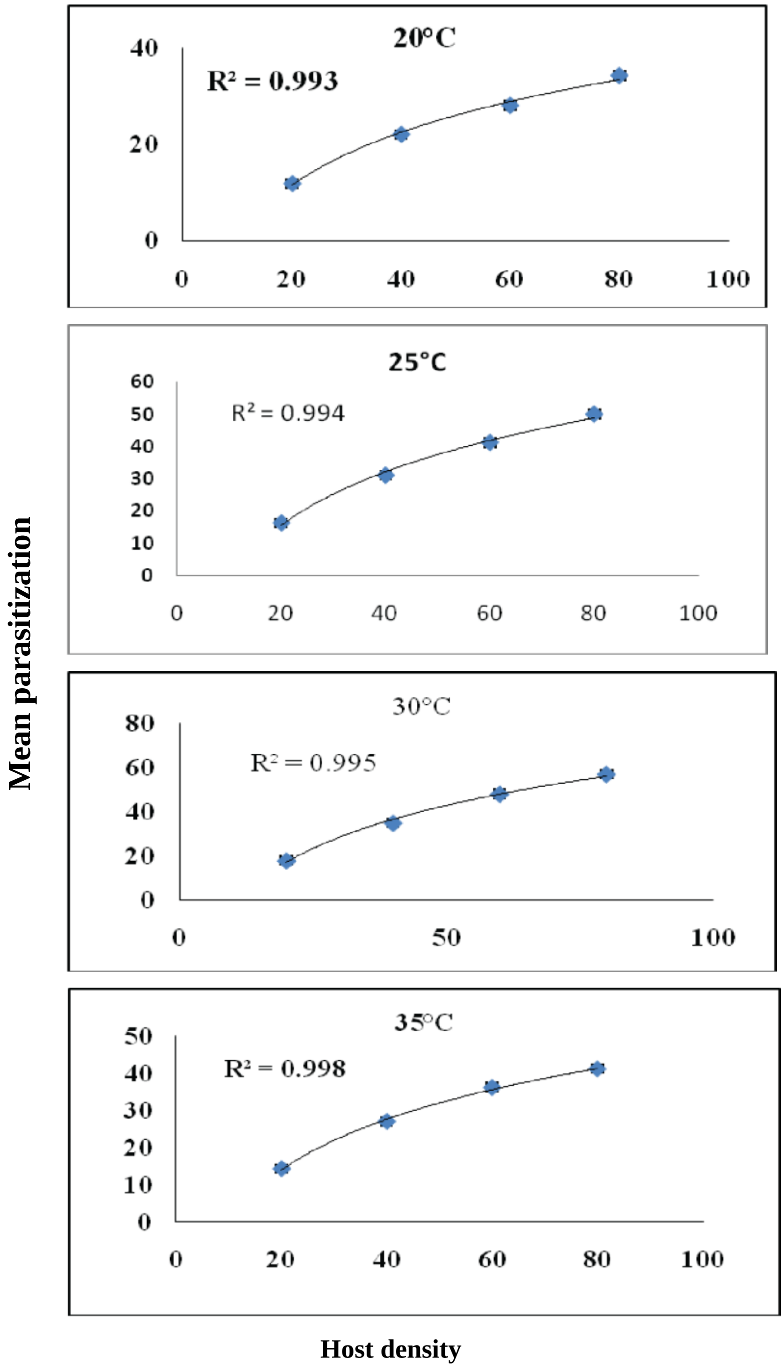

Fig. 2. Functional response of *D. basalis* parasitization to *C. chinensis* hosted on chickpea seed at tested four different temperatures and host density. Error bars show standard error.

Discussion

The functional response is a preliminary step in evaluating the efficiency of the parasitoid in biological control programs. The attractive suppression of pests using bio-control agent indicates fundamental aspects of ecological fitness ability. The adverse environmental conditions negatively affected the potentiality of diverse biological control programs. Development of a parasitoid in determination of optimal thermal requirement is a focal point of any bio-control program against the pests is the most important for its mass rearing, laboratory production, field release and efficiency. Since the potentiality of laboratory strains of parasitoids might be affected after releasing due to fluctuations of temperature as they cultured in confined conditions. So, in fact, the variation of temperature strongly affects the performance of parasitoids cultured in the laboratory (Firake and Khan, 2014).

The data indicates that all temperature levels exhibited to *D. basalis*, were found negative suggesting that the functional responses were type II (Figure 2). A logistic regression model of proportions of prey parasitized (*Pe/N*) versus host density (*N*) was also fitted to confirm the correctness of the functional response type that was obtained, because, it provides a more powerful and accuracy of distinguishing between type II and type III (Trexler *et al.*, 1988). In hypothesis, we have operated functional response by *D. basalis* in our experiment but, found no evidence of type III, suggesting this mechanism repulsive for this parasitoid-prey system. Our experiment was a short term, single-prey species, so that these two suggested mechanisms for type III functional responses couldn't have properly acted in our experiment. Similar type of functional response has been reported by many scientists with other insect species under various abiotic conditions (De Clercq *et al*., 2000; Zamani *et al*., 2006 and Fathi and Nouri-Ganbalani, 2009). This type of functional response earlier reports in support of different parasitoids, together with: *Gonatocerus tuberculifemur* (Hymenoptera: Mymaridae) attacking eggs of glassy-winged sharpshooter, *Homalodisca vitripennis* (Hemiptera: Cicadellidae) (Irvin *et al*., 2009); *Anisopteromalus calandrae* Rondani (Hymenoptera: Pteromalidae) preying on lesser grain borer *Rhizopertha dominica* (Coleoptera: Bostrychidae) (Menon *et al*., 2002); *Lysiphlebus testaceipes* Cresson (Hymenoptra: Braconidae) preying on wheat aphid *Schizaphis graminum* Rondani (Hemiptera: Aphididae) (Jones *et al*., 2003); *Spalangia cameroni* Perkins (Hymenoptera: Pteromalidae) attacking pupae of the stable fly *Stomoxys calcitrans* L. (Skovgard and Nachman, 2015), egg parasitoid of *Telenomus remus* Nixon (Hymenoptera: Scelionidae) to *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (Carneiro, *et al*., 2010). Types of functional response of an insect species estimated parameters could be affected by many factors such as temperature, type of prey or host and host plant (Messina and Hanks, 1998 and Moezipour *et al*., 2008).

The searching rates and handling time has major importance a fundamental aspect in functional response, that provide eminent information about interaction to parasitoid-host, since it can contribute the impact of *D. basalis* on *C. chinensis* population dynamics. Our results suggested that the optimum temperature according to the highest value of *a* (searching ability of parasitoid) while the lowest value of T_h (handling time), was 30 °C. The coefficient of attack rate (*a*) and handling time (T_h) parameters were used to conclude the magnitude of the functional responses exhibited through tested temperature and host density (Table 1). Numerous temperature levels of parasitoid for the *C. chinensis* as prey species; the attack rate *(a)* and handling *(Th)* time rates were varied. The estimated handling time was the lowest (0.003 min) at 30°C while the highest (0.010 min) at 20°C. Similarly, the lowest (0.674) while the highest (0.894) attack rates were experienced at 20°C and 30°C. Similar functional responses have been found in *Euseius finlandicus* Oudemans to *Amblyseius andersoni* Chant (Koveos and Broufas, 2000), *Frankliniella schultzei* Trybom, to *Thrips imagines* Bagnall and *T. tabaci* Lindeman (Wilson *et al.*, 1996), to *Stethorus punctum* (LeConte) (Hull *et al*., 1977). All fitted Holling's type-II responses, in which parasitoid display a decrease in attack rate at increasing prey densities (Sabelis, 1985). Results of the present findings are comparable with (Islam *et al*., 2006). They cited that the search rate and handling of the parasitoid *D. basalis* was a'= 0.123 time and T_h= 0.056 life span^{-1}, respectively. The type of functional response of parasitoid/predator may change from one type to another as environmental conditions (temperature mainly) change (Wang and Ferro, 1998 and Mohaghegh *et al*., 2001).

The suppressive efficiency of the parasitoid was consequently changed with fluctuate of the parasitoid density at corresponding tested temperatures. The parasitism and suppression trends by the parasitoid of the existing study are parallel. The percentage of parasitism among various temperatures were minimum (65.25%) at 20°C temperature while offered 80 host densities although maximum (95.73%) at 30°C temperature of 20 host densities. The suppression by the parasitoid was experienced minimum (68.35%) at 20°C temperature with 80 host densities but maximum (97.44%) at 30°C temperature with 20 host densities. *D. basalis* parasitized 21.4-91.0%, *Anisopteromalus calandrae* parasitized 19-67.2% and a combination of both species parasitized 18.9-82.5% of *C. chinensis* hosted on lentil seed (Qumruzzaman and Islam, 2005). Hossain *et al*., (2014) observed the parasitization rates of *D. basalis* were 62.83 to 99.25% on its habitual host *C. chinensis*.

The parasitization ability of *D. basalis* on *C. chinensis* over a broad range of temperatures makes them good candidates for biological control of stored grain pest. Based on the handling time (the time taken by a parasitoid in locating, capturing, subduing, parasitizing and digesting one prey), attack rate, and the parasitization of pulse beetle, it can be use as a biocontrol agent of *C. chinensis* at temperatures ranging between 25 and 30°C. The findings of the functional response of *D. basalis* on *C. chinensis* at different temperatures could be incorporated as a model to be used in such a system. However, additional studies on the interaction, fecundity, development, potentiality, reproductive ability of *D. basalis* will be needed to develop this for augmentative or conservational biocontrol tactics against *C. chinensis*. Therefore, it could be concluded that the parasitoid *D. basalis* may be released shortly to reduce the infestation against notorious pulse beetles to ensure bio-safety and food security as a vital component of integrated pest management.

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References

Abrams, P. A. and L. R. Ginzburg. 2000. The nature of predation: prey dependent, ratio dependent, or neither. *Trends Ecol. Evol*. **5**: 337-341.

Carneiro, T. R., O. A. Fernandes, I. Cruz1, and R. C. O. F Bueno. 2010. Functional response of *Telenomus remus* Nixon (Hymenoptera, Scelionidae) to *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae) eggs: effect of female age. *Rev. Bras. Entomol*. **54(4):** 692-696.

Cogni, R., A. V. L. Freitas and F. A. Filho. 2000. Influence of prey size on predation success by *Zelus longipes* L. (Hemiptera: Reduviidae). *J. Appl. Ent*. **126**: 74-78.

Danks, H. V. 2003: Studying insect photoperiodism and rhythmicity: Components, approaches and lessons. *Eur J. Entomol*. **100**: 209-221.

De Clercq, P., J. Mohaghegh and L. Tirry. 2000. Effect of host plant on the functional response of the predator *Podisus nigrispinus* (Heteroptera: Pentatomidae). *Biol. Cont*. **18**: 65-70.

Fathi, S. A. A. and G. Nouri-Ganbalani. 2009. Assessing the potential for biological control of potato field pests in Ardabil, Iran: functional responses of *Oriusniger* (Wolf.) and *O. minutus* (L.) (Hemiptera: Anthocoridae). *J. Pest Sci*. **83**: 47-52.

Firake, D. M. and M. A. Khan 2014. Alternating temperatures affect the performance of *Trichogramma* species. *J. Insect Sci*. **14(41):** 1-14.

Holling, C. S. 1959. Some characteristics of simple types of predations and parasitism. *Can. Entomol*. **91(7):** 385-398.

Hossain, M. A., M. A. Alim, K. S. Ahmed, and M. A. Haque. 2014. Biocontrol potential of *Dinarmus basalis* (Hymenoptera: Pteromalidae) Rondani as a parasitoid of *Callosobruchus chinensis* (L.) in stored pulse. *Afr. Entomol*. **22(2):** 285-290.

Hull, L. A. D. Asquith and P. D. Mowery. 1977. The functional responses of *Stethorus punctum* to densities of the European red mite. *Environ. Entomol*. **6**: 85-90.

Irlich, U. M., J. S. Terblanche, T. M. Blackburn and S. L. Chown 2009. Insect rate-temperature relationships: Environmental variation and the metabolic theory of ecology. *Am. Nat.* **174:** 819-835.

Irvin, N., J. Suarez-espinoza and M. Hoddle. 2009. Functional Response of *Gonatocerus ashmeadi* and the “New Association” parasitoid *G. tuberculifemur* attacking eggs of *Homalodisca vitripennis. Environ. Entomol*. **38(6):** 1634-1641.

Islam, W. 1997. Host stage selection and preference for oviposition of the parasitoid *Dinarmus basalis* Rond. (Hymenoptera: Pteromalidae) on *Callosobruchus chinensis* L. *Entomon.* **22(2):** 95-100.

Islam, N., M. W. Islam and K. A. M. S. H. Mondal. 2006. Functional response of *Dinarmus basalis* (Rond.) (Hymenoptera: Pteromalidae) parasitizing *Callosobruchus maculatus* (F.) *J. Biosci*. **14**: 11-16.

Islam, W. and A. R. Khan, 2000. Bruchid research in Bangladesh. *Pak. J. Biol. Sci*. **3**:10-19.

Jerbi-Elayed, M., V. Foray, K. Tougeron, K. Grissa-Lebdi and T. Hance. 2021. developmental temperature affects life-history traits and heat tolerance in the aphid parasitoid *Aphidius colemani. Insects*. **2(10):** 1-12.

Jeschke, J. N., M. Kopp and R. Tollrian. 2002. Predator functional responses: Discriminating between handling and digesting prey. *Ecol Monogr*. **72**: 94-112.

Jones, D. B., K.L. Giles, R. C. Berberet, T. A. Royer, N.C. Elliot and M. E. Payton. 2003. Functional response of an introduced parasitoid and an indigenous parasitoid on green bug at four temperatures. *Environ. Entomol*. **32**: 425-432.

Koveos, D. S. and G. D. Broufas. 2000. Functional response of *Euseius finlandicus* and *Amblyseius andersoni* to *Panonychus ulmi* on apple and peach leaves in the laboratory. *Exp. Appl. Acarol*. **24**: 247-256.

Liu, C.Y., K.W. Chen, and L. Zeng. 2012: Effects of temperature on the development and fecundity of *Diachasmimorpha longicaudata* (Ashmead). *Chin. J. Appl. Ecol*. **23**: 3051-3056.

Livdahl, T. P. and A. E. Stiven. 1983. Statistical difficulties in the analysis of predator functional response data. *Can. Entomol*. **115:** 1365-1370.

Meirelles, R. N., L. R. Redaelli and C. B. Ourique. 2015. Thermal requirements and annual number of generations of *Diachasmimorpha longicaudata* (Hymenoptera: Braconidae) reared in the South American fruit fly and the Mediterranean fruit fly (Diptera: Tephritidae). *Fla. Entomol*. **98**: 1223-1226.

Menon, A., P. W. Flinn and B. A. Dover. 2002. Influence of temperature on the functional response of *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae), a parasitoid of *Rhyzopertha dominica* (Coleoptera: Bostrichidae). *J. Stored Prod. Res*. **38**: 463-469.

Messina, F. J. and J. B. Hanks. 1998. Host plant alters the shape of the functional response of an aphid predator (Coleoptera: Coccinellidae). *Environ. Entomol*. **27**: 1196-1202.

Moezipour, M., M. Kafil and H. Allahyari. 2008. Functional response of *Trichogramma brassicae* at different temperatures and relative humidities. *Bull. Insectology*. **61**: 245-250.

Mohaghegh, J., P. De Clercg and L. Tirry. 2001. Functional response of the predators *Podisus maculiventris* (Say) and *Podisus nigrispinus* (Dallas) (Het.: Pentatomidae) to the beet armyworm, *Spodoptera exigua* (Hunber) (Lep.: Noctuidae): effect of temperature. *J. Appl. Entomol*. **125**: 131-134.

Qumruzzaman, A. H. M. 2003. Efficacy of *Dinarmus basalis* Rond. and *Anisopteromalus calandrae* How. (Hymenoptera: Pteromalidae) against *Callosobruchus chinensis* L., PhD Thesis, Institute of Biological Sciences, Rajshahi University. p. 214.

Qumruzzaman, A.H.M. and M. W. Islam. 2005. Interaction between *Dinarmus basalis* and *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae), at different parasitoid densities of *Callosobruchus chinensis* (Coleoptera: Bruchidae) in red lentil seeds. *Int. J. Trop. Insect Sci*. **25(1):**6-11.

Reznik, S. Ya., N. D. Voinovich and S. G. Karpova. 2009. Daily rhythms in parasitization of the Angoumois grain moth *Sitotroga cerealella* Oliv. (Lepidoptera: Gelechiidae) eggs by the egg parasitoid *Trichogramma principium* Sugonyaev and Sorokina (Hymenoptera, Trichogrammatidae). *Entomol. Rev*. **89**: 5-15.

Rojas, R. D., C. Bressac, C. Thibeaudeau, R. Kalmes, E. Darrouzet and C. Cheviere. 2005. Reproductive capacity of females *Eupelmus vuilleti* (Eupelmidae) inseminated by hyperparasitoid males developed upon the primary parasitoid *Dinarmus basalis* (Pteromalidae). *C. R. Biol*. **328(9):** 802-811.

Sabelis, M. W. 1985. Predation by spicier mites. In: Helle W. and Sabelis M.W. (eds.), World Crop Pests. Spider Mites. Their Biology, Natural Enemies and Control, Vol. 1B, Elsevier, Amsterdam, The Netherlands, pp. 103-129.

Sanon, A., C. Dabire, A. P. Ouedraogo and J. Huignard. 2005. Biological control of *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) populations by two sympatric parasitoid species, *Dinarmus basalis* Rond. and *Eupelmus vuilleti* Croa. *Belg. J. Entomology*. **7(1):** 57-69.

Skovgard, H. and G. Nachman. 2015. Temperature-dependent functional response of *Spalangia cameroni* (Hymenoptera: Pteromalidae), a parasitoid of *Stomoxys calcitrans* (Diptera: Muscidae). *Environ. Entomol*. **44(1):** 90-99.

Smith, L. 1994. Temperature influences functional response of *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) parasitizing maize weevil larvae in shelled corn. *Ann. Entomol. Soc. Am*. **87**: 849-855.

Trexler, J. C., C. E. McCulloch and J. Travis, 1988. How can the functional response best be determined? *Oecologia*. **76**: 206-214.

Wang, B. and D. N. Ferro. 1998: Functional responses of *Trichogramma ostriniae* (Hymenoptera: Trichogrammatidae) to *Ostrinia nubilalis* (Lepidoptera, Pyralidae) under laboratory and field conditions. *Environ. Entomol*. **27**: 752-758.

Wilson, L. J., L. R. Bauer and G. H. Walter. 1996. Phytophagous' thrips are facultative predators of two spotted spider mites (Acari: Tetranychidae) on cotton in Australia. *Bull. Entomol. Res*. **86**: 297-305.

Xiao, Y. and H. Y. Fadamiro. 2010. Functional responses and prey-stage preferences of three species of predacious mites (Acari: Phytoseiidae) on citrus red mite, *Panonychus citri* (Acari: Tetranychidae). *Biol. Cont*. **53**: 345-352.

Zamani, A. A., A. A. Talebi, Y. Fathipour and V. Baniameri. 2006. Temperature-dependent functional response of two aphid parasitoids, *Aphidius colemani* and *Aphidius matricariae* (Hymenoptera: Aphidiidae) on the cotton aphid. *J. Pest Sci*. **79**: 183-188.

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IN VITRO CONSERVATION OF POTATO

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Abstract

A study was conducted to assess the effect of sorbitol on *in vitro* conservation of potato. MS medium supplemented with different concentrations of sorbitol @ 0, 20 and 40 g/l and nodal explants of potato varieties were used in this study and continued upto five months. Days to shoot and root initiation; number of leaf, number of shoot, number of root and length of shoot were assessed. BARI Alu-7 produced the maximum leaflets (29.8) while the BARI Alu-41 produced the minimum leaflets (16.2) in MS supplemented with 20 g/l sorbitol after five months of conservation. The varieties produced 6 to 13.8 shoots and 5 to 11.2 roots in the same medium. The maximum shoot length (12.2 cm) was exhibited in BARI Alu-25 and BARI Alu-28, where minimum (9.9 cm) was found in BARI Alu-37. Among the varieties, BARI Alu-7 and BARI Alu-37 performed better for shoot growth and development. MS medium supplemented with 20g/l sorbitol showed the best performance where the *in vitro* plantlet could be conserved for five months. Three studies were also conducted with or without sorbitol for six weeks, eight weeks and three months. The *in vitro* conservation protocol developed from nodal explants has applicability in improvement of potato.

Keywords: Potato, *Solanum tuberosum*, nodal explant, growth regulators, *in vitro* conservation.

Introduction

Potato (*Solanum tuberosum* L.) is the 3rd important food crop in Bangladesh after rice and wheat. It is a vegetable as well as an industrial crop. Bangladesh is producing about 96.06 lac tons of potatoes annually from 4.62 lac hectares of land with an average of 20.82 tons//ha (BBS, 2022). Potato cultivation contributes to global food security (FAOSTAT. 2022; Zsögön *et al.* 2022). Potato varieties are generally maintained through vegetative propagation in order to maintain their genetic integrity as the crop is highly heterozygous and segregates on sexual production. Factors related to climate change have led to a large *in situ* loss of biodiversity of the plant genetic resource (Kulak *et al.* 2022). Potato tubers are bulky and highly perishable; the crop is generally conserved as clones either in field genebanks (with annual replanting), *in-vitro* conservation in slow growth media for short-to-medium term and cryopreservation for long term. Field genebanks are expensive to maintain and the crop is exposed to many dangers; hence, cryopreservation is the only feasible method for long term conservation.

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However, given the high cost of cryopreservation, longterm conservation of potato genetic resources is poorly developed in most resource-poor countries leading to high rates of genetic erosion. *In vitro* techniques have thus been advocated as a useful alternative to conserve potato plantlets under diseases-free conditions (Golmirzaie *et al.* 1999; Gopal *et al.* 2002). Under optimum propagation conditions (MS medium with 30g sucrose, 16h photoperiod, 22 to 24^{0}C), the plantlets require sub-culturing every four to eight weeks (Gopal and Chauhan, 2010). *In situ* and *ex situ* conservation of potato collections are essential in breeding programs. Plant biotechnology offers different alternatives for germplasm conservation through plant tissue culture, which allows *in vitro* conservation and the regeneration of germplasm. The *in vitro* conservation is classified into three categories: short-, medium- and long-term. Medium-term *in vitro* conservation has more advantages than short-term periods, such as control over storage conditions, and compared to long-term periods that require a constant supply of liquid nitrogen for cryopreservation, which is not cost effective for use in commercial laboratories (Panis *et al.* 2020, Engels and Andreas, 2021). In addition, medium-term *in vitro* conservation allows for slow-growth storage, reduces labor costs and allows for the availability of the germplasm bank (Spinoso-Castillo *et al.* 2022). Slow-growth storage consists of modifying the physical and chemical conditions of the *in vitro* culture to reduce the metabolism and development of cells, tissues, organs or whole plants (Salgotra *et al.* 2023). Physical factors include incubation at low temperatures, the use of nutrient-poor culture media, increased osmotic potential of the culture medium and the use of growth inhibitors such as ABA and gibberellin synthesis inhibitors (GAs) (Ruta *et al.* 2020). BARI released 104 varieties of potato. They need *in vitro* conservation to reduce the sub-culturing strategies. Therefore, the present study was undertaken to develop an *in vitro* medium term conservation protocol of potato for potato propagation.

Materials and Methods

Eleven (11) varieties of potato viz. BARI Alu-7, BARI Alu-8, BARI Alu-13, BARI Alu-21, BARI Alu-24, BARI Alu-25, BARI Alu-27, BARI Alu-28, BARI Alu-30, BARI Alu-31 and BARI Alu-32 were used in this study at the *In vitro* Conservation Laboratory of Plant Genetic Resources Centre, BARI, Joydebpur Gazipur during 2012-13 to 2015-16. These are the introduced varieties from Netherlands and Germany and commercially cultivated in Bangladesh. In the first study, eight weeks old *in vitro* plantlets of 11 potato varieties were collected from Tuber Crop Research Centre of BARI TCRC on 22 August 2012. The MS medium was prepared. The pH of the medium was adjusted to 5.8 before autoclaving and the media were solidified with agar @ 8 g/l. The medium was autoclaved at 1.06 kg/cm^2 pressure and 121°C for 15 min. Nodal explants were prepared under Laminar Air Flow aseptically and inoculated into test tube (25 x 150 mm) containing 15 ml of the basal MS medium. Explant having one node and two leaves was cultured in each test tube. Aluminum foil was used as closure. The explants were incubated for six weeks in a culture room at 23 ± 1°C under about 500 lux light provided by cool-white fluorescent tubes maintaining a 16/8hr alternate light/dark cycle and 60-70% relative humidity. Completely randomized design with four replications were applied in the first study where each replication contained of 5 test tubes. Data from the experiment were subjected to ANOVA and mean separations were carried out by the LSD using the MSTAT program.

During 2013-14 (2nd study), six varieties (BARI-Alu-7, BARI Alu-8, BARI Alu-12, BARI Alu-21, BARI Alu-25 and BARI Alu-28) of potato were tested (Table 2). Nodal explants of 4 weeks old plantlets were prepared and inoculated one explant of into test tube containing 15 ml MS medium supplemented with 0, 20 g and 40g/l sorbitol, plus 2% sucrose. The media were solidified with agar @ 8 g/l. The explants were incubated for eight weeks in a culture room at 22 ± 1°C temperature. The experimental set up was in a 3 X 6 factorial in a completely randomized design with five replications and each replication contained five explants.

During 2014-15, the 3rd study was conducted with 10 varieties (BARI Alu-7, BARI Alu-8, BARI Alu-12, BARI Alu-21, BARI Alu-25, BARI Alu-28, BARI Alu-32, BARI Alu-33, BARI Alu-37 and BARI Alu-41). The MS media containing 20 g/l sorbitol were prepared. Nodal explants of 4 weeks old were prepared and inoculated one explant into the test tube containing 15 ml MS medium supplemented with 20g/l sorbitol. The explants were incubated for three months at 22 ± 1°C temperature. The experimental set up was in a completely randomized design with five replications and each replication consisted of 5 explants. Data from the experiment were subjected to ANOVA and mean separation was carried out using the MSTAT program.

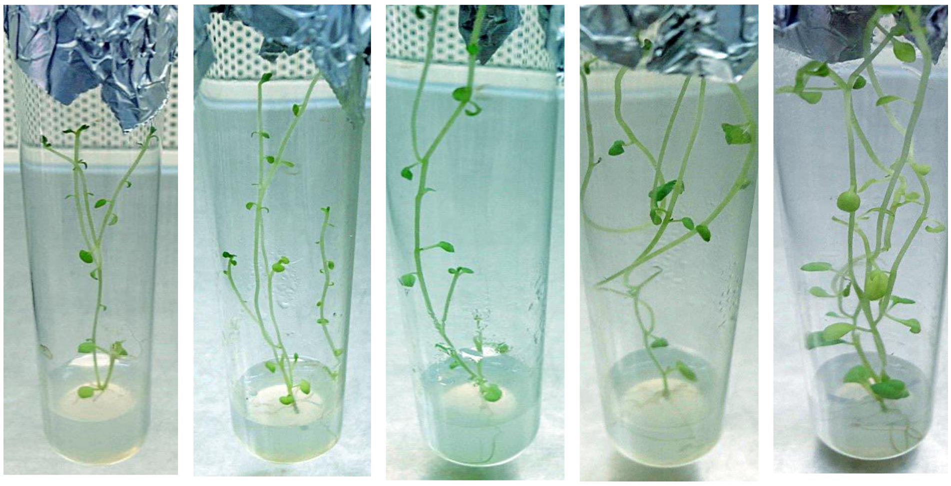
The 4th study was conducted with 9 varieties (BARI Alu-7, BARI Alu-8, BARI Alu-12, BARI Alu-25, BARI Alu-28, BARI Alu-32, BARI Alu-33, BARI Alu-37, BARI Alu-41) of potato from Study-3 during 2015-16. Nodal explants of 4 weeks old were used in this study. The MS medium supplemented with 20 g/l sorbitol was used. The explants were incubated for five months in a culture room at 22 ± 1°C temperature. The experimental set up was in a completely randomized design with five replications and each replication consisted of 5 explants. Data from the experiment were subjected to ANOVA and LSD values were calculated using the MSTAT program.

Result and Discussion

Growth and development of potato varieties, *in vitro* cultivated for six weeks in MS medium are shown in Table 1 and Fig.1. All the potato varieties initiated root and shoot within a week of culture. The number of roots produced from the varieties ranged from 2.5 to 6.25. However, no significant variations were observed in the ability of explants to develop roots. BARI Alu-30 (Meridian) took the maximum number of days (6 days) to root initiation and the remaining varieties initiated roots within 4 to 5 days (Table 1). The maximum number of leaves was found in BARI Alu-32 (23.75), followed by BARI Alu-28 (23) and BARI Alu-8 (19.75) and the minimum leaves were found in BARI Alu-27 (7.75). The maximum shoot length (11.88 cm) was found in BARI Alu-8 (Cardinal) followed by BARI Alu-31 (Sagitla, 11.63cm) and BARI Alu-21 (Provento, 10.75cm). The minimum shoot length (6.5 cm) was found in BARI Alu-30 (Meridian). The highest number of shoot (6.5) was exhibited in BARI Alu-28 (Lady Rosseta) and the lowest (2.75) in BARI Alu-7 (Diamant) which was statistically significant.

Table 1. *In vitro* conservation of potato varieties for six weeks in MS medium-2012-13

Name of variety	Days to root initiation	No. of Leaves/plantlet	Length of shoot (cm)	No. of shoots	No. of roots
BARI Alu-7 (Diamant)	4	13.50	9.25	2.75	4.00
BARI Alu-8 (Cardinal)	4	19.75	11.88	5.25	4.50
BARI Alu-13 (Granola)	4	15.75	10.38	5.25	4.50
BARI Alu-21 (Provento)	5	14.25	10.75	3.50	4.75
BARI Alu-24 (Dura)	5	11.25	7.25	4.50	3.25
BARI Alu-25 (Asterix)	4	12.25	8.63	5.75	5.00
BARI Alu-27 (Esprit)	5	7.75	6.88	3.50	2.50
BARI Alu-28 (Lady Rosseta)	5	23.00	10.13	6.50	4.50
BARI Alu-30 (Meridian)	6	15.00	6.50	5.25	3.50
BARI Alu-31 (Sagitla)	4	11.50	11.63	4.00	5.25
BARI Alu-32 (Quincy)	4	23.75	10.00	4.75	6.25
LSD (0.01)	1.63	8.30	3.39	3.41	3.62



BARI Alu-8 BARI Alu-13 BARI Alu-28 BARI Alu-31 BARI Alu-32

Fig. 1 Response of potato varieties on MS medium at six weeks of culture.

Effect of sorbitol on *in vitro* growth and development from nodal explant of six potato varieties are shown in Table 2 and Fig.2. The highest, 97% explants produced roots initiation was seen in MS medium supplemented with 20g sorbitol/l while the lowest 87% explant produced roots in 40g sorbitol/l (Table 2). The 6 potato varieties had 87 to 93% root initiation (Table 3).The combination of 20 and 40g/l sorbitol with the varieties produced 80 to 100% root initiation (Table 4). Cent percent explants (100%) produced shoots in both 0 and 20 g/l sorbitol and the lowest shoot (93%) was found in 40 g/l sorbitol containing MS medium (Table 4). The varieties produced 93 to 100% shoot proliferation (Table 3). Potato varieties produced 100% shoots in MS medium supplemented with 20 g/l sorbitol. Control treatment also produced 100% shoots (Table 3). However, the lowest (80%) shoot initiation was exhibited in 40g/l sorbitol supplemented MS medium with BARI Alu-25 and BARI Alu-28 (Table 4). Earlier root initiation within (4-5 days) was observed in 0 and 20g/l sorbitol supplemented MS medium. Without sorbitol the plantlets were produced the maximum number (16.3) of leaves per shoot while the minimum number of leaves (10) was obtained from 40g sorbitol/l (Table 4). BARI Alu-28 produced the maximum (19.3) of leaves. The minimum number of leaves (10.9) was obtained from BARI Alu-21. Sorbitol-free MS medium produced the higher number (2.0) of shoots. The remaining treatments produced 1.0 to 1.2 shoots. Potato varieties produced 1.0 to 2.5 shoots per plantlet. The highest (8.0 cm) and the lowest (7.9 cm) shoot lengths were obtained from sorbitol free MS media and 40 g/l sorbitol, respectively. Maximum shoot length (11.3 cm) was obtained from BARI Alu-28 with MS while the minimum (2.5 cm) from BARI Alu-8 and BARI Alu-28 with 40 g/l sorbitol. Sorbitol (40.0 mg/l) produced the highest number of 11.3 roots per shoot while the lowest number of roots (7.9) was obtained from without sorbitol. Sorbitol metabolism plays multiple roles in plants, including energy and carbon enrichment, effective defence against various stresses and other emerging specific roles. It has been clear that enriching carbohydrate metabolism with a sorbitol branch improves plant fitness under stress. Nevertheless, this is probably valid only when appropriate growth and defence trade-offs are ensured. Information on the ectopic expression of sorbitol metabolism genes has contributed substantially of the sorbitol roles and raises new questions regarding sorbitol signalling potential (Pleyerová *et al*. 2022).The maximum number (12.1) of roots was obtained from BARI Alu-12 while the minimum number (8.5) of roots was obtained from BARI Alu-8 (Table 4). After 8 weeks, the terminal leaves of some varieties were become yellow. BARI Alu-28 was the superior for shoot proliferation through node culture.

Table 2. Effect of sorbitol on *in vitro* conservation of potato from nodal explant at eight weeks -2013-14

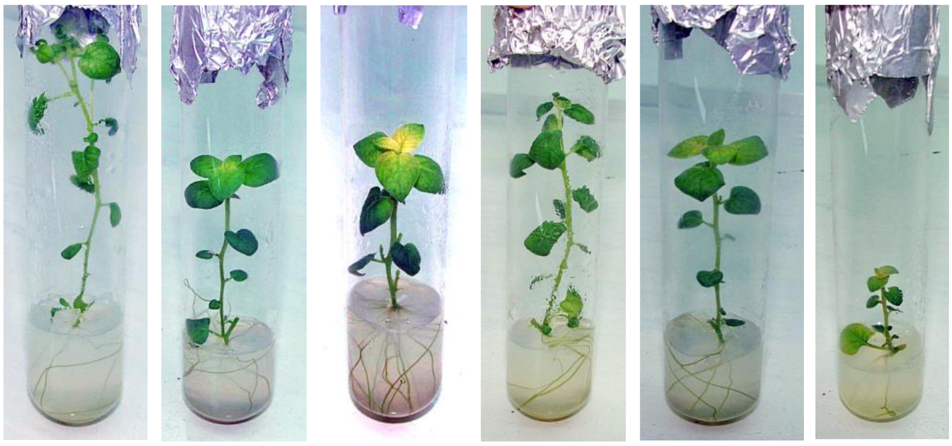
Sorbitol (g/l)	% of root initiation	% of shoot initiation	Days of root initiation	Days to shoot initiation	Number of leaf/shoot	Number of shoot/ explant	Length of shoot (cm)	Number of root/ plantlet
0	93	100	5	8	16.3	2.0	8.0	7.9
20	97	100	5	8	12.1	1.0	6.6	10.2
40	87	93	8	11	10.2	1.2	3.4	11.3

Table 3. Effect of potato varieties on *in vitro* conservation from nodal explant at eight weeks

Name of variety	% of root initiation	% of shoot initiation	Days of root initiation	Days to shoot initiation	Number of leaf/shoot	Number of shoot/ explant	Length of shoot (cm)	Number of root/plantlet
BARI Alu-7	87	100	5.5	9.7	13.1	1.8	5.9	9.6
BARI Alu-8	93	100	6.9	10.1	11.3	1.1	5.6	8.5
BARI Alu-12	93	100	6.3	10.8	11.1	1.0	4.8	9.5
BARI Alu-21	93	100	5.2	9.1	10.9	1.1	6.1	12.1
BARI Alu-25	93	93	5	5.9	11.5	1.0	6.8	10.3
BARI Alu-28	93	93	8.3	8.8	19.3	2.5	7.0	8.9

Table 4. Combined effect of sorbitol and potato varieties on *In vitro* conservation from nodal explant at eight weeks

Sorbitol (g/l)	Name of variety	% of root initiation	% of shoot initiation	Days of root initiation	Days to shoot initiation	Number of leaf/shoot	Number of shoot	Length of shoot (cm)	Number of root/ plantlet
0	BARI Alu-7	80	100	5	7	16.4	2.8	8.4	5.0
	BARI Alu-8	100	100	4	7	15.2	1.2	8.2	10.0
	BARI Alu-12	80	100	6	12	10.2	1.0	5.4	6.2
	BARI Alu-21	100	100	5	7	10.8	1.0	5.8	8.0
	BARI Alu-25	100	100	4	6	11.6	1.0	9.1	10.4
	BARI Alu-28	100	100	7	7	33.8	5.0	11.3	7.6
20	BARI Alu-7	80	100	5	11	12.2	1.2	5.5	9.6
	BARI Alu8	100	100	6	10	11.4	1.0	6.1	10.6
	BARI Alu-12	100	100	4	9	12.6	1.0	4.7	9.8
	BARI Alu-21	100	100	5	7	10.8	1.0	8.6	10.0
	BARI Alu-25	100	100	5	5	11.0	1.0	7.7	11.6
	BARI Alu-28	100	100	7	7	14.6	1.0	7.1	9.8
40	BARI Alu-7	100	100	7	11	10.8	1.4	3.8	14.2
	BARI Alu8	80	100	10	13	7.4	1.2	2.5	4.8
	BARI Alu-12	100	100	9	12	10.6	1.0	4.2	12.6
	BARI Alu-21	80	100	5	13	11.0	1.2	3.9	18.2
	BARI Alu-25	80	80	6	6	11.8	1.0	3.6	8.8
	BARI Alu-28	80	80	11	12	9.4	1.4	2.5	9.2



0 20 40 g/l 0 20 40 g/l

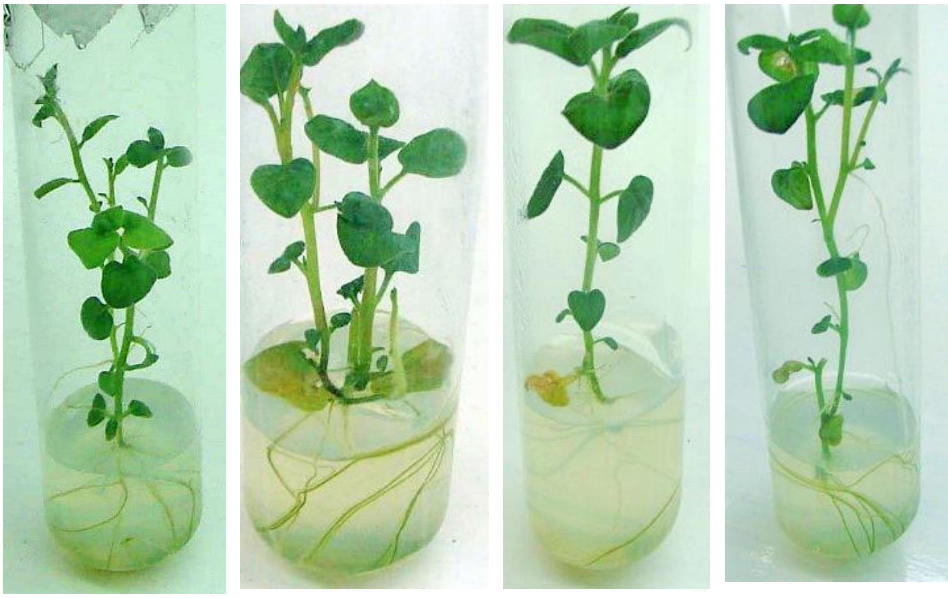
BARI Alu-7 BARI Alu-8

Fig.2. *In vitro* response of potato varieties on different concentrations of sorbitol after eight weeks of

In vitro performances of ten potato varieties in 20g/l Sorbitol supplemented MS medium from nodal explant are shown in Table 5 and Fig.3. Cent percent shoots and roots were initiated from BARI Alu-28 and BARI Alu-32 produced after three months conservation. BARI Alu-8 produced the lowest roots (78%) and BARI Alu-7 produced the lowest (50%) shoots (Table 5).

Table 5. In vitro conservation of potato in sorbitol from nodal explant after three months of culture during 2014-15

Name of variety	% Root initiation	% shoot initiation	Days to root initiation	No. of leaflet	No. of shoot	Length of shoot (cm)	No. of root
BARI Alu-7	90	50	9.4	10.2	3	6.2	5.2
BARI Alu-8	78	78	9.4	18.6	3.4	11.7	11.6
BARI Alu-12	82	80	9.6	15.2	3	5.3	5.4
BARI Alu-21	80	80	9.2	15.8	2	5	3.4
BARI Alu-25	83	83	9.8	14.4	4	11.9	12.4
BARI Alu-28	100	100	10.6	20	3	9.1	7.2
BARI Alu-32	100	100	8.8	16.2	3.4	8.3	8
BARI Alu-33	83	84	8.4	20.2	2	11.6	5.4
BARI Alu-37	81	83	8.6	13.8	2	5.1	5.8
BARI Alu-41	83	82	8.6	19	2.6	6.5	6.8
Average	86	82	9.2	16.3	2.8	8.1	7.1
LSD (1%)	1.83	1.23	2.21	9.96	2.86	3.1	2.61



BARI Alu-8 BARI Alu-7 BARI Alu-32 BARI Alu-28

Fig. 3. *In vitro* conservation potato varieties for three months culturing in MS medium with 20g/l sorbitol

All the varieties initiated roots and shoots within 8.4 to 10.6 days. BARI Alu-28 and BARI Alu-33 produced the maximum leaflets (20 and 20.2) while the BARI Alu-7 produced the minimum leaflets (10.2). The varieties produced 2 to 4 shoots and 3.4 to 12.4 roots. The maximum shoot length (11.9 cm) was exhibited in BARI Alu-25, BARI Alu-8 (11.7) and BARI Alu-33 (11.6), and minimum (5 cm) obtained from BARI Alu-21. Considering all parameters, BARI Alu-28 and BARI Alu-32 performed better for shoot proliferation through node culture.

In vitro performances of nine potato varieties in sorbitol (20 g/l) from nodal explant are shown in Table 6 and Fig.4. The varieties produced 86 to 100% roots within 7 days and 90 to 100% shoots within 11 days. After five months conserved, BARI Alu-7 produced the maximum leaflets (29.8) while the BARI Alu-41 produced the minimum leaflets (16.2).

The varieties produced 6 to 13.8 shoots and 5 to 11.2 roots. The maximum shoot length (12.2 cm) was exhibited in BARI Alu-25 and BARI Alu-28, and minimum (9.9 cm) obtained from BARI Alu-37. Among the varieties, BARI Alu-7 and BARI Alu-37 performed better for shoot proliferation (minimum growth) through node culture.

Table 6. ***In vitro*** **conservation of potato in sorbitol from nodal explant for five months during 2015-16**

Name of variety	% Root initiation	% Shoot initiation	Days to root initiation	Days to shoot initiation	No. of leaflet	No of shoot/ plantlet	No. of root/ plantlet	Shoot length (cm)
BARI Alu-7	100	100	6	11	29.8	7	6.2	10.7
BARI Alu-8	86	100	7	8	26.8	6	5	11.1
BARI Alu-12	100	100	5	6	27	6.6	6.4	11
BARI Alu-25	100	90	6	11	26	10	7.4	12.2
BARI Alu-28	100	100	7	7	24	9.4	8.8	12.2
BARI Alu-32	100	100	7	6	27	10.2	9.8	12
BARI Alu-33	100	100	5	5	28	13.2	13	11.6
BARI Alu-37	90	100	3	4	18.8	12.6	11.2	9.9
BARI Alu-41	100	100	5	6	16.2	13.8	11.2	11.2
Average	97.3	98.9	5.6	7.2	24.8	9.9	8.7	11.3
LSD (0.01)	-	-	2.33	2.77	9.29	5.11	1.74	2.94

BARI Alu-7 BARI Alu-8 BARI Alu-28 BARI Alu-37 BARI Alu-41

Fig. 4. *In vitro* conservation of potato varieties for five months culturing in MS medium with 20g/l sorbitol.

The efficacy of mannitol versus sorbitol for *in vitro* conservation of potato microplants at low (7±1 °C) temperature was previously studied. Two concentrations of sucrose (20 and 40 g/l) in combination with two concentrations (20 and 40 g/l) of either mannitol or sorbitol in Murashige and Skoog (MS) medium were tested. Microplant survival, microplant condition, and root growth in three potato genotypes belonging to different maturity groups were studied up to 18 months of *in vitro* storage without subculturing. Best results were achieved with MS medium having 20 g/l sucrose plus 40 g/l sorbitol. After 18 months without subculturing, maximum survival 58.0%) coupled with a microplant condition good enough to provide suitable nodes for subculturing was observed with the use of this medium (Gopal and Chauhan, 2010).

Many potato conservation units use low temperatures (6 to 8^0C) and 16 h photoperiod (15 to 30 µmol m^2 s^1 light intensity from cool white fluorescent lamps) for potato conservation despite the fact that maintenance of plantlets at 6 to 8^0C can be energy demanding due to high electricity charges. Previous report also showed that *in vitro* plantlets can be effectively conserved at 24 ± 1^0C using 20g/l sucrose and 40g Sorbitol for 12 months (Gopal *et al.* 2002). Thus minimizing cooling costs associated with low temperature conservation. Present study demonstrated that potato can be conserved efficiently at 22 ± 1^0C for 5 months.

Conclusion

The results of the present study suggested that sorbitol (20 g/l) with 3% sucrose showed good performance in *in vitro* conservation of potato varieties. The minimal shoot proliferation was achieved in BARI Alu-7 and BARI Alu-37 through node culture. A protocol for *in vitro* conservation from nodal explants of potato varieties has been developed in this study. This protocol can be used for *in vitro* medium term conservation of potato varieties for germplasm and variety maintenance.

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References

BBS. 2022. Bangladesh Bureau of Statistics. Year Book of Agricultural Statistics. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

Engels, J. M. M. and W. E. Andreas. 2021. A critical review of the current global ex situ conservation system for plant agrobiodiversity. I. History of the development of the global system in the context of the political/legal framework and its major conservation components. *Plants.* **10**: 1557.

FAOSTAT. 2022. Food and Agriculture Organization of the United Nations. 2022. Available online: http://www.fao.org/faostat/es/#data (accessed on 25 April 2023).

Golmirzaie A., A. Panta and J. Toledo. 1999. Advances in the conservation of root and tuber crops. In: Plant Coservation Biotechnology. E. E. Benson (ed.). Yaylor and Francis, London. pp. 165-78.

Gopal J., A. Chamail and D. Sarkar. 2002. Slow-growth *In vitro* conservation of potato germplasm at normal propagation temperature. *Potato Res*. **45**: 203-213.

Gopal J. and N. S. Chauhan. 2010. Slow-growth *In vitro* conservation of potato germplasm at low temperature. *Potato Res*. **53**: 141-149.

Kulak, V., S. Longboat, N. D. Brunet, M. Shukla, P. Saxena. 2022**.** In Vitro Technology in Plant Conservation: Relevance to Biocultural Diversity. *Plants*. **11**: 503.

Panis, B., M. Nagel and I. Van den Houwe. 2020. Challenges and prospects for the conservation of crop genetic resources in field genebanks, in In vitro collections and/or in liquid nitrogen. *Plants.* **12**: 1634.

Pleyerová, I., J. Hamet, H. Konrádová. *et al*. 2022. Versatile roles of sorbitol in higher plants: luxury resource, effective defender or something else?. *Planta* **256:** 13. https://doi.org/10.1007/s00425-022-03925-z

Ruta, C., M. Lambardi and E. A. Ozudogru.2020. Biobanking of vegetable genetic resources by in vitro conservation and cryopreservation. *Biodivers. Conserv.* **29**: 3495–3532.

Salgotra, R.K. and B. S. Chauhan. 2023. Genetic Diversity, Conservation and Utilization of Plant Genetic Resources. *Genes.* **14**: 174.

Spinoso-Castillo, J.L.; J. A. Pérez-Sato; S. S. Chettino-Salomón; J. J. Bello-Bello.2022**.** An alternative method for medium-term in vitro conservation of different plant species through gibberellin inhibitors. *Vitr. Cell. Dev. Biol.-Plant.* **58**: 606–614.

Zsögön, A., L.E.P Peres, Y. Xiao, J. Yan, A. R. Fernie. 2022. Enhancing crop diversity for food security in the face of climate uncertainty. *Plant J*. **109**: 402–414.

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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.

Cano, H., N. Gabas and J. P. Canselier. 2001. Experimental study on the ibuprofen crystal growth morphology in solution. *J. Crystal Growth* **224:** 335.

De Beer, G. R.1940. Embryology and Taxonomy. *In: The New Systematics.* (Ed. Huxely, J.). Oxford Univ. Press, London. pp. 365-393.

Dockery, D. J. and C. A. Pope, 1994. Acute respiratory effects of particulate air pollution. *Ann. Rev. Public Health* **15:** 107-110.

Edmonds, J. and K. M. Karp. 1997. Theoretical improvements in Algorithmic Efficiency for network flow problems. *J. Assoc. Comput. Mach.* **19:** 248-264.

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