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EFFECT OF GIBBERELIC ACID APPLICATION ON THE GERMINATION AND SEEDLING GROWTH OF BARI HYBRID BHUTTA-16 UNDER SALINE CONDITION

N. J. EMU¹, I. J. MUMU², M. A. H. CHOWDHURY³
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Abstract

The study was conducted at Agronomy Laboratory of Agrotechnology Discipline, Khulna University, Khulna, during August 2022, to assess the germination and seedling growth of BARI Hybrid Bhutta-16 under salinity stress with application of gibberellic acid. The experiment was carried out in a factorial design with two factors: four different concentrations of salt solutions and three different concentrations of gibberellic acid solutions. Salt concentrations were 10 dS/m, 20 dS/m, 30 dS/m and 0 dS/m as control and gibberellic acid concentrations 100 ppm, 150 ppm and 0 ppm as control. Three replications of the experiment were set up using a Completely Randomized Design. Data related to seed germination and seedling growth parameters were collected. Germination and seedling growth parameters decreased with increase in salinity levels but increased with increase in gibberellic acid levels. In case of interaction, there were inconsistent variation in germination parameters; germination percentage, germination capacity, germination energy, germination speed. Seedling growth parameters like root fresh weight and root dry weight showed better results; 436 to 480 mg and 55 to 67 mg, respectively, against different salinity levels with gibberellic acid application. Other parameters like root length, shoot length, shoot fresh weight, shoot dry weight and seedling vigor index were found better upto 20 dS/m salinity with 0, 100 and 150 ppm gibberellic acid but in higher salinity (30 dS/m) their performance was not good.

Key Word: Maize, Salinity stress, Growth regulator, Gibberellic Acid, Seedling growth, Shoot length, BARI Hybrid Bhutta-16.

Introduction

Maize (*Zea mays*) is a cereal grain first domesticated by indigenous people in southern Mexico about 10,000 years ago. A study by Matsuoka *et al.* (2002) and Vigouroux *et al.* (2003) demonstrated that, rather than the multiple independent domestication models, all maize arose from a single domestication in southern Mexico about 9,000 years ago. The study also showed that the highland maize

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varieties from Mexico are the oldest varieties still in existence. Maize becomes a staple food in many parts of the world, with the total production surpassing that of wheat or rice. It is an important C₄ plant from the Poaceae family and moderately sensitive to salt stress (Mass *et al.* 1983 and Solaimani *et al.* 2020). In 2021, total world production was about 1.2 billion tones led by the U.S.A with 31.0% and China 22.4% (FAOSTAT, 2018).

Maize is grown under a wide spectrum of soil and climatic conditions and it is an extremely versatile crop (Fernandez-Armesto, 2011). Soil salinity poses a severe threat to global production of maize for its moderate sensitivity to salt stress. Germination and stand establishment of maize are more sensitive to salt stress than later development stages (Solaimani *et al.* 2020). Symbiotically-interacting rhizosphere microorganisms, assist root plant transformation and mobilization of important nutrients such as nitrogen, phosphorus, potassium and micronutrients (Adal, 2023; Das and Haque, 2025 and Fu *et al.* 2025). High rhizosphere Na⁺ and Cl⁻ decrease plant uptake of N, P, Ca, Mg and Fe. Reduced grain weight and number is responsible for low grain yield in maize under salt stress. Poor kernel setting under salt stress is caused by sink restrictions and decreased acid invertase activity in growing grains. Exclusion of excessive Na⁺ or its compartmentation into vacuoles is an important adaptive strategy for maize under salt stress. Salt resistance in maize is mostly dependent on the up-regulation of genes involved in antioxidant defense and β-expansin proteins. Soils with excess soluble salts or exchangeable Na⁺ in the root zone are termed as salt-affected soils. More than 800 million hectares of land worldwide is affected by either salinity (397 million hectares) or sodicity (434 million hectares) (FAO, 2005). Osmotic stress caused by short-term salt stress on maize plants affects plant growth in the early stages of salt stress (Sümer *et al.* 2004) before lethal Na concentrations are reached (Fortmeier and Schubert, 1995).

Gibberellic acid is a phyto-hormone found in plants and fungi that stimulates cell growth and elongation. Gibberellic acid induces the production of mRNA molecules that code for hydrolytic enzymes in the cells of germination-initiating seeds. Applications of extremely low quantities can have a significant impact while too much will have the reverse result since gibberellic acid controls growth, they can stimulate rapid stem and root growth, induce mitotic division in the leaves of some plants and increase seed germination rates (Miriam, 1976). As a growth regulator or promoter, gibberellic acid has a great capacity of alleviation of salinity stress (Shaddad *et al.* 2013). Application of gibberellic acid significantly promotes plant length and plant fresh/dry biomass while markedly hindered by salinity stress (Hamayun *et al.* 2010).

In view of the above facts, the present research work has been undertaken in the Agronomy laboratory of Agrotechnology Discipline, Khulna University, Khulna,

with the objective to evaluate the germination and seedling growth of BARI Hybrid Bhutta-16 under salinity stress condition with the application of gibberellic acid.

Materials and Methods

BARI Hybrid Bhutta-16 is lodging tolerant due to its short-stature properties. The saline-tolerant BARI Hybrid Bhutta-16 can withstand salinities of up to 8 dS/m in the soil. The experiment was set through the glass petri-dishes of 9 cm in diameter. Seeds were soaked in 0.1% HgCl₂ for 10 minutes in a glass beaker for surface sterilization. After 10 minutes, seeds were rinsed by distilled water for three times. Then the surface sterilized seeds were air dried for 30 minutes. After drying, the seeds were soaked into gibberellic acid (0, 100 and 150 ppm) for 24h. The gibberellic acid treated seeds were placed on the filter papers soaked by 0, 10, 20 and 30 dS/m salt solutions on the petri-dishes. There were three layers of filter papers per petri-dish. In each petri-dish, 12 seeds were placed with the help of forceps. After five days of placement of seeds, salt solution was applied on a regular basis to prevent dehydration. The layer of filter papers could absorb approximately 6 ml of salt solution. It was ensured that there should not be any standing water. The salt solutions were applied as the absorbance level of the layer of filter papers. A Completely Randomized Design (CRD) was followed with three replications in the experiment. Each treatment combination was consisted of four petri-dishes. So, the whole study was performed in altogether 144 petri-dishes. After 15 days of planting the seeds, eight seedlings from each treatment were collected randomly for the measurement of the root length, shoot length, root fresh weight, shoot fresh weight, root dry weight, shoot dry weight and seedling vigor index. After measuring the root length, shoot length, root fresh weight and shoot fresh weight, the plant samples were oven dried for 24h. After 24h, root dry weight and shoot dry weight were recorded.

$$10 \text{ dS/m} = 6.4 \text{ g/L}$$

$$100 \text{ ppm} = 0.1 \text{ g/L}$$

$$\text{Germination Percentage (\%)} = \frac{\text{Total number of seeds germinated}}{\text{Total number of seeds set for test}} \times 100$$

$$\text{Germination Capacity (\%)} = \frac{\text{Number of seeds germinated at 168h}}{\text{Total number of seeds set for test}} \times 100$$

$$\text{Germination Energy (\%)} = \frac{\text{Number of seeds germinated at 72h}}{\text{Total number of seeds set for test}} \times 100$$

$$\text{Germination Speed (\%)} = \frac{\text{Number of seeds germinated at 72h}}{\text{Number of seeds germinated at 168h}} \times 100$$

$$\text{Seedling Vigor Index} = \text{Av. shoot length} + \text{Av. root length} \times \text{Germination percentage}$$

All the growth parameters of seedlings were recorded after 15 days of seed placement. The measurement of root length and shoot length in centimeter (cm) were taken from the collar region to the root tip and shoot tip. The measurement of root fresh weight and shoot fresh weight in gram (g) were recorded immediately after the collection of the seedling samples to prevent the moisture loss. The measurement of root dry weight and shoot dry weight in milligram (mg) were recorded after 24h of oven dry of the root and shoot collected from seedling samples. All the data collected on different parameters were statistically analyzed following the analysis of variance (ANOVA) technique using Statistix 10 computer package program. The mean differences were adjusted at 1% and 5% level of significance using the Duncan's New Multiple Range Test (DMRT).

Results and Discussion

Germination Percentage

Results showed that germination percentage differed from 79.17% to 91.67% (Table 1 to Table 3). The highest germination (91.67%) was found at salinity level of 0 dS/m and gibberellic acid level of 100 ppm and 150 ppm. The lowest germination (79.17%) was found in levels of 20 dS/m salinity and 0 ppm gibberellic acid (control). Gibberellic acid can mitigate moderate level of salinity stress in seed germination. It is not effective in high salinity condition.

Germination Capacity

Results showed that germination capacity differed from 79.17% to 91.67% (Table 1 to Table 3). The highest germination capacity (91.67%) was found at salinity level of 0 dS/m and gibberellic acid level of 100 ppm and 150 ppm. The lowest germination capacity (79.17%) was found in levels of 20 dS/m salinity and 0 ppm gibberellic acid (control). Germination capacity sharply decreased with the increase of salinity level and decrease of gibberellic acid level.

Germination Energy

Results showed that germination energy differed from 65.97% to 84.72% (Table 1 to Table 3). The highest germination energy (84.72%) was found at salinity level of 0 dS/m and gibberellic acid level of 150 ppm on the other hand the lowest germination energy (65.97%) was recorded in levels of 20 dS/m salinity and 100 ppm gibberellic acid. Germination energy sharply decreased with the increase of salinity level.

Germination Speed

Results showed that germination speed differed from 81.58% to 94.63% (Table 1 to Table 3). The highest germination speed (94.63%) was found at salinity level of

0 dS/m and gibberellic acid level of 0 ppm (control) on the other hand the lowest germination speed (81.58%) was found in levels of 30 dS/m salinity and 100 ppm gibberellic acid. Germination speed sharply decreased with the increase of salinity level.

Germination parameters like germination percentage, germination capacity, germination energy and germination speed were significantly affected by salinity levels showing a lower value with higher salinity that agreed with El-Kamar *et al.* (2013) and Ali and Hamza (2014). However, these parameters did not show significantly variable response due to different levels of gibberellic acid application.

Significant variation was found for the interaction between salinity and gibberellic acid levels in relation to germination percentage (Table 3). Interaction effect of salinity and gibberellic acid responded significantly on germination parameters but were not consistent and did not maintain a definite trend.

Table 1. Effect of salinity levels on seed germination parameters of BARI Hybrid Bhutta-16

Salinity level (EC dS/m)	Germination Percentage (%)	Germination Capacity (%)	Germination Energy (%)	Germination Speed (%)
S ₀	90.5 a	90.5 a	84.02 a	92.92 a
S ₁	87.5 ab	87.5 ab	80.78 ab	92.35 ab
S ₂	82.87 b	82.87 b	72.91 c	87.83 ab
S ₃	84.49 b	84.49 b	73.61 bc	86.74 b
CV (%)	6.37	6.37	9.85	6.47
Level of Significance	*	*	*	*

Table 2. Effect of gibberellic acid levels on seed germination parameters of BARI Hybrid Bhutta-16

GA ₃ level (ppm)	Germination Percentage (%)	Germination Capacity (%)	Germination Energy (%)	Germination Speed (%)
G ₀	85.59	85.59	78.12	91.16
G ₁	85.41	85.41	75.17	87.67
G ₂	88.02	88.02	80.2	91.0658
CV (%)	6.37	6.37	9.85	6.47
Level of Significance	NS	NS	NS	NS

Table 3. Interaction effect of salinity and gibberellic acid levels on seed germination parameters of BARI Hybrid Bhutta-16

Salinity level (EC dS/m)	GA ₃ level (ppm)	Germination Percentage (%)	Germination Capacity (%)	Germination Energy (%)	Germination Speed (%)
S ₀	G ₀	88.19 a-c	88.19 a-c	83.333 ab	94.63 a
S ₀	G ₁	91.67 a	91.67 a	84.03 a	91.653 ab
S ₀	G ₂	91.67 a	91.67 a	84.72 a	92.49 ab
S ₁	G ₀	86.11 a-c	86.11 a-c	79.167 a-c	91.95 ab
S ₁	G ₁	86.8 a-c	86.8 a-c	81.943 ab	94.34 a
S ₁	G ₂	89.583 ab	89.583 ab	81.25 a-c	90.783 a-c
S ₂	G ₀	79.86 c	79.86 c	70.833 b-d	88.943 a-c
S ₂	G ₁	79.17 c	79.17 c	65.97 d	83.123 bc
S ₂	G ₂	89.587 ab	89.587 ab	81.943 ab	91.443 ab
S ₃	G ₀	88.19 a-c	88.19 a-c	79.170 a-c	89.107 a-c
S ₃	G ₁	84.03 a-c	84.03 a-c	68.747 cd	81.58 c
S ₃	G ₂	81.25 bc	81.25 bc	72.917 a-d	89.547 a-c
CV (%)		6.37	6.37	9.85	6.47
Level of Significance		*	*	*	*

The figures having same letter(s) in a column are not significantly different by DMRT.

When compared to non-stimulated seed, seedlings from stimulated with gibberellic acid exhibited greater germination and other characteristics. They also had lower ratios of salt to potassium and higher chlorophyll content, two chemical indications of increased plant tolerance to salinity that agreed with Ali and Hamza (2014).

Root Length: Results showed that root length of seedlings differed from 8.88 cm to 19.75 cm (Table 4 to Table 6). The highest root length of seedlings (19.75 cm) was found at salinity level of 0 dS/m and gibberellic acid level of 0 ppm (control), which was statistically similar to that of salinity level of 0 dS/m and gibberellic acid level of 150 ppm. The lowest root length of seedlings (8.88 cm) was found in salinity levels of 30 dS/m and 100 ppm gibberellic acid. Root length of seedlings sharply decreased with the increase of salinity level and decrease of gibberellic acid level.

Shoot Length: Results showed that shoot length of seedlings varied significantly and ranged from 21.92 cm to 42.63 cm (Table 4 to Table 6). The highest shoot length of seedlings (42.63 cm) was found at salinity level of 0 dS/m and gibberellic acid level of 150 ppm. The lowest shoot length of seedlings (21.92 cm) was

recorded in levels of 30 dS/m salinity and 0 ppm gibberellic acid (control). Shoot length of seedlings sharply decreased with the increase of salinity level and decrease of gibberellic acid level.

Root Fresh Weight: Results showed that root fresh weight of seedlings differed from 0.32 g to 0.54 g (Table 4 to Table 6). The highest root fresh weight of seedlings (0.54 g) was found at salinity level of 30 dS/m and gibberellic acid level of 0 ppm (control) that was similar with the salinity level of 0 dS/m and gibberellic acid level of 0 ppm (0.53 g). The lowest root fresh weight of seedlings (0.32 g) was found in levels of 0 dS/m salinity (control) and 100 ppm gibberellic acid.

Shoot Fresh Weight: Results showed that shoot fresh weight of seedlings differed from 0.389 g to 0.861 g (Table 4 to Table 6). The highest shoot fresh weight of seedlings (0.861 g) was found at salinity level of 0 dS/m (control) and gibberellic acid level of 150 ppm. The lowest shoot fresh weight of seedlings (0.389 g) was found in levels of 30 dS/m salinity and 100 ppm gibberellic acid. Shoot fresh weight of seedlings sharply decreased with the increase of salinity level and decrease of gibberellic acid level.

Root Dry Weight: Results showed that root dry weight of seedlings differed from 52 mg to 74 mg (Table 4 to Table 6). The highest root dry weight of seedlings (74 mg) was found at salinity level of 0 dS/m (control) and gibberellic acid level of 0 ppm (control). The lowest root dry weight of seedlings (52 mg) was found in levels of 30 dS/m salinity and 100 ppm gibberellic acid.

Shoot Dry Weight: Results showed that shoot dry weight of seedlings differed from 46 mg to 79 mg (Table 4 to Table 6). The trend is similar to that of shoot fresh weight. The lowest shoot dry weight of seedlings (46 mg) was found in level of 20 dS/m salinity and 150 ppm gibberellic acid. Shoot dry weight of seedlings sharply decreased with the increase of salinity level.

Seedling Vigor Index: Results showed that seedling vigor index of seedlings differed from 748.6 to 1775.2 (Table 4 to Table 6). The highest seedling vigor index of seedlings (1775.2) was found at salinity level of 0 dS/m (control) and gibberellic acid level of 0 ppm (control). The lowest seedling vigor index of seedlings (748.6) was found in levels of 30 dS/m salinity and 150 ppm gibberellic acid. Seedling vigor index of seedlings sharply decreased with the increase of salinity level.

Seedling growth parameters were significantly affected due to increase in salinity levels with an exception in root fresh weight. Gibberellic acid application influenced some seedling growth parameters like shoot length, root fresh weight, root dry weight and shoot dry weight that agreed with Shahzad *et al.* (2021) but differed with Khan and Ansari (1998).

Results showed significant variation in the interaction between salinity and gibberellic acid levels in relation to root length of seedlings (Table 6). Interaction effect of salinity and gibberellic acid showed significant variation on all the seedling growth parameters.

Remarkable improvement was not found in root length, shoot length, shoot fresh weight, shoot dry weight and seedling vigor index due to gibberellic acid application in high salinity level (30 dS/m) but gibberellic acid improved the salinity effect on root fresh weight and root dry weight.

In our study we applied high levels of salinity (0-30 dS/m) and it was observed that gibberellic acid application can alleviate salinity effect on seedling growth upto 20 dS/m and in case of higher salinity (30 dS/m) it was ineffective.

Table 4. Effect of salinity levels on seedling growth parameters of BARI Hybrid Bhutta-16

Salinity level (EC dS/m)	Root Length (cm)	Shoot Length (cm)	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Root Dry Weight (mg)	Shoot Dry Weight (mg)	Seedling Vigor Index
S ₀	17.72 a	38.65 a	0.48	0.83 a	67 a	73 a	1641.41 a
S ₁	12.61 b	35.43 b	0.45	0.69 b	63 ab	70.4 a	1144.4 b
S ₂	10.06 c	28.05 c	0.438	0.48 c	55 b	49.8 b	861.38 c
S ₃	9.42 c	24.19 d	0.436	0.43 c	61 ab	49.5 b	817.97 c
CV (%)	14.08	6.7	15.83	13.17	13.16	13.4	15.7
Level of Significance	*	*	NS	*	*	*	*

Table 5. Effect of gibberellic acid levels on seedling growth parameters of BARI Bhutta-16

GA ₃ level (ppm)	Root Length (cm)	Shoot Length (cm)	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Root Dry Weight (mg)	Shoot Dry Weight (mg)	Seedling Vigor Index
G ₀	13.13	26.39 b	0.49 a	0.61	66 a	57 b	1156.94
G ₁	12.15	34.08 a	0.4 b	0.59	58 b	64 a	1083.72
G ₂	12.09	34.28 a	0.45 ab	0.64	62 ab	62 a	1108.21
CV (%)	14.08	6.70	15.83	13.17	13.16	13.40	15.70
Level of Significance	NS	*	*	NS	*	*	NS

Table 6. Interaction effect of salinity and gibberellic acid levels on seedling growth parameters of BARI Hybrid Bhutta-16

Salinity level (EC dS/m)	GA ₃ level (ppm)	Root Length (cm)	Shoot Length (cm)	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Root Dry Weight (mg)	Shoot Dry Weight (mg)	Seedling Vigor Index
S ₀	G ₀	19.75 a	31.16 c	0.53 a	0.85 a	74 a	67.1 ab	1775.2 a
S ₀	G ₁	16.06 b	42.17 a	0.32 c	0.79 ab	60.4 a-c	75.8 a	1517.17 a
S ₀	G ₂	17.35 ab	42.63 a	0.46 ab	0.861 a	69 ab	79 a	1631.903 a
S ₁	G ₀	12.15c-e	28.9 cd	0.44 ab	0.68 b	65 a-c	60 bc	1083.98 b-d
S ₁	G ₁	13.08 c	37.77 b	0.482 ab	0.66 b	61 a-c	76 a	1176.284 b
S ₁	G ₂	12.63 cd	39.6 ab	0.458 ab	0.76 ab	63 a-c	75 a	1172.956 bc
S ₂	G ₀	10.1 d-f	23.5 ef	0.483 ab	0.49 c	57 bc	50 cd	828.6 de
S ₂	G ₁	10.6 c-f	31.98 c	0.439 ab	0.52 c	58 bc	54 b-d	876.247 de
S ₂	G ₂	9.48 ef	28.6 cd	0.394 bc	0.47 c	53 c	46 d	879.35 c-e
S ₃	G ₀	10.5 c-f	21.92 f	0.54 a	0.446 c	67 ab	51 cd	940.096 b-e
S ₃	G ₁	8.88 f	24.4 ef	0.398 bc	0.389 c	52 c	48.8 cd	765.187 e
S ₃	G ₂	8.9 f	26.3 de	0.51 ab	0.47 c	64 a-c	49.2 cd	748.6 e
CV (%)		14.08	6.7	15.83	13.17	13.16	13.4	15.7
Level of Significance		*	*	*	*	*	*	*

The figures having same letter(s) in a column are not significantly different by DMRT.

EC = Electrical Conductivity, S₀ = 0 dS/m, S₁ = 10 dS/m, S₂ = 20 dS/m, S₃ = 30 dS/m, G₀ = 0 ppm, G₁ = 100 ppm, G₂ = 150 ppm, CV = Coefficient of Variation, * Significant variation shown by DRMT.

Conclusion

Results indicated that germination and seedling growth parameters decreased with the increased effect of salinity levels. It also indicated that germination and seedling growth parameters increased with the increased effect of gibberellic acid levels. It further indicated that salinity decreases germination and seedling growth. Gibberellic acid showed great influence on shoot length increase but does not enhance root growth. So, the interaction effect of salinity levels and gibberellic acid levels showed no variation. Gibberellic acid was effective to alleviate salinity stress up to 10 dS/m on germination and seedling growth parameters. Seedling shoot length was found better with 100 ppm of gibberellic acid for 20 dS/m of salinity. Over application of gibberellic acid might be the reason behind deterioration of the growth of the seedlings that supports Zhu *et al.* (2019), as the growth regulators have trace amount of necessity for the plants. As BARI Hybrid

Bhutta-16 can tolerate up to 8 dS/m salinity level, the performance in 30 dS/m salinity level is very poor. At the level of 20 dS/m salinity stress, the seedlings of BARI Hybrid Bhutta-16 can show some better performance with the help of 100 ppm gibberellic acid concentration by alleviating the salinity stress.

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POTTING MEDIA OPTIMIZATION FOR QUALITY SEEDLING PRODUCTION OF BLACK PEPPER (*PIPER NIGRAM*) USING RUNNER SHOOT CUTTINGS

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Abstract

The present study was conducted in the lath house of Citrus Research Station, Bangladesh Agricultural Research Institute, Jaintapur, Sylhet, during the years 2020 and 2021 (from April to July) to find out the best potting media for quality seedling production of black pepper from runner shoot cuttings. Two growing media, namely soil and coco dust, and two nutrient sources, viz. vermicompost and farmyard manure (FYM) were combined in different ratios to make nine potting media combinations. These were: T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v). The experiment was laid out in a randomized complete block design with three replications using ten cuttings per replication for each treatment. Among the different potting media compositions, coco dust + vermicompost at 1:1 v/v ratio resulted in the earliest sprouting (17 days and 19 days), the highest success in sprouting percentage (100% and 86.67%), maximum survival percentage (94.33% and 89%), and maximum number of newly emerged leaves cutting⁻¹ (4.67) compared to the control and other treatments in both years (2020 and 2021). This treatment also performed best in terms of root parameters viz. maximum number of primary roots cutting⁻¹ (15.67 and 16), longest root (24 cm and 19 cm), maximum root fresh weight (1.05 g and 1.14 g) and root dry weight (0.07 g and 0.42 g). Additionally, the longest shoot (37 cm and 39 cm) and the maximum shoot fresh weight (12.90 g and 17.99 g) and dry weight (3.14 g and 4.29 g) were also recorded in coco dust + vermicompost (1:1 v/v). The study suggests that the media consisting of coco dust + vermicompost (1:1 v/v) could be a better option for maximizing high- quality seedling production of black pepper using runner shoots cutting.

Keywords: Black pepper, Seedling, Potting media, Coco dust, Vermicompost, Cutting, Runner shoot

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Introduction

Black pepper (*Piper nigrum* L.), a member of the Piperaceae family, is a perennial climbing plant which dried fruits are used as spice. In Bangladesh, it is popularly known as ‘Golmorich’ cultivated mainly in Sylhet, Habiganj, Chattogram and Bogura districts including three hill districts, Khagrachari, Rangamati and Bandarban. Black pepper is a familiar spice in our country because it is a constant companion in the cooking of women to make their cooking taste incomparable. It is called the ‘King of Spices’ and ‘black gold’ worldwide. The crop originated in India and is now cultivated in tropical regions of the world (Hao *et al.*, 2012). Currently, it is largely grown in India, Brazil, Indonesia, Malaysia, Vietnam and China (Talucder, 2019). Bangladesh has a strong domestic demand for black pepper and imports regularly to meet the national demand (Anon., 2018). However, among several challenges, which hinder black pepper production in Bangladesh, the unavailability of quality planting materials for large scale multiplication is an important one (Talucder, 2019). Black pepper can be propagated through both sexually by seeds and asexually by cuttings, grafting, budding and layering. Due to its heterozygous nature, seedlings do not breed true to type and known to have long juvenile (pre-bearing) period. So, vegetative propagation is commercially adopted in this crop. Among vegetative methods, propagation through cuttings is preferred for large scale multiplication of this spice crop because this method is comparatively easy compared to other vegetative means. Good quality planting material of black pepper can be produced vegetatively, especially by cutting in a short period, which is ideal and also cost-effective (Abassi *et al.*, 2010; Ee and Shang, 2017). Cuttings taken from runner shoots (Creeping shoots on the ground) and orthotropic shoots (erect growing shoots) are used commercially for black pepper’s vegetative propagation. However, it is quite difficult to establish vine cuttings in the nursery because of their high mortality rate (Ee and Shang, 2017). As a result, to select a proper potting media for raising quality seedlings of black pepper using runner shoot cuttings in the nursery is very important.

Potting or rooting medium is important for rooting and overall success of the cuttings under nursery conditions (Agbo and Omaliko, 2006). Moreover, potting media plays a crucial role by providing the necessary support, aeration, moisture retention, and nutrients for healthy root development, directly impact the overall growth and success of young plants; essentially acting as a foundation for strong, robust root systems that can effectively absorb water and nutrients (Nadoda *et al.*, 2023). A high-quality growing medium significantly influences the growth, establishment, and survival, as well as aiding in further establishment of the saplings under field conditions (Landis *et al.*, 2014). However, there are a limited number of researches regarding the outcomes of different potting media on black pepper cuttings in Bangladesh. Therefore, the present investigation was carried out to optimize the potting media for raising quality seedlings of black pepper using runner shoot cutting under nursery condition.

Materials and Methods

The present investigation was conducted in a naturally well-ventilated lath house at the nursery of Citrus Research Station, Bangladesh Agricultural Research Institute (BARI), Jaintapur, Sylhet, for two consecutive years, 2020 and 2021. The study area was geographically located between 25.13562° N latitude and 92.13217° E longitude with an average elevation of 34 meters. The climatic condition was characterized by hot and humid summer and a relatively cold winter with the maximum temperature of 35.45°C in May, and the lowest 9.48°C in January, while maximum rainfall occurs in June (762 mm) and minimum in January (0.42 mm) (Rahman *et al.*, 2022). The experimental location lies on the Northern and Eastern Piedmont Plains (AEZ 22 of Bangladesh) having very strongly acidic (pH < 4.2) sandy loam soil. We have used garden top soil for the experiment. The soil analysis stated that the present status of nitrogen 0.14%, potassium 0.26 meq 100 g⁻¹ soil, calcium 1.09 meq 100 g⁻¹ soil, magnesium 0.57 meq 100 g⁻¹ soil, sulfur 20.62 µg g⁻¹ soil, zinc 3.07 µg g⁻¹ soil and boron 1.56 µg g⁻¹ soil. Nutrient and chemical properties of farmyard manure and vermicompost with coco dust from the secondary sources are presented in Table 1.

Table 1. Nutrients and chemical properties of Farm Yard Manure (FYM) (Ravimycin, 2016; Hoque *et al.*, 2022), Vermicompost (VC) (Ravimycin, 2016; Chahal *et al.*, 2019) and Coco dust (Raquipo *et al.*, 2024)

Nutrients/Chemical properties	Farm Yard Manure	Vermicompost	Coco dust
Organic C (%)	13.6	11.8	8.61
N (%)	2.63	1.03	0.431
P (%)	9.17	6.59	0.061
K (%)	1.55	2.95	1.792
Ca (%)	7.8	4.55	0.228
Mg (%)	2.44	1.19	0.134
Na (%)	-	-	0.279
Cl (%)	-	-	1.172
S (%)	0.42	0.5	0.039
B (ppm)	33.7	35	23.5
Zn (ppm)	22.8	16.2	29.4
Mn (ppm)	84.9	65.3	27.3
Cu (ppm)	4.8	3.12	6.5
Fe (ppm)	182	132.8	510.5
pH	6.7	6.9	6.2
EC (dS m ⁻¹)	3.6	3.1	1.28

The treatments comprised nine treatments, viz. T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost soil (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v) where soil and coco dust was used as the basal potting media, and farmyard manure (FYM) and vermicompost as nutrient suppliers. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each replication contained 10 black poly bags (7"×6") filled with the respective potting media. A total number of 270 (9×3×10) poly bags and 270 cuttings were used in the study.

Runner shoot cuttings of black pepper (*Piper nigrum* 'BARI Golmorich-1') were used as the planting material. The cuttings were collected from the black pepper garden of Citrus Research Station. The runner shoots (3 months old) were collected from the healthy mother plants (5-10 years old) for preparing the cuttings. The cuttings were prepared by giving a slant cut at the bottom and a round cut at the top keeping 4 nodes (approximate length 19 cm, diameter 2.3 mm and internode distance 6.3 cm) and one leaf at the top. To avoid fungal contamination, the cuttings were soaked in Mancozeb (Indofil @ 2g L⁻¹ of water) for 30 minutes followed by drying under shade for 30 minutes.

The cuttings were planted in nursery poly bags inserting two basal nodes deep in the potting media. One cutting was planted in each poly bag. The poly bags were watered immediately after planting the cuttings. Nursery poly bags having 8 (eight) holes at the bottom were used in the study so that the excess water can drain out easily. Other nursery managements were done at a regular interval.

Data were recorded on number of newly emerged leaves cutting⁻¹, number of primary roots cutting⁻¹, root length (cm), shoot length (cm), root fresh weight (g), root dry weight (g), shoot fresh weight (g) and dry weight (g) from 5 cuttings in both 2020 and 2021 after 60 days of cutting plantation. Data were also recorded on days to first sprouting, percentage of success, percentage of survival in both years. Percentage of success and percentage of survival data collected from the experiment were subjected to arc-sin transformation for normal distribution. Then, the transformed data were analyzed. Data on shoot and root parameters were also collected. Before recording the root parameters data, all the roots were gently washed under running water and dried under shade for 30 minutes. In case of dry weight determination, all the roots and shoots were oven dried in a convection oven (ESCO, Singapore) for 72 hours at 80°C. The recorded data were compiled and analyzed statistically using R 4.2.0 program and means were separated by Least Significant Difference (LSD) test at 5% level of significance.

Results and Discussion

Days to first sprout

The influence of potting media on days to first sprouting of black pepper cutting varied significantly among the treatments in both years of 2020 and 2021 (Fig. 1A). The results showed that T₆ treatment took the shortest time (17 and 19 days in 2020 and 2021, respectively) followed by T₃ and T₄ (20 days) in the first year and by T₇ (24 days) in the second year. The maximum days required for sprouting was recorded in T₁ (24 days in 2020 and 28 days in 2021) followed by T₉ (22.33 days) in the first year and by T₄ and T₅ (27 days) in the second year. From the results it is evident that time required for sprouting of black pepper cutting in 2021 was higher than that of 2020.

Sprouting of black pepper cutting could be achieved easily when the potting media has enough porosity, sufficient water holding and draining capacity, providing aeration to ensure root formation and growth (Landis *et al.*, 2014). Early sprouting using T₆ in our study indicated that T₆ offered superior conditions to the black pepper cuttings for the sprouting, compared to the other treatments. This could be due to using coco dust in this potting media, which have higher water holding and draining capacity, maximizing moisture supply as well as sufficient porosity, which could be resulted in faster roots emergence in cuttings. This potting media also contains vermicompost derived from cattle waste. Edwards and Burrows (1988) reported that vermicompost is highly porous, offering sufficient aeration, drainage and water-holding capacity. Moreover, it contains readily available plant nutrients, like nitrates, phosphorus, potassium, calcium, magnesium, and others etc. Furthermore, it contains biologically active substances like plant growth regulators (Tomati *et al.*, 1990). This finding agrees with Prajwal *et al.*, (2024) who recorded the least number of days to first and complete sprouting.

Number of newly emerged leaves cutting⁻¹

Number of newly emerged leaves cutting⁻¹ was significantly affected by different potting media (Fig. 1B). The maximum number of newly emerged leaves cutting⁻¹ was found in T₆ (4.67) in both years. In the first year, the second highest leaves cutting⁻¹ was recorded in T₅ (3.33), while, in the second year, treatment T₇ (4.0) gave the second highest leaves cutting⁻¹. In 2020, the least number of newly emerged leaves cutting⁻¹ was observed in T₈ and T₉ (1.33) followed by T₁ (1.67), whereas in 2021, its least number was noted in T₁ (2.0).

The number of leaves per plant is an important indicator of the ability of the plant to accumulate assimilates for the development of the plant (Weraduwege *et al.*, 2015). It was observed that the vines sprouted earlier had higher number of leaves than those delayed to sprout. However, the subsequent increase in the number of leaves is regulated by the ability of the young plant to uptake nutrients required for

growth and development, which is governed by the media composition (Akinrinola *et al.*, 2023). In the present study, we found maximum number of leaves cutting⁻¹ from treatment T₆ (coco dust + vermicompost at 1:1 v/v ratio), which could be attributed to the well-balanced growing environment created by coco dust and vermicompost together. Coco dust provides water retention and drainage facilities as well as improves aeration; while, vermicompost provides adequate supply of nutrients required for photosynthate accumulation (Prajwal *et al.*, 2024). Moreover, vermicompost is a rich source of nitrogen, which is required for photosynthesis and cell multiplication leading to maximize leaf number (Akinrinola *et al.*, 2023). Balanced media conditions are conducive to optimal root health also. As vermicompost contains some natural plant growth substances, these substances can stimulate cell division and leaf initiation, lead to an increase in the number of leaves (Grobkinsky *et al.*, 2016). Prasath *et al.* (2014) found higher number of leaves in black pepper cuttings grown in media consisting of cocopeat + vermicompost + *Trichoderma viridae* compared to other media. Usendi *et al.* (2022) also achieved maximum number of leaves in *Piper betel* treated with regular potting mixture and vermicompost (1:1). Contrary, lower number of leaves cutting⁻¹ was observed in T₁ (soil alone) agrees with the findings of Ismail-Embong *et al.* (2021), who reported under nutrient deficient conditions that fewer leaves are produced.

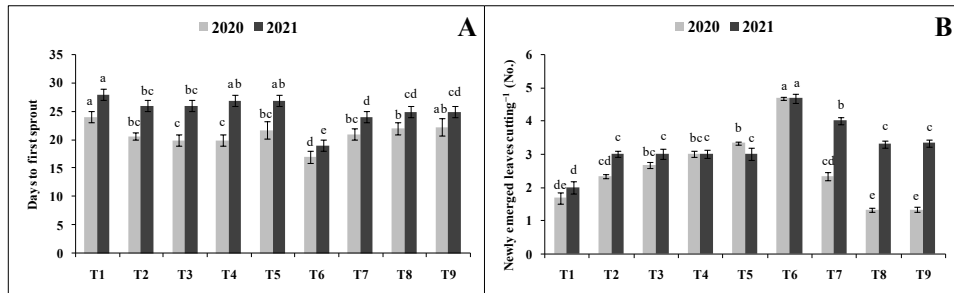


Fig.1. Effect of different potting media on time required to first sprouting (A), and number of newly emerged leaves cutting⁻¹ (B) in black pepper cuttings under nursery conditions.

[T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost soil (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v)]. * Means followed by similar letter (s) are not significantly different at 5 % level of probability by Least Significant Difference (LSD) test.

Success percentage of sprouting

After 60 days of cutting plantation, success percentage of sprouting of black pepper cutting was significantly influenced by potting media treatments in both years

(Table 2). The highest sprouting percentage was found in T₆ treatment (100.00% in 2020 and 89.00% in 2021) followed by T₄ (91.33%), T₂ (91.67%) and T₅ (93.67%) in the first year and by T₇ (82.33%) in the second year. In 2020, the least sprouting percentage was recorded in T₉ (73.00%), followed by T₈ (73.33%), whereas it's minimum percentage was found in T₁ (44.67%) in 2021.

Coco dust holds moisture effectively, that prevents dehydration of the cuttings. Vermicompost provides essential elements for plant growth. Moreover, vermicompost contains growth promoting substances and beneficial microorganisms that improve media health and nutrient cycling, creating a thriving ecosystem that improve nutrient availability and enhanced sprouting. Therefore, the superior performance of T₆ (coco dust + vermicompost at 1:1 v/v ratio) could be attributed to the nutrient rich environment of this potting media which support stout sprouting. Besides, the presence of growth promoting substances in the media might assist in better utilization of stored carbohydrates, and other factors for sprouting. Similar result was also reported by Akshay *et al.* (2014) who obtained highest sprouting in black pepper cuttings growing on the potting media comprised regular potting mixture and vermicompost at an equal ratio. Vadiraj *et al.* (1992) also reported similar results, stated that vermicompost could be an excellent source of plant growth regulators, which enhanced plant growth. Additionally, the higher sprouting percentage might be linked to the higher porosity and water holding capacity of coco peat (Landis *et al.*, 2014).

Percentage of survival

In both years of the study, the potting media treatments significantly influenced percentage of survival of black pepper cuttings (Table 2). The maximum survival was found in T₆ (94.33% and 86.67% in 2020 and 2021, respectively) followed by T₅ (89.67%) in 2020. The second highest survival was recorded in T₇ (73.33%) in 2021. In the first year, the minimum survival was recorded in T₈ (42.00%), followed by T₇ (59.33%); while in the second year, the least survival was observed in T₁ (33.33%) followed by T₅ (40.33%), and both T₃ and T₄ (46.67).

Lower survival percentage is generally occurred due to unfavorable environmental conditions or inherent properties of the growing media that hampers development (Akinrinola *et al.*, 2023). As our experiment was conducted in lath house the effect of environment was little. Therefore, percent survival of the black pepper cuttings might be attributed to the compositions of the potting media. Coco dust is an excellent potting media and improves root development, enhance nutrient uptake and increase diseases resistance. It also ensures the production of healthy, vigorous and uniform quality seedlings (Mohanta *et al.*, 2020). On the other hand, vermicompost contains growth promoting substances and beneficial microorganisms that improve media health and nutrient cycling. The combined effect of coco dust and vermicompost in the potting media create a convenient

environment for the black pepper cuttings and allocate more resources to root development and overall growth and contributes in higher survival percentage. Moreover, Atiyeh *et al.* (2002) stated that the presence of humic acid in vermicompost improves the physical properties of soil and facilitates to utilize plant nutrients, which also contributed to higher survival rates. Similar result for black pepper cuttings was also reported by Prajwal *et al.* (2024) in their study.

Table 2. Effect of different potting media on sprouting and survival (%) of black pepper cuttings under nursery conditions (60 days after cutting plantation)

Treatments	Success in sprouting (%)		Survival (%)	
	2020	2021	2020	2021
T ₁	80.33 # (63.70)	44.67 (41.93)	67.33 (55.15)	33.33 (35.20)
T ₂	91.67 (73.31)	75.33 (60.27)	82.33 (65.20)	53.33 (46.92)
T ₃	85.00 (67.40)	69.00 (56.19)	77.67 (61.82)	46.67 (43.08)
T ₄	91.33 (73.25)	69.00 (56.19)	78.67 (62.53)	46.67 (43.08)
T ₅	93.67 (75.49)	69.00 (56.19)	89.67 (71.53)	40.33 (39.39)
T ₆	100.00 (90.00)	89.00 (70.80)	94.33 (76.31)	86.67 (68.99)
T ₇	80.00 (63.45)	82.33 (65.24)	59.33 (50.39)	73.33 (59.02)
T ₈	73.33 (58.91)	75.33 (60.27)	42.00 (40.39)	60.00 (50.81)
T ₉	73.00 (58.70)	75.33 (60.27)	64.67 (53.54)	60.00 (50.81)
LSD (0.05)	4.93 (4.47)	2.31 (1.62)	3.90 (2.56)	0.60 (1.06)

Figures in the parenthesis are arc sine transformed values. [T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v)].

Root parameters

Number of primary roots cutting⁻¹

Table 3 illustrated that the treatment T₆ gave the maximum number of primary roots cutting⁻¹ (15.67 and 16 in 2020 and 2021, respectively), followed by T₃ and T₅ (11) in the first year and by T₂ (11.67) and T₇ (11.67) in the second year (Table 3). In 2020, the lowest number of primary roots cutting⁻¹ was recorded in T₁ and T₉ (4.33) followed by T₈ (6), whereas in 2021, its minimum value was found in T₁ (4.33), which was statistically similar to T₄ (5).

An adequate nutrient level is essential for root growth and development, and promotes formation of multiple roots. In our study potting media comprising coco

dust and vermicompost performed better in terms of number of primary roots cutting⁻¹, which might be due to the excellent structure, porosity and nutrients in available form such as nitrate nitrogen and soluble phosphorus for excellent in rooting. Moreover, growth promoting substances in vermicompost might offer better rooting ability (Singh *et al.*, 2002). The results corroborate with the results of previous researchers (Munasinghe, 2023; Hazarika *et al.*, 2022).

Root length

Root length was significantly influenced by different potting media (Table 3). Maximum root length was found in T₆ (24 cm in 2020 and 19 cm in 2021) followed by T₃ (15.33 cm) in the first year and by T₈ (15 cm) in the second year. In 2020, the minimum root length was recorded in T₉ (6 cm) followed by T₁ (9 cm) while, in 2021, its least value was observed in T₁ (4.33 cm).

Among the various treatments, the potting media containing coco dust with soil and vermicompost increased root growth. In our study, maximum increase in root length was obtained in media comprising coco dust + vermicompost at an equal ratio (1:1 v/v). Coco dust with great porosity and good aeration leads to proper gas exchange by maintaining sufficient oxygen supply to the root side by side simultaneous removal of respiratory CO₂ helped in root elongation. Nutrient (N, P and K) rich vermicompost maintains easy availability of nutrients that ultimately helps root growth and development (Prajwal *et al.*, 2024). Thus, coco dusts amend with vermicompost in the ratio of 1:1 v/v enhance nutrient availability as well as gaseous: exchange that led to root proliferation, resulting in longer and thicker roots with increased volume. Since this treatment is a balance of air, moisture and nutrition, helps in increasing in physiological activity might have resulted in accumulation of carbohydrates which cause more root growth. Similar findings were reported by Renuka *et al.*, (2015) in media cocopeat + vermicompost (2:1) in Gerbera, Renuka and Chandra (2017) in the media comprising cocopeat + vermicompost in carnation, Munasinghe (2023) and Prajwal *et al.* (2024) in media coco peat and vermicompost in black pepper.

Root fresh weight

The maximum root fresh weight was observed in T₆ (1.05 and 1.14 g in 2020 and 2021, respectively) followed by T₄ (0.50 g) in 2020 and T₂ (0.84 g) in 2021 (Table 3). The lowest root fresh weight was found in T₁ (0.07 g and 0.19 g in 2020 and 2021, respectively) which was statistically similar with T₉ (0.13 g) in 2020.

Essentially, the environmental conditions within the root zone significantly influence root development and root mass. The increase in root mass in potted

cuttings depends on various factors including moisture content of the media, media texture and structure (compaction), root zone temperature, capability of the media to release nutrient in sufficient amount, media porosity for better aeration (oxygen levels), pH level, light conditions, and the presence of beneficial microbes (Lynch *et al.*, 2012). In our study the potting media formulating with coco dust and vermicompost increased root fresh weight, which might be due to the better rooting zone microclimate created by the mutual interaction of coco dust and vermicompost. Similar result was also stipulated by Prajwal *et al.* (2024) who found maximum root fresh weight in black pepper cuttings using potting media composed of coco dust and vermicompost.

Root dry weight

The maximum root dry weight was found in T₆ (0.39 and 0.42 g in 2020 and 2021, respectively) followed by T₅ (0.20 g) and T₄ (0.19 g) in 2020 and T₂ (0.33 g) in 2021 (Table 3). In 2020, the least root dry weight was recorded in T₁ (0.03 g), followed by T₉ (0.05 g) and T₈ (0.08 g), whereas in 2021, the treatment T₄ (0.03 g) recorded the lowest root dry weight, followed by and T₁ (0.07 g) and T₃ (0.09 g).

Root dry mass of potted cuttings could be affected by various factors like growing media compaction (structure and texture), water stress (drought or water logging), nutrient availability, aeration, temperature, light intensity, all of which influence the plant's ability to produce and allocate carbohydrates to increase root dry matter (Brouwer, 1963). The present study showed maximum dry root weight in the media coco dust and vermicompost in an equal ratio, which might be due to vigorous growth of roots for the porosity, water holding capacity, and nutrient exchange properties of the media. The ability of coco dust for retaining nutrients in the root zone ensures a steady supply of essential nutrients for the cutting's growth and development, leading to increase dry matter production in roots. The vermicompost benefits include nutrient enrichment, microbial activity, hormonal stimulation, moisture retention, pH stability, disease resistance, stress tolerance, and support for photosynthesis. Thus, the combined effect of coco dust and vermicompost might have stimulated the cuttings to increase root dry mass. These results get support from the findings of Thankamani *et al.* (1996) in black pepper with soil + vermicompost. Usendi *et al.* (2022) also noticed highest root dry weight in betel vine with potting mixture and vermicompost at an equal proportion.

Table 3. Effect of potting media on root parameters of black pepper cuttings under nursery conditions (60 days after cutting plantation)

Treatments	Primary roots Cutting ⁻¹ (No.)		Maximum root length (cm)		Root fresh weight (g)		Root dry weight (g)	
	2020	2021	2020	2021	2020	2021	2020	2021
T ₁	4.33	4.33	9.00	4.33	0.07	0.19	0.03	0.07
T ₂	8.00	11.67	12.00	7.33	0.32	0.84	0.12	0.33
T ₃	11.00	6.67	15.33	7.67	0.43	0.24	0.16	0.09
T ₄	9.00	5.00	11.67	4.67	0.50	0.08	0.19	0.03
T ₅	11.00	5.67	13.00	7.67	0.51	0.29	0.20	0.11
T ₆	15.67	16.00	24.00	19.00	1.05	1.14	0.39	0.43
T ₇	8.33	11.67	11.00	11.33	0.32	0.71	0.13	0.29
T ₈	6.00	8.00	10.00	15.00	0.21	0.66	0.08	0.25
T ₉	4.33	10.67	6.00	12.67	0.13	0.47	0.05	0.18
LSD (0.05)	2.50	1.07	2.55	1.20	0.06	0.06	0.008	0.007

T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v).

Shoot parameters

Shoot length

The different potting media significantly influenced shoot length of black pepper cuttings in both years (Table 4). The treatment T₆ produced the maximum shoot length (37 cm and 39 cm in 2020 and 2021, respectively) followed by T₃ (31.67 cm) and T₅ (31.33 cm) in 2020 and by T₄ (35 cm) and T₂ (34 cm) in 2021. The lowest shoot length was recorded in T₁ (20.67 cm in 2020 and 26 cm in 2021).

Rate of increase in shoot growth is an important factor for nursery grown potted seedlings. Potting media significantly affect the shoot length by ensuring nutrients availability especially nitrogen and phosphorus, and other necessary factors such as moisture content of the media, media pH, texture, microclimate, as well as aeration levels. As a result, nutrient deficiencies, poor water drainage, extreme pH, lower porous media as well as extreme high or low temperatures leading to reduced shoot length (Passioura, 2002). In our study, black pepper cuttings grown in the media T₆ (coco dust + vermicompost at 1:1 v/v ratio) recorded the longest shoot which might be attributed to favorable microclimatic condition as well as the presence of adequate nutrients in the media. Similar results were also reported by Akshay *et al.* (2014) in the media comprising regular potting mixture and vermicompost at equal ratio in black pepper, Prasath *et al.* (2014) in the media containing coir pith with *Trichoderma viridae* and vermicompost; and Usendi *et*

al. (2022) in *Piper betle* L. with media composed of regular potting mixture and vermicompost at equal ratio.

Shoot fresh weight

Shoot fresh weight was also significantly influenced by various potting media (Table 4). The highest shoot fresh weight was recorded in T₆ (12.90 and 17.99 g in 2020 and 2021, respectively) followed by T₃ (8.63 g), T₄ (8.40 g) and T₅ (8.24 g) in 2020 and by T₉ (16.90 g) in 2021. In 2020, the lowest shoot fresh weight was found in T₁ (3.95 g) followed by T₈ (3.99 g) while the least shoot fresh weight was noted in T₁ (10.25 g) followed by T₇ (10.76 g) and T₅ (10.91 g).

Shoot fresh weight is one of the most important attributes for evaluating seedling growth and development, which are significantly influenced by the types of potting media. Difference in potting media compositions could lead to variations in the overall shoot fresh weight due to various factors like nutrient availability, drainage capacity, and aeration within the medium. Generally, a well-draining, nutrient-rich rooting medium will promote higher shoot fresh weight compared to a poorly draining or nutrient-deficient one (Passioura, 2002). In our study the highest shoot fresh weight was obtained from the cuttings grown on the potting media T₆ (coco dust + vermicompost at 1:1 v/v ratio) might be due to its excellent water holding capacity, nutrient availability, porosity as well as the presence of growth promoting substances. These results are in line with the findings of Kodithuwakku *et al.* (2016) in black pepper cuttings.

Shoot dry weight

Potting media treatments significantly affected shoot dry weight of cuttings (Table 4). In 2020, the treatment T₆ gave the maximum shoot dry weight (3.14 g) followed by T₃ (2.76 g) being identical with T₂ (2.36 g) and T₅ (2.25 g) and the minimum shoot dry weight was recorded in T₁ (0.76 g), which was followed by T₈ (1.02 g) and T₉ (1.04 g) (Table 4). But in 2021, the highest shoot dry weight was obtained from T₂ (4.74 g) followed by T₆ (4.29 g) and the lowest shoot dry weight was recorded in T₁ (1.92 g).

Shoot dry weight of the potted seedlings are also affected by the composition of media. The potting media characters that affect shoot dry weight includes water retention capacity, nutrient releasing ability, and microclimate in the pot created by the media itself (Passioura, 2002). In our study cuttings grown in T₆ (coco dust + vermicompost 1:1 v/v) exhibited maximum shoot dry weight in both 2020 and 2021, might be due to the presence of coco dust that assisted in increased shoot dry weight. These results are in conformity with Vadiraj *et al.* (1992) and Srinivasan and Hamza (2000).

Table 4. Effect of different potting media on shoot growth attributes of black pepper cuttings under nursery conditions (60 days after cutting plantation)

Treatments	Shoot length (cm)		Shoot fresh weight (g)		Shoot dry weight (g)	
	2020	2021	2020	2021	2020	2021
T ₁	20.67	26.00	3.95	10.25	0.76	1.92
T ₂	26.67	34.00	7.33	15.13	2.36	4.74
T ₃	31.67	32.00	8.63	13.14	2.76	4.09
T ₄	30.33	35.00	8.40	15.44	1.83	3.29
T ₅	31.33	29.00	8.24	10.91	2.25	2.89
T ₆	37.00	39.00	12.90	17.99	3.14	4.29
T ₇	25.67	27.00	5.67	10.76	1.27	2.37
T ₈	23.67	30.00	3.99	12.33	1.02	3.15
T ₉	22.67	38.00	4.53	16.90	1.04	3.77
LSD (0.05)	1.98	1.73	0.57	0.67	0.031	0.077

[T₁ = soil alone, T₂ = coco dust alone, T₃ = soil + coco dust (1:1 v/v), T₄ = soil + vermicompost (1:1 v/v), T₅ = soil + FYM (1:1 v/v), T₆ = coco dust + vermicompost (1:1 v/v), T₇ = coco dust + FYM (1:1 v/v), T₈ = soil + coco dust + vermicompost (1:1:1 v/v), T₉ = soil + coco dust + FYM (1:1:1 v/v)].

Conclusion

Based on the experimental results, it can be concluded that coco dust in combination with vermicompost at a 1:1 ratio in volume basis was a superior growing media for producing the maximum number of healthy seedlings of black pepper within a short period. Therefore, this media could be suggested for the production of high-quality seedlings of black pepper using cuttings raised from runner shoots.

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RESPONSE OF GARDEN PEA TO DIFFERENT LEVEL OF IRRIGATION AND NITROGEN FERTILIZER

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Abstract

The experiment was conducted during 2017-18 to evaluate the effect of irrigation and nitrogen for enhancing the productivity and profitability of garden pea. The experiment consisted of five irrigation treatments *viz.*, no irrigation, one irrigation at vegetative stage (15 days after sowing, DAS), one irrigation at flowering stage (30 DAS), one irrigation at pod developing stage (45 DAS) and two irrigations, one irrigation at vegetative stage (15 DAS) + one irrigation at pod developing stage (45 DAS) and five levels of nitrogen *viz.*, 0, 20, 30, 40 and 50 kg N ha⁻¹. The experiment was laid out in a spilt plot design with three replications assigning nitrogen doses in main plots and irrigation treatments in sub-plots. Garden pea variety 'BARI Motorshuti-3' was used in this study. The combined effect of irrigation at flowering stage and fertilization with 30 kg N ha⁻¹ gave the highest green pod yield (7.57 t ha⁻¹) and green stover yield (6.19 t ha⁻¹), which was followed by no irrigation and fertilization with 30 kg N ha⁻¹ that produced green pod yield of 7.54 t ha⁻¹ and green stover yield of 6.12 t ha⁻¹ in garden pea. According to cost and return analysis, among all the treatment combinations, no irrigation and fertilization with 30 kg N ha⁻¹ was the best combination for enhancing gross margin (Tk. 448687.58 ha⁻¹) and BCR (2.90) for maximum green pod yield. Irrigation at flowering stage coupled with 30 kg N ha⁻¹ gave appreciable amount of gross margin (Tk 438363.40) and BCR (2.48) followed by the combination of irrigation at pod developing stage and 30 kg N ha⁻¹ (gross margin: Tk 378018.40 and BCR: 2.42). Therefore, irrigation given at either at flowering stage (30 DAS) or pod developing stages (45 DAS) each in combination with 30 kg N ha⁻¹ application is also a better combination for higher green pod production with better profitability under Bogura region when the crop needs to be irrigated.

Key words: Garden pea, irrigation, crop stages, nitrogen, gross margin, fresh pod yield and stover yield.

Introduction

Garden pea (*Pisum sativum* L.) is one of the most important winter minor pulse crops in Bangladesh. Garden peas are full of nutrition because its grain is rich in

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protein (27.8%), complex carbohydrates (42.65%), vitamins, minerals, dietary fibers and antioxidant compounds (Dahl *et al.*, 2012). Pea crop has a great impact in the rice-based cropping system to utilization of fallow land where land remains fallow about 80-90 days between *T. Aman* and *Boro* rice. In the high and medium high lands of Bangladesh, *T. Aman* – Fallow - *Boro* cropping pattern is practiced by the farmers. It was found that short duration pea variety (BARI Motorshuti-3) can be comfortably grown after harvest of short duration *T. Aman* variety in the fallow period of *T. Aman* and *Boro* cropping pattern. Further, this crop also plays a significant role in soil fertility restoration as a suitable rotation crop that fixes atmospheric nitrogen and also serves as rotational crop that plays great role in controlling disease epidemics and weeds (Hoorman *et al.*, 2009). It was therefore, planned to evaluate the performance of the short duration pea variety (BARI Motorshuti-3) as sole crop after harvest of short duration *T. Aman* rice under farmer's condition. Pea production in Bangladesh depends on many factors, of which nutrition is the most important one. Worldwide the aggressive exploitation of natural resources endangers water resources, biodiversity and soil quality. Scarcity of water is the most severe constraint for development of agriculture in arid and semi-arid areas. Under these conditions, the need to use available water economically and efficiently is unquestionable. Based on the actual crop need, the irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving high yield. Already more than 1.2 billion people in over 110 countries are affected by the social and environmental effects of the land degradation in dry areas (Schuster, 2003). Acute shortage of irrigation water and drought are adversely affecting crop production in general and vegetable production in particular. Pea plants do not tolerate water-logged conditions (Cannell *et al.*, 1979), and on the other side, reacts to the irrigation. However, during growth and development, especially, in the flowering and pod formation stages, drought causes aborting flowers and pods, following by decreasing yield and yield components. Also, decreasing of the quality of the product can be observed. Nitrogen increased seed protein content in peas and may be correlated with improved germination and seedling vigour (Ries, 1971). Boyd *et al.* (1971) have reported a relationship between seed size and vigour which may be increased by nitrogen application. There is general agreement that nitrogen fertilizer has the most important effect in increasing number of flowers, seed yield and quality of a wide variety of plant species. (Streeter, 1978) reported that the nitrogen contents of soybean decreased when nitrogen became limiting towards the end of the flowering season and during seed formation. Biological nitrogen fixation is an important source of nitrogen for plant growth and development requirements. Sometimes this source is enough to meet the plant requirements of nitrogen. If the factors affecting nodule activities (such as soil temperature, soil moisture, soil gaseous status, soil pH, soil salinity and soil nutrients like phosphorus and molybdenum) are inadequate or not favourable for enzymatic activities then the

amount of nitrogen fixed through this source becomes insufficient to meet the plant requirement. Nodule activity generally increases from seedling stage and during vegetative growth and reaches a maximum at reproductive growth (flowering), but then decreases rapidly during seed filling (Hardy *et al.*, 1971). This means that at the time of seed filling when the crop has its greatest requirement for nitrogen it may be beneficial to provide extra nitrogen. Pea production in Bangladesh is very low due to lack of proper agronomic management practices such as sowing time and method, row spacing, seed rate as well as irrigation and nutrient management. Therefore, the present study was conducted to evaluate the effect of irrigation and nitrogen for enhancing the productivity and profitability of pea to achieve the goal of increased pea production in Bangladesh.

Materials and Methods

The experiment was conducted at the Tuber Crops Research Sub-Center, Bangladesh Agricultural Research Institute (BARI), Bogura, Bangladesh during *rabi* season 2017-18. It was located at 24.51° N latitude and 89.18° E longitudes which is 17 m above the sea level (UNDP and FAO 1988) and belongs to the Barind Level Tract "AEZ 25". The experimental site was associated with a medium high land with sandy-loam soil texture and the soil was slightly acidic in reaction. The physico-chemical properties of the soil have been presented in Table 1.

Table 1: Physical and chemical properties of soil

Physical characteristics of the soil	Chemical characteristics of the soil
1. Sand (%) (0.2-0.02 min):58	1. pH: 6.0
2. Silt (%) (0.02-0.002 min): 35	2. Organic matter (%): 1.58
3. Clay (%) (<0.002 min): 7	3. Total nitrogen (%): 0.08
4. Soil textural class: sandy loam	4. Available sulphur (ppm): 12.14
5. Particle density (g/cc): 2.60	5. Available phosphorus (ppm): 29.02
6. Bulk density (g/cc): 1.35	6. Exchangeable potassium (meq/100 g soil) : 0.18
7. Porosity (%): 56.23	7. Magnesium (meq/100g soil): 0.45
	8. Boron (Micro gram/g soil): 0.29
	9. Zinc (Micro gram/g soil): 0.89

The experiment was laid out in a split-plot design with three replications. The experiment consisted of five irrigations *viz.*, (i) No irrigation (rainfed condition) (I₀), (ii) One irrigation at vegetative stages (15 days after sowing, DAS) (I₁), (iii) One irrigation at flowering stages (30 DAS) (I₂), (iv) One irrigation at pod developing stages (45 DAS) (I₃), (v) Two irrigations, one at vegetative stages (15 DAS) + one at pod developing stages (45 DAS) (I₄) and five nitrogen doses *viz.*, i) 0.0 kg N ha⁻¹ (N₀), (ii) 20 kg N ha⁻¹ (N₁), (iii) 30 kg N ha⁻¹ (N₂), (iv) 40 kg N

ha⁻¹ (N₃). Irrigation treatments were allocated in main plots and nitrogen doses in sub-plots. Different levels of N through urea were applied along with recommended or blanket doses of fertilizer of P (20 kg ha⁻¹), K (20 kg ha⁻¹), Sulphur (10 kg ha⁻¹) and boron (7 kg ha⁻¹) through Triple super phosphate (TSP), Muriate of potash (MP), Gypsum and Boric acid, respectively at final land preparation. Five flood irrigations were applied at different growth stages of plant as per treatment. The unit plot size was 2.5 m x 1.8 m. The garden pea var. BARI Motorshuti-3 was used in the study. Seeds of garden pea were sown @ 200 kg ha⁻¹. Seeds were sown continuously in rows on 10 November, 2016. The distance maintained between row to row was 20 cm. Finally, approximately 5 cm plant to plant distance along with row was maintained through thinning to have uniform population in all the rows of treatments. Different intercultural operations such as weeding, thinning, gap filling, pesticide spray and irrigation were accomplished time to time for better growth and development of the crop. The crop was harvested plot-wise at green pod maturity stages from separate area of each plot. Data were collected from the sampling area of the plots excluding border plants and one m² middle of plot were kept for final harvest to record data on yields. Five plants were uprooted each time randomly from the sampling area of each plot. Data were recorded on plant height, number of pods plant⁻¹, pod length, number of seeds pod⁻¹, weight of 1000 seeds, seed yield and dry stover yield. The yield was converted into t ha⁻¹. The yield was converted into t ha⁻¹. The collected data of different parameters were statistically analyzed with the help of R Software and differences among the treatment means were adjudged by Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Results and Discussion

Interaction effect of irrigation and nitrogen on plant height

Plant height of garden pea was significantly influenced by the combination of irrigation and N application at different growth stages. The highest plant height (42.54 cm) was recorded from irrigation at flowering stage with 40 kg N ha⁻¹ followed by the combination of no irrigation and 30 kg N ha⁻¹ (40.91 cm), irrigation at flowering stage and 0.0 kg N ha⁻¹ (40.05 cm), irrigation at flowering stage and 20 kg N ha⁻¹ (41.98 cm), irrigation at flowering stage and 30 kg N ha⁻¹ (41.22 cm), irrigation at flowering stage and 50 kg N ha⁻¹ (41.09 cm), irrigation at pod developing stage and 20 kg N ha⁻¹ (39.89 cm), irrigation at pod developing stage and 30 kg N ha⁻¹ (39.98 cm), irrigation at pod developing stage and 40 kg N ha⁻¹ (40.47 cm) and irrigation at pod developing stage and 50 kg N ha⁻¹ (40.98 cm), while the lowest plant height was observed in irrigation at vegetative stage under no N ha⁻¹ (36.58 cm). This result may be attributed to intolerant of this garden pea variety to waterlogging condition at vegetative stage because flood irrigation caused a decrease in plant height or internode extension. These findings are in

consonance with the findings of Uzun and Acikgoz (2009). On the other hand, the plant height increased with the increase in nitrogen levels upto 40 kg N ha⁻¹, then decreased at 50 kg N ha⁻¹. It might be due to the role of nitrogen in cell differentiation, growth and development of plant. Similar results were reported by Uniyal and Pant (2009).

Interaction effect of irrigation and nitrogen on number of pods plant⁻¹

Number of pods plant⁻¹ of pea was significantly influenced by irrigation in combination with nitrogen at different growth stages (table 2). The highest number of pods plant⁻¹ (3.90) was recorded from the combination of irrigation at flowering stage and 30 kg N ha⁻¹ application followed by no irrigation and 30 kg N ha⁻¹ (3.88), while the lowest pods plant⁻¹ was found in the treatment combination of irrigation at vegetative stage and no nitrogen or control plot (2.06) followed by irrigation at vegetative stage and 20 kg N ha⁻¹ (2.21), irrigation at vegetative stage + irrigation at pod developing stage and 0.0 kg N ha⁻¹ (2.11), irrigation at vegetative stage + irrigation at pod developing stage and 50 kg N ha⁻¹ (2.35), respectively. It might be due to intolerant of garden pea variety to waterlogging condition caused by irrigation at vegetative stage which can cause a decrease in number of pods plant⁻¹. These findings are in agreement with the findings of Uzun and Acikgoz (2009). The increase in the level of N was responsible for higher photosynthesis and assimilation rate and metabolic activity and cell-division, which were responsible for the significant increase in the growth characters, yield attributes and ultimately the pod yields. The results of the present investigation are in perfect agreement with the findings of Singh and Dixit (1989).

Interaction effect of irrigation and nitrogen on pod length

Pod length of garden pea was significantly influenced by irrigation and nitrogen application (Table 2). The highest pod length (6.74 cm) was recorded from the combination of irrigation at flowering stage and 30 kg N ha⁻¹ application followed by no irrigation with application of 30 kg N ha⁻¹ (6.58 cm), no irrigation and 40 kg N ha⁻¹ (6.73 cm), no irrigation and 50 kg N ha⁻¹ (6.64 cm), irrigation at flowering stage and 40 kg N ha⁻¹ (6.39 cm), irrigation at flowering stage and 50 kg N ha⁻¹ (6.51 cm), irrigation at pod developing stage and 30 kg N ha⁻¹ (6.71 cm), irrigation at pod developing stage and 40 kg N ha⁻¹ (6.52 cm) and irrigation at pod developing stage and 50 kg N ha⁻¹ (6.47 cm), while the lowest in irrigation at vegetative stage + irrigation at pod developing stage and 0.0 kg N ha⁻¹ (5.27 cm). It might be due to intolerant of this garden pea variety to waterlogging condition created by irrigation at vegetative stage which inhibited nitrogen uptake from the soil as a result leading to reduced nitrogen concentrations in vegetative and reproductive tissues. Similar results were reported by Jackson (1979).

Table 2. Interaction effect of (irrigation x nitrogen) on crop characters, yield contributing characters and yield of pea

Interaction (IXN)	Plant height (cm)	Number of pods plant ⁻¹	Pod Length (cm)	Number of seeds pod ⁻¹	Weight of 100 fresh pods (g)	Green pod yield (t ha ⁻¹)	Green stover yield (t ha ⁻¹)
I ₀ x N ₀	38.40cdef	3.45cdef	5.98bcde	5.82bcde	338.92c	6.30bc	5.55abc
I ₀ x N ₁	38.86cdef	3.67bcd	6.08bcde	5.95bc	342.54bc	6.69bc	5.62abc
I ₀ x N ₂	40.91abc	3.77ab	6.58ab	5.99ab	351.96a	7.54a	6.12a
I ₀ x N ₃	39.51bcdef	3.74bc	6.73a	5.98bc	346.29b	7.36a	6.00ab
I ₀ x N ₄	38.99cdef	3.68bc	6.64ab	5.92bc	345.93b	7.30a	6.05b
I ₁ x N ₀	36.58f	2.06j	5.28f	5.20i	248.78h	3.85f	3.55e
I ₁ x N ₁	38.34cdef	2.21hij	5.35f	5.29hi	252.08fg	3.93ef	3.59e
I ₁ x N ₂	39.41bcdef	2.31ghi	5.76def	5.32hi	253.99f	4.07ef	3.66e
I ₁ x N ₃	38.35cdef	2.40gh	5.77def	5.42ghi	254.98f	4.33ef	3.92e
I ₁ x N ₄	38.46cdef	2.35gh	5.57ef	5.40ghi	254.63f	4.22ef	3.74e
I ₂ x N ₀	40.05abcde	3.44cdef	6.07bcde	5.81bcde	339.82c	6.37bc	5.95ab
I ₂ x N ₁	41.98ab	3.63bcde	6.34abcd	5.83bcde	343.21b	6.78b	5.68abc
I ₂ x N ₂	41.22abc	3.95a	6.74a	6.25a	349.11a	7.57a	6.19a
I ₂ x N ₃	42.54a	3.64bcde	6.39abc	5.85bcd	345.32b	7.35a	6.03ab
I ₂ x N ₄	41.09abc	3.65bcde	6.51ab	6.00ab	346.00b	7.49a	6.10ab
I ₃ x N ₀	38.90cdef	3.38f	6.10bcde	5.61efg	322.84d	5.47d	5.40bcd
I ₃ x N ₁	39.89abcde	3.42ef	6.23bcd	5.64def	324.24d	5.62d	4.80d
I ₃ x N ₂	39.98abcde	3.51cdef	6.71ab	5.94bc	342.80bc	6.57bc	5.96ab
I ₃ x N ₃	40.87abcd	3.46cdef	6.52ab	5.82bcde	339.82c	6.43bc	5.55abc
I ₃ x N ₄	40.98abc	3.45cdef	6.47ab	5.75cde	261.05e	6.14c	5.08cd
I ₄ x N ₀	38.41cdef	2.11ij	5.27f	5.22hi	250.10g	3.87f	3.58e
I ₄ x N ₁	37.20ef	2.29ghi	5.40f	5.34hi	253.52f	4.01ef	3.28e
I ₄ x N ₂	36.91f	2.47g	5.79cdef	5.44fgh	255.32f	4.52e	3.62e
I ₄ x N ₃	37.94def	2.26ghij	5.37f	5.31hi	252.14fg	3.94ef	3.60e
I ₄ x N ₄	36.88f	2.35gh	5.59ef	5.42ghi	253.90f	4.13ef	3.49e
CV (%)	3.58	3.40	5.16	2.20	1.33	0.181	0.209

N.B.: I₀=no irrigation, I₁= One irrigation at vegetative stage (15 DAS), I₁= One irrigation at flowering stage (30 DAS), I₃ = One irrigation at podding stage (45 DAS), I₄= Two irrigations, one at vegetative stage + one at podding stage (15 & 45 DAS), N₀ = 0.0 kg ha⁻¹, N₁= 20 kg ha⁻¹, N₂= 30 kg ha⁻¹, N₃= 40 kg ha⁻¹, N₄= 50 kg ha⁻¹.

Interaction effect of irrigation and nitrogen on number of seeds pod⁻¹

Number of seeds pod⁻¹ of pea was significantly influenced by irrigation and nitrogen at different growth stages (Table 2). The highest number of seeds pod⁻¹ (6.25) was recorded from irrigation at flowering stage accompanied with 30 kg N ha⁻¹ followed by the combination of no irrigation and 30 kg N ha⁻¹ (5.99) and irrigation at flowering stage and 40 kg N ha⁻¹ (6.00), while the lowest in irrigation at vegetative stage and 0.0 kg N ha⁻¹ (5.20). The higher number of seeds pod⁻¹ might be due to adequate supply of nitrogen. The findings of this investigation are in close conformity with the results obtained by Uniyal and Pant (2009).

Interaction effect of irrigation and nitrogen on weight of 100 fresh pods

Weight of 100 fresh pods of pea was significantly influenced by interaction of irrigation and nitrogen at different growth stages (Table 2). Interaction of no irrigation and 30 kg N ha⁻¹ gave the highest weight of 100 fresh pods (351.96g) followed by interaction of irrigation at flowering stage and 30 kg N ha⁻¹ (349.11g), while the lowest 100 fresh pod weight was found in irrigation at vegetative stage with 0.0 kg N ha⁻¹ (248.78g). It might be due to weight of seeds is an inherent character which is directly correlated with seed yield plot⁻¹ (Singh and Malik, 1994).

Main effect of irrigation on green pod yield

Green pod yield of garden was greatly influenced by irrigation at different crop stages (Fig. 1). The maximum green pod yield was obtained from irrigation given at flowering stage (30 days after sowing, DAS) (7.11 t ha⁻¹) which was statistically similar to no irrigation (7.04 t ha⁻¹) and then followed by irrigation provided at pod developing stage (45 DAS). The lowest green pod yield was observed at irrigation given at vegetative stage (15 DAS) being identical with two irrigations given at vegetative stage (15 DAS and pod development stage (55 DAS). Pumphrey and Schwank (1974) stated that irrigation at pod filling stage increased yield more than irrigation at any other growth stage of pea. This result is somewhat different from this experimental result where irrigation at flowering stage gave higher green pod yield than other crop growth stages. On the contrary, the highest grain yield of pea was obtained from irrigation at branching, flowering and pod development stage (Rajak *et al.*, 2025).

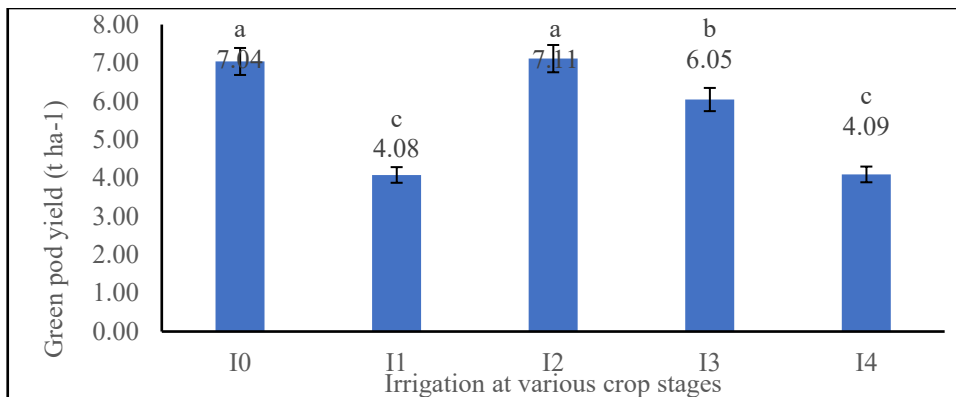


Fig 1. Effect of irrigation on green pod yield of garden pea.

I0 = No irrigation, I1 = One irrigation at vegetative stages (15 DAS), I2 = One irrigation at flowering stages (30 DAS), I3 = One irrigation at pod developing stages (45 DAS) and I4 = Two irrigations, one at vegetative stages (15 DAS) + one at pod developing stages (45 DAS).

Main effect of nitrogen on green pod yield

Green pod yield per hectare was significantly influenced by application of nitrogen (N) (Fig.2). The highest green pod yield of garden pea was recorded at 30 Kg N ha⁻¹ (6.03 t ha⁻¹) which was identical with 40 kg N ha⁻¹ and 50 kg N ha⁻¹ and the lowest green pod yield was obtained when N was not applied. This result corroborates the result of Uddin *et al.* (2014). Saini *et al.* (1996) stated that green pod yield increased with up to 30 kg N/ha. Bhopal and Singh (1990) found similar result with 40 kg N/ha.

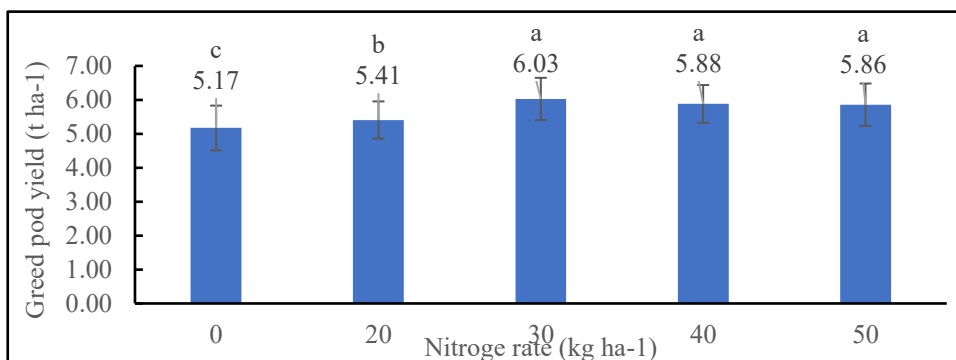


Fig 2. Effect of nitrogen on green pod yield of garden pea.

N.B.: I₀=no irrigation, I₁= One irrigation at vegetative stage (15 DAS), I₂= One irrigation at flowering stage (30 DAS), I₃ = One irrigation at podding stage (45 DAS), I₄= Two irrigations, one at vegetative stage + one at podding stage (15 & 45 DAS), N₀ = 0.0 kg ha⁻¹, N₁ = 20 kg ha⁻¹, N₂= 30 kg ha⁻¹, N₃= 40 kg ha⁻¹, N₄= 50 kg ha⁻¹.

Interaction effect of irrigation and nitrogen on green pod yield

Green pod yield of pea was significantly influenced by interaction of irrigation and nitrogen (Table 2). The highest green pod yield (7.57 t ha^{-1}) was obtained from irrigation at flowering stage coupled with 30 kg N ha^{-1} followed by irrigation at flowering with application of N at 40 kg ha^{-1} (7.35 t ha^{-1}), irrigation at flowering stage and 50 kg N ha^{-1} (7.49 t ha^{-1}), no irrigation and 30 kg N ha^{-1} (7.54 t ha^{-1}), no irrigation and 40 kg N ha^{-1} (7.36 t ha^{-1}) and no irrigation and 50 kg N ha^{-1} (7.30 t ha^{-1}), while the lowest pod yield was found in irrigation at vegetative stage with 0.0 kg N ha^{-1} (3.85 t ha^{-1}). It might be due to intolerant of garden pea variety to waterlogging condition created by irrigation. Similar result have been reported by Uzun and Acikgoz (2009).

Interaction effect of irrigation and nitrogen on green stover yield

Green stover yield of pea was significantly affected by interaction of irrigation and nitrogen (Table 2). Irrigation at flowering stage coupled with 30 kg N ha^{-1} application recorded the highest green stover yield (6.19 t ha^{-1}) followed by the combination of no irrigation and 0.0 kg N ha^{-1} (5.55 t ha^{-1}), no irrigation with 20 kg N ha^{-1} application (5.62 t ha^{-1}), no irrigation with 30 kg N ha^{-1} (6.12 t ha^{-1}), no irrigation and 40 kg N ha^{-1} (6.00 t ha^{-1}), irrigation at flowering stage and 0.0 kg N ha^{-1} (5.95 t ha^{-1}), irrigation at flowering stage and 20 kg N ha^{-1} (5.68 t ha^{-1}), irrigation at flowering stage and 40 kg N ha^{-1} (6.03 t ha^{-1}), irrigation at flowering stage and 40 kg N ha^{-1} (6.10 t ha^{-1}), irrigation at pod developing stage and with 30 kg N ha^{-1} (5.96 t ha^{-1}) and irrigation at pod developing stage and 40 kg N ha^{-1} (5.55 t ha^{-1}), while the lowest green stover yield was observed in the combination of irrigation at vegetative stage + irrigation at pod developing stage and 20 kg N ha^{-1} (3.28 t ha^{-1}). It might be due to intolerant of the used variety to waterlogging condition at vegetative stage created by irrigation and lack of nitrogen in soil which can cause a decrease in root mass, root penetration depth, plant height or internode extension, leaf expansion, biomass and chlorophyll content. Similar results were reported by Przywara and Stepniewski (1999).

Economic analysis

The highest gross margin (Tk 448687.58/ha) and BCR (2.90) was obtained from the interaction of no irrigation and application of 30 kg N ha^{-1} closely followed by no irrigation coupled with application with 40 kg N ha^{-1} (gross margin: 442931.20 and BCR:2.86), while the lowest gross margin (Tk 157845) and BCR (1.02) was noticed in the combination of irrigation at vegetative stage and no N application (Table 3). The better gross margin and BCR were also obtained from irrigation at flowering stage or from pod developing stage in combination with 30 kg N ha^{-1} . Irrigation at flowering stage coupled with 30 kg N ha^{-1} gave appreciable amount of gross margin (Tk 438363.40) and BCR (2.48) followed by the combination of

Table 3. Comparative agro-economic performance of Pea under interaction of irrigation and nitrogen for green pod production

Interaction (I×N)	Yield (t ha ⁻¹)		Total variable cost (Taka ha ⁻¹)	Gross return (Taka ha ⁻¹)	Gross margin (Taka ha ⁻¹)	BCR
	Green pod	Green Stover				
I _{0x} N ₀	6.30	5.55	153480.00	504000+8325 = 512325.00	358845.00	2.34
I _{0x} N ₁	6.69	5.62	154174.40	535200+8430 = 543630.00	389455.60	2.53
I _{0x} N ₂	7.54	6.12	154521.60	603200+9180 = 603209.18	448687.58	2.90
I _{0x} N ₃	7.36	6.00	154868.80	588800+9000 = 597800.00	442931.20	2.86
I _{0x} N ₄	7.30	6.05	155216.00	584000+9075 = 593075.00	437859.00	2.82
I _{1x} N ₀	3.85	3.55	155480.00	308000+5325 = 313325.00	157845.00	1.02
I _{1x} N ₁	3.93	3.59	156174.40	314400+5385 = 319785.00	163610.60	1.05
I _{1x} N ₂	4.07	3.66	156521.60	325600+5490 = 331090.00	174568.40	1.12
I _{1x} N ₃	4.33	3.92	156868.80	346400+5880 = 351335.00	194466.20	1.24
I _{1x} N ₄	4.22	3.74	157216.00	337600+5610 = 343210.00	185994.00	1.18
I _{2x} N ₀	6.37	5.95	175480.00	509600+8925 = 518525.00	343045.00	1.95
I _{2x} N ₁	6.78	5.68	176174.40	542400+8520 = 550920.00	374745.60	2.13
I _{2x} N ₂	7.57	6.19	176521.60	605600+9285 = 614885.00	438363.40	2.48
I _{2x} N ₃	7.35	6.03	176868.80	588000+9045 = 597045.00	420176.20	2.38
I _{2x} N ₄	7.49	6.10	177216.00	599200+9150 = 608350.00	431134.00	2.43
I _{3x} N ₀	5.47	5.40	155480.00	437600+8100 = 445700.00	290220.00	1.87
I _{3x} N ₁	5.62	4.80	156174.40	449600+7200 = 456800.00	300625.60	1.92
I _{3x} N ₂	6.57	5.96	156521.60	525600+8940 = 534540.00	378018.40	2.42

Interaction (I _x N)	Yield (t ha ⁻¹)		Total variable cost (Taka ha ⁻¹)	Gross return (Taka ha ⁻¹)	Gross margin (Taka ha ⁻¹)	BCR
	Green pod	Green Stover				
I ₃ x N ₃	6.43	5.55	156868.80	514400+8325 = 522725.00	365856.20	2.33
I ₃ x N ₄	6.14	5.08	157216.00	491200+7620 = 498820.00	341604.00	2.17
I ₄ x N ₀	3.94	3.60	158868.80	315200+5400 = 320600.00	161731.20	1.02
I ₄ x N ₁	4.01	3.28	158174.40	320800+4920 = 325720.00	167545.60	1.06
I ₄ x N ₂	4.52	3.62	158521.60	361600+5430 = 367030.00	208508.40	1.32
I ₄ x N ₃	3.87	3.58	157480.00	314985+5370 = 320355.00	162875.00	1.03
I ₄ x N ₄	4.13	3.49	159216.00	330400+5235 = 335635.00	176419.00	1.11

N.B.: I₀=no irrigation, I₁= One irrigation at vegetative stage (15 DAS), I₁= One irrigation at flowering stage (30 DAS), I₃ = One irrigation at podding stage (45 DAS), I₄= Two irrigations, one at vegetative stage + one at podding stage (15 & 45 DAS), N₀ = 0.0 kg ha⁻¹, N₁= 20 kg ha⁻¹, N₂= 30 kg ha⁻¹, N₃= 40 kg ha⁻¹, N₄= 50 kg ha⁻¹.

N.B.: Urea = Tk 16.00 /kg, TSP = Tk 22.00 /kg, MOP = Tk 15.00 /kg, Boric acid =Tk 190 /Kg, Gypsum = Tk 10.00 /kg, Manures= Tk 1.50 /kg, Labour = Tk 400.00/ 8 hr /head, Irrigation = Tk 2000 /ha, ploughing= Tk 1500/plough/ha, Green pod sale price= Tk.80 /kg, Dry stover = TK. 0.75 /kg, Seed= Tk 150 /kg, Non-seed= Tk 130 /kg, Seed treatment= TK 1500 /ha, Fungicide spray (two times) = TK 6000 /ha, Harvesting/pod picking = Tk 5.00 /kg, Bird man= Tk 3000/15 days/ha.

irrigation at pod developing stage (Tk 378018.40) and BCR (2.42). This result revealed that the treatment of no irrigation and application of 30 kg N ha⁻¹ was the best combination for enhancing pod yield, gross margin and BCR for fresh pod production of garden pea var. BARI Motorshuti-3 under the climatic condition of Bogura. Irrigation given at either fat lowering stage or pod developing stages each in combination with 30 kg N ha⁻¹ application was also a better combination for higher green pod production with better profitability under Bogura region when the crop needs to be irrigated.

Relationship between green pod yield and number of irrigations

The relationship between green pod yield and number of irrigations at different crop stages has been presented in Fig. 1. The regression analysis indicated that the green pod yield of garden pea was linearly and negatively correlated to the number of irrigations. The linear regression line was $y = 7.146 - 1.472x$, $R^2 = 0.476$, $r = 0.69^*$). From the estimated relationship, it can be expected that the green pod yield decreased with the increase of number of irrigations. The coefficient of determination (R^2) indicates that irrigation levels accounted for 47.6% of the variation in green pod yield. It is also evident that from the regression equation that a decrease of 1.47 t/ha green pod yield can be expected for per unit increase of irrigation.

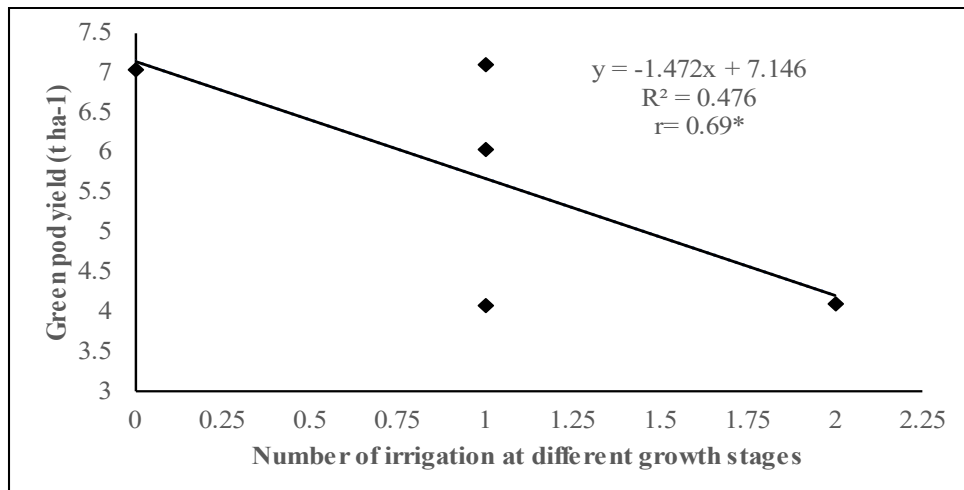


Fig. 1 Relationship between number of irrigations and green pod yield of garden pea.

Relationship between green pod yield and nitrogen fertilization

Regression analysis was done to quantify the relationship of applied nitrogen (N) with green pod yield (t ha⁻¹). Applied N showed a linear positive relationship with green pod yield of garden pea (Fig. 2). From the estimated relationship, it can be

expected that the green pod yield increased with the increase of N application. The coefficient of determination indicates that N fertilization accounted for 84% of the variation in green pod yield. It also revealed that by increasing per kg of N, green pod yield of garden pea was increased by 15.8 kg ha^{-1} .

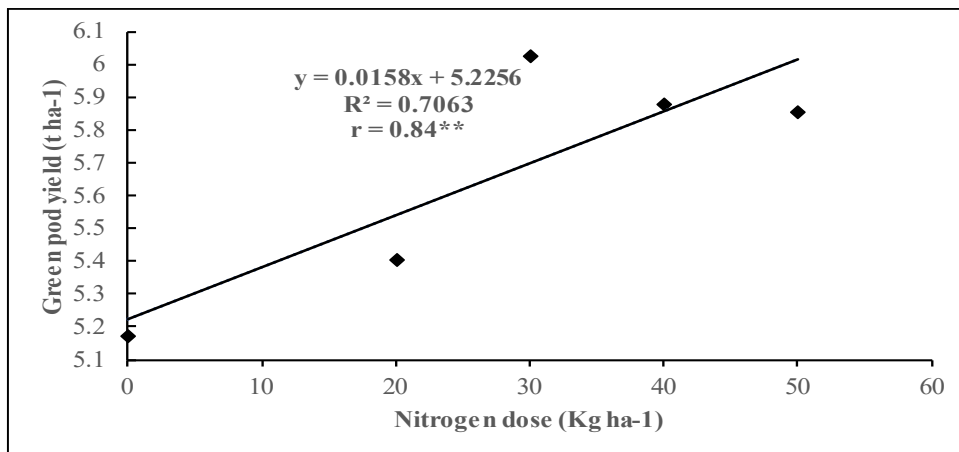


Fig. 2 Relationship between nitrogen rate and green pod yield of garden pea.

Conclusion

From the above study, it may be concluded that irrigation at either flowering stage or pod developing stage and in combination with fertilization of 30 kg N ha⁻¹ was the most suitable combination to give the highest green pod yield and fresh stover yield of the garden pea var. BARI Motorshuti-3. Economic analysis showed that no irrigation i.e. rainfed condition in combination with fertilization of 30 kg N ha⁻¹ was found to be the best combination for enhancing gross margin and BCR. Irrigation given at either flowering stage or pod developing stages each in combination with application of 30 kg N ha⁻¹ was also better combinations for higher and profitable green pod production with better profitability under Bogura region when the crop needs to be irrigated.

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EFFECT OF WASHING METHOD AND STORAGE TEMPERATURE ON QUALITY AND SHELF LIFE OF WINTER SQUASH

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Abstract

An experiment was conducted at the Postharvest Technology Division Laboratory, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh, during 10 January 2020 to 10 March 2020 to find out the suitable storage temperature for winter squash (*Cucurbita pepo*) and extend its shelf life. The experiment comprised two sets of treatments *viz.*, washing methods consisting of tap water washing (W₁) and chlorinated water washing (W₂), and four storage temperature composed of control room temperature; 25±2 °C (T₁); 8±0.5 °C (T₂); 12±0.5 °C (T₃) and 16±0.5 °C (T₄). The experiment was carried out in a Completely Randomized Design with three replications. For chlorinated water wash (120 ppm chlorine) was used which was prepared from sodium hypochlorite. The variety 'BARI Squash-1' was used in this experiment. The results showed that squash fruit stored in 8±0.5 °C with chlorinated water wash had the highest firmness and vitamin C during the storage period (10-50 days at 10 days interval). However, squash fruits stored at 12±0.5 °C with chlorinated water wash showed the maximum total soluble solid (TSS) during the storage. Shelf life was recorded maximum (57.33 days) from the combination of squash fruits stored in 8±0.5 °C and chlorinated water wash which was statistically similar to the combination of squash fruits stored in 12±0.5 °C and chlorinated water wash (55.33 days). It is concluded that chlorinated water wash using 120 ppm chlorine and storage temperature at 8 to 12 °C are suitable for storing squash fruits.

Keywords: Squash (*Cucurbita pepo*), washing method, storage temperature, quality and shelf life.

Introduction

Squash (*Cucurbita pepo* L.) is one of the important vegetables belonging to the family Cucurbitaceae. It is grown worldwide in both temperate and tropical climatic zones. In Italy, France, South America, Saudi Arabia it is called 'Zucchini', 'Courgette', 'Summer squash' and 'Kusa', respectively. Both the

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words ‘Zucchini’ and ‘Courgette’ mean ‘small gourd’ or ‘small squash’. The squash fruits are harvested at edible stage and are consumed cooked when young and tender.

Squash has various health benefits to human as well as medicinal potentials (Mohammad *et al.*, 2011). It contains a variety of vitamins (β -carotene, vitamin A, vitamin C, vitamin B₂, α -tocopherol and vitamin E), minerals, amino acids, carbohydrates, and minerals, especially potassium, as well as phenolics and flavonoids. Fresh squash is a good source of fiber, relatively low in calories (around 16-20 kcal/100g FW).

Storage of vegetable produces is an important means for improving shelf life, avoiding market surplus and ensuring supply through the year as well as increasing profit to the producers (Magray *et al.*, 2017). Temperature both- high or low plays a vital role in the determination of postharvest quality and shelf life of tropical fruits and vegetables. Different levels of temperature subjected to different postharvest deterioration (Kader, 1993). Squash gets affected when it is stored below sub optimal temperature but above the freezing point (Sevillano *et al.*, 2009). Chilling injury symptoms may persist after transfer of fruit from 4 to 20 °C. Megias *et al.* (2014) reported that over the first week of storage, squash fruits lose only 5–7% of their initial weight, irrespective of the storage temperature but, after the second week of storage period, fruits stored at both 12 °C and 20 °C lost more weight than those fruit stored at 4 °C.

Cleaning and washing are very important practices in order to improve the hygiene, which can help extend shelf life of squash. Proper sanitation of the washing water is essential to maintain to prevent spread of diseases and inoculums build up in the wash water. The most commonly used sanitizer to wash fruits and vegetables is chlorine (100-150 ppm) solution (Anon., 2019; Gunathilake and Tiwari, 2017).

Squash is a quick growing, short duration vegetable (40-60 days from transplanting 16-days-old seedlings) which had made it a popular vegetable crop in Bangladesh. As it is a newly introduced crop in Bangladesh and there is little research information on this crop regarding its shelf life. The present investigation was carried out to develop a suitable washing method and optimum storage temperature for storage of squash.

Materials and Methods

Research Location

The experiment was conducted at the Postharvest Technology Division Laboratory of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, during 10 January 2020 to 10 March 2020: 60 days.

Treatment setting

The experiment consisted of two factors, Factor A: two washing methods- Tap water washing (W_1) and chlorinated water washing (Sodium hypochlorite 120 ppm) (W_2) and Factor B: four storage temperature- Control (room temperature: 25 ± 2 °C) (T_1); 8 ± 0.5 °C (T_2); 12 ± 0.5 °C (T_3) and 16 ± 0.5 °C (T_4). Therefore, treatment combinations were 8 comprising Factor A and Factor B. The experiment was laid out in Completely Randomized Design (CRD) with three replications. The variety 'BARI Squash-1' producing elongated, dark green coloured fruit was used in this experiment.

Plant materials and storage conditions:

Freshly harvested squash fruits of 'BARI Squash-1' were collected from the vegetable research field of HRC, BARI. Eighteen-day-old uniform seedlings were transplanted in the Vegetable Research Field on 01 November 2019. First female flowering occurred in plants 35 days after transplanting of seedlings. Squash fruits were harvested on 10 January 2020 in the morning at proper edible stage when the fruits were young and tender (green coloured, smooth, bright shiny fruits and the nails entered the fruits easily after pressing them with nails). The harvested fruits were carried to the Postharvest Technology Division Laboratory of BARI keeping fruits in plastic crates with perforated polythene cover spread over the fruits. 240 fruits were used in this study and fruits were selected on the basis of uniformity in size (800-900 g). No physical injuries or infections were considered.

At first all the selected fruits ($8 \times 10 \times 3 = 240$) were divided into two groups. According to washing treatments, the selected fruits of 1st group (120 fruits) were soaked into tap water and washed, and the 2nd group fruits (120 fruits) were soaked into 120 ppm chlorinated water for 5 min. and washed. Tap water washed ten fruits weighing approximately 8.5 kg (packed in 1% perforated Polyethylene bags) were selected for each storage temperature treatment or 40 tap water washed fruits (4 perforated Polyethylene bags with 10 fruits per bag) were used for each replication. In the same way, 120 ppm chlorinated washed ten fruits weighing approximately 8.5 kg (packed in 1% perforated Polyethylene bags) were selected for each storage temperature treatment or 40 chlorinated water washed fruits (4 perforated Polyethylene bags with 10 fruits per bag) were used for each replication. Nine perforated polyethylene bags containing 10 tap water washed fruits per bag and 9 perforated polyethylene bags with 10 chlorinated washed fruits per bag totaling 180 fruits ($10 \times 3 \times 3 + 10 \times 3 \times 3$) were kept in constant temperature and humidity chambers (Model: VS-111H-350, Korea) for 10 days maintaining temperature 8 °C, 12 °C and 16 °C. Eighteen bags containing 180 squash fruits (9 bags with 90 tap water washed fruits and 9 bags with 90 chlorinated washed fruits) at the rate of 10 fruits per bag were kept in different chambers with fixed temperature (8, 12 and

16 °C) according to temperature treatment. Three bags (10 fruits per bag) containing 30 tap water washed fruits and three bags (10 fruits per bag) containing 30 chlorinated washed fruits were kept in room condition (temperature (25±2 °C) and 70±5 % RH). In all chambers the relative humidity (RH) was adjusted to 70±5%, squash fruits kept in room temperature conditions (25±2 °C and 70±5% RH) were used as control. One squash fruit was collected (from each polythene bag) for data collection of TSS and Vitamin C at 10 days intervals and it was continued up to 50 days of storage. Five fruits were used to record data of weight loss and firmness.

Parameters studies and their data collection procedure:

Total Soluble Solid:

Total soluble solids (TSS) content was determined by a hand-held refractometer (model: ATAGO PAL-1 made in Japan and TSS measuring range 0-53 °Brix) by placing drop of homogenized pulp juice on its prism. TSS was obtained from direct reading of the refractometer. At first the middle size of the fruit (about 5 cm length) was cut from the whole fruit, and the portion was peeled out and this portion was cut into several thin pieces by sharp knife. Pulp juice was then collected from these thin pieces after hand pressing.

Vitamin-C content: (Ranganna, 1986).

The reagent used for the estimation vitamin C were as follows

- a) Metaphosphoric acid solution (3%)
- b) Standard ascorbic solution
- c) Dye solution

The estimate procedure of vitamin C was as follows:

Five ml of standard ascorbic solution was taken in conical flask and 5 ml metaphosphoric acid (HPO₃) was added to it and shaken.

A micro burette was filled with dye solution then the mixed solution was titrated with dye using phenolphthalein as indicator solution to a pinked coloured end point, which persisted at least for 15 seconds. The dye factor was calculated using the following formula-

$$\text{Dye factor} = \frac{0.5}{\text{Titre}}$$

Preparation of sample

10 g of fresh sample was taken and transferred to 250 ml volumetric flask and the volume was made up to the mark with metaphosphoric acid.

Titration

Five ml of metaphosphoric acid extracted sample was taken in an aliquot and titrated with standard dye solution, using phenolphthalein as indicator to a pink-coloured end point which persisted for at least for 15 seconds.

Vitamin C content was calculated using the following formula-

$$\text{Vitamin C content (mg/100 g fresh sample)} = \frac{T \times D \times V_1}{V_2 \times W} \times 100$$

Where,

T = Titre

D = Dye factor

V₁ = Volume made up

V₂ = Volume of extract taken for estimation

W = Weight of sample taken for estimation

Firmness:

Fruit firmness of squash fruit was measured (Rahman *et al.*, 2014) using a Digital Firmness Tester (DFT 14, Agro-Technologie, France) equipped with 5 mm diameter stainless probe. The tester was checked before use. The plunger of the tester was moved in and out about 10 times to ensure that it was running smoothly. Firmness was reported in kilogram-force cm⁻² (kg-f-cm⁻²). Measurements were taken at three different places of each fruit and mean was calculated.

Weight loss of fruits: Squash (10 fruits) were weighed at the beginning of the experiment at fresh condition and there after weighing was continued up to 50th day at every 10 days. Weight loss was calculated and expressed as the percentage weight loss of initial total weight according to the formula used by Moniruzzaman *et al.* (2015).

$$\text{Total weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Shelf life: Shelf life of squash as influenced by different postharvest treatments was estimated by counting the days from the harvest of squash-fruits up to its last edible stage.

Statistical analysis:

The recorded quantitative data were analyzed statistically by using MSTAT-C computer- based program. Treatment means were compared by Duncan Multiple Range Test (DMRT) at 5% level of probability.

Results and Discussion

Effect of washing methods

Total soluble solids content (TSS), vitamin C content, weight loss (%) and firmness of squash were not affected significantly due to washing method of squash (Table 1). TSS and vitamin C content were decreased gradually with the increase of storage duration as compared to initial stage, while weight loss (%) and firmness were increased gradually with the increase of storage duration as compared to initial stage (Table 1).

Table 1. Changes in percent TSS, vitamin C content, weight loss and firmness of stored squash as influenced by different washing method.

Washing methods	Days after storage (DAS)					
	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS
<i>Total soluble solids (TSS)</i>						
W ₁	5.78	5.20	4.40	3.90	3.15	2.48
W ₂	5.81	5.26	4.55	4.03	3.20	2.51
CV (%)	3.10	3.17	3.69	2.46	3.68	6.08
<i>Vitamin C content (mg/100 g Fresh Weight)</i>						
W ₁	12.15	11.04	10.00	8.96	8.10	7.40
W ₂	12.20	11.16	10.05	9.21	8.24	7.50
CV (%)	1.9	1.59	1.51	1.54	1.95	1.36
<i>Weight loss (%)</i>						
W ₁	0	2.38	4.21	5.34	6.54	8.60
W ₂	0	2.24	3.96	4.89	6.06	7.78
CV (%)	-	6.17	7.17	7.91	6.3	7.04
<i>Firmness (kg-f-cm⁻²)</i>						
W ₁	1.74	1.98	2.21	2.38	2.58	2.80
W ₂	1.75	2.05	2.26	2.44	2.63	2.83
CV (%)	1.86	4.21	6.19	5.92	5.4	3.9

W₁ = Tap water wash, W₂ = 120 ppm Chlorinated water wash DAS = Days after storage

There was a significant variation on shelf life of squash influenced by different washing methods (Fig. 1). Results revealed that the maximum shelf life (43.42 days) was recorded from the treatment W₂ (chlorinated water wash) whereas control treatment W₁ (tap water wash) showed minimum shelf life (37.25 days) of squash (Fig. 1). Arah *et al.* (2016) reported that different washing methods techniques before storage helped to minimize the postharvest losses and extend the

shelf life of fruits which was also supported by the findings of Tolasa *et al.* (2021) and Nyamende *et al.* (2021).

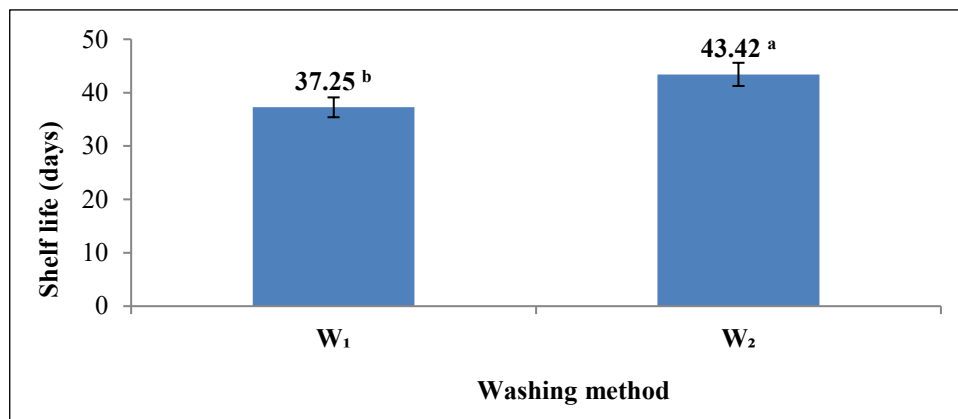


Fig. 1. Shelf life of stored squash fruits as influenced by different washing methods.

Vertical Bars indicates mean \pm SE of three replicates. Means having different letter (s) are significantly different at 5% level of probability by DMRT; W₁ = Tap water wash, W₂ = 120 ppm Chlorinated water wash

Effect of storage temperature

Total soluble solid (TSS) was gradually decreased with the advancement of storage (DAS) in all storage temperature treatments (Table 2). At the beginning (0.0 DAS), TSS and vitamin C content did not differ significantly by storage temperature. At 10 DAS and 50 DAS, TSS content of squash fruits was found nonsignificant but at 20, 30 and 40 DAS, significant variation was observed recorded due to different storage temperature (Table 2). At 20, 30 and 40 DAS, the storage temperature 12 \pm 0.5 °C (T₃) gave the highest TSS content (4.80, 4.15 and 3.50%, respectively) followed by the storage temperature 16 \pm 0.5 °C (T₄) (4.40, 4.00 and 3.20%, respectively) and 8 \pm 0.5 °C (T₂) (4.45, 3.95 and 3.15%, respectively) at 20, 30 and 40 DAS with no significant difference between T₄ and T₃ treatments while control temperature treatment T₁ (room temperature) showed the lowest TSS content (4.25, 3.75 and 2.85%, respectively). Vitamin C content of squash fruits decreased gradually with the increase of storage duration (Table 2). At 10 and 20 DAS, significant variation was observed in vitamin C content but at initial (0.00 DAS), 30, 40 and 50 DAS vitamin C content was not differed significantly due to storage temperature. Results revealed that at 10 and 20 DAS, the maximum vitamin C content (11.40 and 10.20 mg/100g FW, respectively) was recorded from the temperature 8 \pm 0.5°C (T₂) which was statistically identical with temperature 12 \pm 0.5°C (T₃) and 16 \pm 0.5°C (T₄), whereas control temperature (room temperature) (T₁) showed the lowest vitamin C content (10.55 and 9.83 mg/100g FW, respectively). (Table 2). Similar findings were also found by Sharma *et al.*

(2002) who reported that the decline in vitamin C in plum squash might be due to its degradation into dehydro-ascorbic acid at room temperature.

Table 2. Changes in percent TSS and vitamin C content, weight loss (%) and firmness of stored squash as influenced by different storage temperatures

Storage temperature	Days After Storage (DAS)					
	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS
<i>Total soluble solids (% TSS)</i>						
T ₁	5.78	5.13	4.25 c	3.75 c	2.85 c	2.43
T ₂	5.80	5.19	4.45 b	3.95 b	3.15 b	2.48
T ₃	5.80	5.35	4.80 a	4.15 a	3.50 a	2.58
T ₄	5.80	5.24	4.40 b	4.00 b	3.20 b	2.49
CV (%)	3.10	3.17	3.69	2.46	3.68	6.08
<i>Vitamin C content (mg/100 g FW)</i>						
T ₁	12.13	10.55 b	9.83 b	8.95	8.03	7.40
T ₂	12.18	11.40 a	10.20 a	9.23	8.25	7.50
T ₃	12.18	11.28 a	10.08 a	9.08	8.23	7.45
T ₄	12.23	11.18 a	10.00 a	9.10	8.18	7.45
CV (%)	1.9	1.59	1.51	1.54	1.95	1.36

In a column means having similar letter (s) are not statistically significant and those having dissimilar letter (s) differ significant at 5% level of probability by DMRT. T₁ = Control (room temperature, 25±2 °C), T₂ = 8±0.5°C, T₃ = 12±0.5°C, T₄ = 16±0.5°C. DAS = Days after storage.

Significant variation was found for weight loss of squash fruits at different days after storage (DAS) due to different storage temperatures (Table 3). At 10, 20, 30, 40 and 50 DAS, the highest weight loss (3.88, 7.58, 9.68, 11.88 and 16.10%, respectively) was recorded from the control temperature (room temperature) (T₁) which differed significantly to other treatments, whereas the lowest weight loss (1.25, 2.13, 2.60, 3.35 and 4.60%, respectively) was recorded from the 8±0.5 °C (T₂) closely followed by 12±0.5 °C (T₃) (1.73, 2.70, 3.33, 4.43 and 5.38%, respectively) (Table 3). There were no significant difference among the T₂ (8±0.5 °C), T₃ (12±0.5 °C) and T₄ (16±0.5 °C). This result was in conformity with the findings of Jany *et al.* (2008) who reported that the rate of weight loss increased with time progress of the storage period in all conditions. Firmness of squash fruits was significantly influenced by different days after storage (DAS) due to different storage temperatures except initiating day (Table 3). Fruit firmness increased gradually with the increasing storage duration (Table 3). At 10, 20, 30, 40 and 50 DAS, the maximum firmness (2.10, 2.28, 2.48, 2.68 and 2.88 kg-f-cm⁻², respectively) was recorded from the temperature 8±0.5 °C (T₂) followed by the temperature 12±0.5 °C (T₃) (2.05, 2.26, 2.43, 2.63 and 2.83 kg-f-cm⁻²), whereas the lowest firmness (1.93, 2.18, 2.35, 2.52 and 2.77 kg-f-cm⁻², respectively) was

recorded from the control (room temperature (T₁)). Tano *et al.* (2007) also observed similar results.

Table 3. Changes in weight loss (%) and firmness of stored squash fruits as influenced by different storage temperatures.

Storage temperature	Days After Storage					
	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS
<i>Weight loss (%)</i>						
T ₁	0	3.88 a	7.58 a	9.68 a	11.88 a	16.10 a
T ₂	0	1.25 b	2.13 b	2.60 b	3.35 b	4.60 b
T ₃	0	1.73 b	2.70 b	3.33 b	4.43 b	5.38 b
T ₄	0	2.40 b	3.95 b	4.85 b	5.55 b	6.68 b
CV (%)	-	6.17	7.17	7.91	6.3	7.04
<i>Firmness (kg-f-cm²)</i>						
T ₁	1.74	1.93 c	2.18 c	2.35 c	2.52 d	2.77 c
T ₂	1.76	2.10 a	2.28 a	2.48 a	2.68 a	2.88 a
T ₃	1.73	2.05 b	2.26 a	2.43 b	2.63 b	2.83 b
T ₄	1.74	1.98 c	2.23 b	2.38 c	2.58 c	2.79 c
CV (%)	1.86	4.21	6.19	5.92	5.4	3.9

In a column means having dissimilar letter (s) are not statistically significant at 5% level of probability by DMRT. T₁ = Control (room temperature) (25±2 °C), T₂ = 8±0.5°C, T₃ = 12±0.5°C, T₄ = 16±0.5°C. DAS = Days after storage.

Significant variation was observed on shelf life of squash as influenced by different temperature treatments.

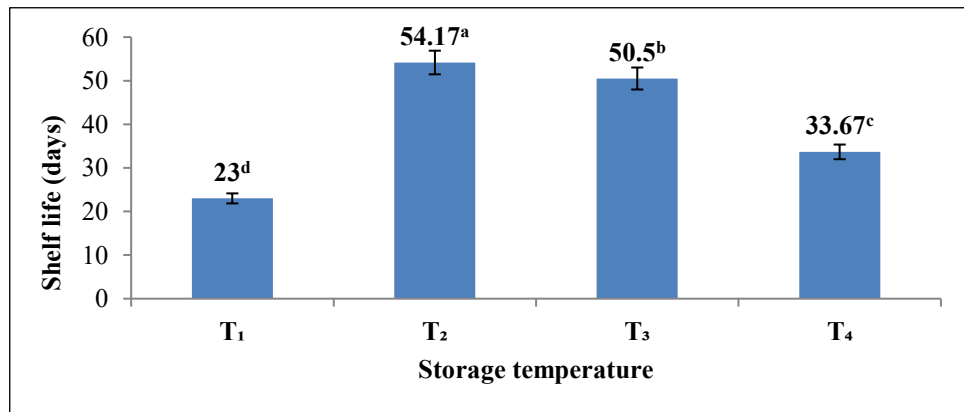


Fig. 2. Shelf life of stored squash fruits as influenced by different storage temperature.

Vertical Bar indicates mean±SE of three replicates. Means having different letter (s) are not significantly different at 5% level of probability by DMRT.

T₁ = Control (room temperature) (25±2 °C), T₂ = 8±0.5°C, T₃ = 12±0.5°C, T₄ = 16±0.5°C.

Significant variation was observed on shelf life of squash fruits as influenced by different temperature treatments (Fig. 2). Results revealed that the maximum shelf life (54.17 days) was recorded from the temperature 8 ± 0.5 °C (T_2) which was significantly different to other temperature treatments followed by temperature 12 ± 0.5 °C (T_3) (50.5 days), whereas control temperature (room temperature) (T_1) showed the lowest shelf life (23.0 days) (Fig. 2). This result suggested that a higher shelf life was achieved with lower temperature. Han *et al.* (2007) reported that the spoiling rate of squash fruits was affected more by the storage temperature. Above critical threshold level of temperature, lower temperature showed reduced respiration rate which resulted higher shelf life (Posmyk *et al.*, 2005).

Interaction effect of washing methods and storage temperature

Different washing methods of squash fruits in combination with different storage temperatures showed significant variation in TSS content at 20, 30 and 40 DAS, but interaction of washing method and storage temperature had no significant effect on TSS content at initial stage (before storage), 10 and 50 days after storage (Table 4). In interaction treatments, it is seen that TSS content was decreased gradually with the advancement of storage duration. At 20, 30 and 40 DAS, the highest TSS content (4.90, 4.40 and 3.60%, respectively) was recorded from W_2T_3 combination which was statistically similar to the combinations W_1T_2 (3.40%) and W_1T_3 (3.40%) at 40 DAS, whereas the lowest TSS content (4.20, 3.70 and 2.70%, respectively) was obtained from W_1T_1 combination that was significantly similar to the W_2T_1 combination at 20 and 30 DAS. Numerically at 50 DAS, the maximum TSS content (2.60%) was noticed in W_2T_3 combination and the minimum TSS (2.40%) was recorded from W_1T_1 combination. Different storage temperatures in combination with two washing methods of squash fruits showed significant variation on vitamin C content at 10, 20, 30 and 40 DAS except initial stage and 50 DAS (Table 4). In all combinations, vitamin C content of squash fruits decreased gradually with the advancement of storage duration. At 10 DAS, the maximum vitamin C content (11.45 mg/100 g FW) was recorded from the treatment combination of W_2T_2 which was statistically similar to W_2T_3 (11.15 mg/100 g FW), W_2T_4 (11.25 mg/100 g FW), W_1T_2 (11.35 mg/100 g FW) and W_1T_3 (11.40 mg/100 g FW), whereas W_1T_1 gave the minimum vitamin C content (10.30 mg/100 g FW). Similarly, at 20 DAS, the maximum vitamin C content (10.30 mg/100 g FW) was found from the combination W_2T_2 which was statistically similar to W_1T_2 (10.10 mg/100 g FW), W_1T_3 (10.20 mg/100 g FW) and W_2T_4 (10.10 mg/100 g FW), and the minimum vitamin C was recorded from the combination W_1T_1 (9.80 mg/100 g FW). At 30 DAS, the treatment combination of W_2T_2 gave the maximum vitamin C content (9.35 mg/100 g FW) which was identical with W_2T_3 (9.25 mg/100 g FW) and W_2T_4 (9.20 mg/100 g FW). The minimum vitamin C was recorded from W_1T_1 combination (8.85 mg/100 g FW). At 40 DAS, the maximum vitamin C content was also recorded from the

combination W₂T₂ (8.30 mg/100 g FW) closely followed by the combinations W₂T₃ (8.25 mg/100 g FW), W₂T₄ (8.25 mg/100 g FW), W₁T₂ (8.20 mg/100 g FW), W₁T₃ (8.20 mg/100 g FW) and W₁T₄ (8.10 mg/100 g FW) whereas the minimum vitamin C was found in combination W₁T₁ (7.90 mg/100 g FW).

Table 4. Changes in TSS and vitamin C content of stored squash fruits as influenced by the interaction of different washing methods and storage temperature

Washing methods x Storage temperature	Days After Storage					
	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS
<i>Total soluble solids (TSS)</i>						
W ₁ T ₁	5.75	5.10	4.20 d	3.70 c	2.70 e	2.40
W ₁ T ₂	5.80	5.20	4.30 d	4.00 b	3.40 ab	2.45
W ₁ T ₃	5.80	5.30	4.70 b	3.90 b	3.40 ab	2.55
W ₁ T ₄	5.75	5.18	4.40 cd	4.00 b	3.10 cd	2.50
W ₂ T ₁	5.80	5.15	4.30 d	3.80 c	3.00 cd	2.45
W ₂ T ₂	5.80	5.17	4.60 bc	3.90 b	2.90 d	2.50
W ₂ T ₃	5.80	5.40	4.90 a	4.40 a	3.60 a	2.60
W ₂ T ₄	5.85	5.30	4.40 cd	4.00 b	3.30 bc	2.48
CV (%)	3.10	3.17	3.69	2.46	3.68	6.08
<i>Vitamin C content (mg/100 g FW)</i>						
W ₁ T ₁	12.10	10.30 d	9.80 c	8.85 d	7.90 b	7.35
W ₁ T ₂	12.15	11.35 ab	10.10 abc	9.10 bcd	8.20 a	7.45
W ₁ T ₃	12.10	11.40 ab	10.20 ab	8.90 d	8.20 a	7.40
W ₁ T ₄	12.25	11.10 bc	9.90 c	9.00 cd	8.10 ab	7.40
W ₂ T ₁	12.15	10.80 c	9.85 c	9.05 bcd	8.15 ab	7.45
W ₂ T ₂	12.20	11.45 a	10.30 a	9.35 a	8.30 a	7.55
W ₂ T ₃	12.25	11.15 ab	9.95 bc	9.25 ab	8.25 a	7.50
W ₂ T ₄	12.20	11.25 ab	10.10 abc	9.20 abc	8.25 a	7.50
CV (%)	1.9	1.59	1.51	1.54	1.95	1.36

In a column, figures having similar letter (s) are not significantly different at 1% or 5% probability level by DMRT. DAS = Days after storage.

Interaction of four storage temperature and two washing methods of squash fruits had significant effect on weight loss (Table 5). It was observed that at all storage duration, % weight loss was decreased gradually with the advancement of storage duration (from 10 to 50 DAS). The combination W₁T₁ gave the highest weight loss (3.95, 7.65, 9.80, 12.05 and 16.70% at 10, 20, 30, 40 and 50 DAS, respectively) which was statistically similar to W₂T₁ (Chlorinated water wash with storage in room temperature) (3.80, 7.50, 9.55, 11.70 and 15.5%, respectively), whereas the combination W₂T₂ recorded the weight loss of squash fruits (1.15, 1.95, 2.25, 3.05

and 4.25% at 10, 20, 30, 40 and 50 DAS, respectively) which was statistically similar to W_1T_2 , W_1T_3 and W_2T_3 (Table 5).

Table 5. Changes in percent weight loss (%) and firmness of stored squash fruits as influenced by the interaction of different washing methods and storage temperature

Washing methods x Storage temperature	Days After Storage					
	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS
<i>Weight loss (%)</i>						
W_1T_1	0	3.95 a	7.65 a	9.80 a	12.05 a	16.70 a
W_1T_2	0	1.35 c	2.30 bc	2.95 bc	3.65 bc	4.95 bc
W_1T_3	0	1.80 c	2.85 bc	3.55 bc	4.60 bc	5.80 bc
W_1T_4	0	2.45 bc	4.05 b	5.05 b	5.85 b	6.95 b
W_2T_1	0	3.80 ab	7.50 a	9.55 a	11.70 a	15.5 a
W_2T_2	0	1.15 c	1.95 c	2.25 c	3.05 c	4.25 c
W_2T_3	0	1.65 c	2.55 bc	3.10 bc	4.25 bc	4.95 bc
W_2T_4	0	2.35 c	3.85 b	4.65 b	5.25 bc	6.40 b
CV (%)	-	6.17	7.17	7.91	6.3	7.04
<i>Firmness (kg-f-cm⁻²)</i>						
W_1T_1	1.74	1.90 f	2.15 d	2.30 e	2.50 e	2.75 d
W_1T_2	1.75	2.05 c	2.25 ab	2.45 b	2.65 b	2.85 b
W_1T_3	1.70	2.00 d	2.25 ab	2.40 c	2.60 c	2.80 c
W_1T_4	1.75	1.95 e	2.20 c	2.35 d	2.55 d	2.78 cd
W_2T_1	1.74	1.95 e	2.20 c	2.40 c	2.55 d	2.78 cd
W_2T_2	1.77	2.15 a	2.30 a	2.50 a	2.72 a	2.89 a
W_2T_3	1.75	2.10 b	2.27 a	2.45 b	2.65 b	2.85 b
W_2T_4	1.72	2.00 d	2.25 ab	2.40 c	2.60 c	2.80 cd
CV(%)	1.86	4.21	6.19	5.92	5.4	3.9

In a column means having dissimilar letter (s) are not statistically different at 5% level of probability by DMRT. DAS = Days after storage

Four storage temperature in combination with two washing methods of squash fruits put significant effect on firmness at various storage duration except initial stage (Table 5). In all interaction treatments, firmness of squash fruits was gradually increased with the advancement of storage duration (10 to 50 DAS), the combination W_2T_2 showed the maximum firmness of squash fruits whereas W_1T_1 showed the minimum firmness of squash fruits with significant difference but at initial stage it was found that firmness was 1.77 and 1.74 kg-f-cm⁻² in the combinations W_2T_2 and W_1T_1 respectively with non-significant difference between these two combinations. The results indicated that, at 10, 20, 30, 40 and 50

DAS, the highest firmness (2.15, 2.30, 2.50, 2.72 and 2.89 kg-f-cm⁻², respectively) was recorded from the combination W₂T₂ which was significantly different from the other combinations and followed by W₂T₃ (2.10, 2.27, 2.45, 2.65 and 2.85 kg-f-cm⁻² at 10, 20, 30, 40 and 50 DAS, respectively) and W₁T₂ (2.05, 2.25, 2.45, 2.65 and 2.85 kg-f-cm⁻² 10, 20, 30, 40 and 50 DAS, respectively), whereas W₁T₁ combination gave the lowest firmness (1.90, 2.15, 2.30, 2.50 and 2.75 kg-f-cm⁻² at 10, 20, 30, 40 and 50 DAS, respectively) (Table 5). Shelf life of squash fruits was significantly influenced by the interaction of different storage temperature and different washing methods of squash fruits (Fig. 3). It was observed that the maximum shelf life was recorded from the combination W₂T₂ (57.33 days) which was statistically similar to W₂T₃ combination (55.33 days), whereas the combination W₁T₁ gave the minimum shelf life (21.33 days) (Fig. 3).

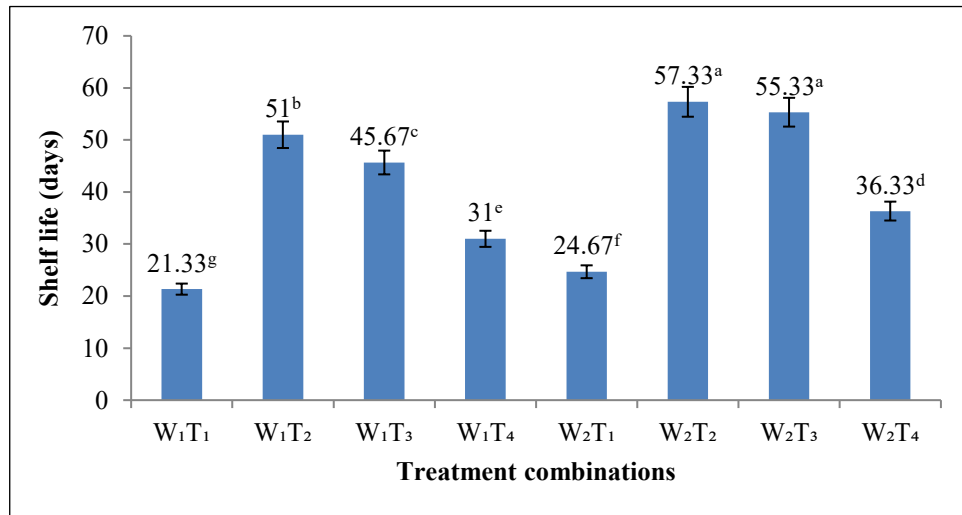


Fig. 3. Shelf life of stored squash fruits as influenced by different treatment combinations of washing methods and storage temperature

Vertical bars indicate mean±SE of three replicates. Means having different letter (s) are not significantly different at 5% level of probability by LSD.

W₁ = Tap water wash, W₂ = 120 ppm Chlorinated water wash.

T₁ = Control (room temperature 25±2 °C), T₂ = 8±0.5°C, T₃ = 12±0.5°C, T₄ = 16±0.5°C.

Conclusion

From the study, it may be concluded that, total soluble solids and vitamin C content of squash fruits were gradually decreased but weight loss and firmness increased with the advancement of storage duration from 10 to 50 days after storage at 10 days interval. TSS, vitamin C and fruit firmness were found maximum from the combination of chlorinated water washing using 120 ppm sodium hypochlorite

solution and the storage temperature of 12 ± 0.5 °C. Minimum weight loss was also recorded from this combination. The maximum shelf life (57.33 days) was recorded from the combination chlorinated water washing and the storage temperature of 8 ± 0.5 °C which was statistically similar to chlorinated water washing with storage temperature of 12 ± 0.5 °C (55.33 days). Chlorinated water washed squash fruits using (120 ppm sodium hypochlorite solution) and storage temperature of 8 to 12 °C are suitable for the storage of squash fruits.

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REVIEW ON BIOLOGICAL CONTROL OF ROOT-KNOT NEMATODE (*MELOIDOGYNE* SPP.) IN TOMATO

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Abstract

Root-knot nematode (*Meloidogyne* spp. such as *Meloidogyne javanica*, *M. hapla* and *M. incognita*), belongs to endoparasite, is one of the most important agricultural harmful organisms. These harmful pathogens are responsible for causing significant yield losses in a wide range of agricultural crops, mostly vegetables, especially in tropical and subtropical regions. For controlling root-knot nematode, biological control became more acceptable than any other methods for general users since it is an eco-friendly, effective, economical and non-polluting method with the environment. Moreover, biological controls were being used due to environmental awareness and changing regulation. Different types of biocontrol agents such as fungi and bacteria are being used for controlling different plant pathogens including root-knot nematodes. However, emphasizing on the application of biological agents against of root-knot nematodes (RKN) among farmers for increasing the tomato yield all over the world. This review describes the general biology of root-knot nematodes (RKN), their nature of the damage on tomato plants, and finally the current research progress in biological control by using different organisms as well as their effects on the environment.

Keywords: Root-knot nematodes (*Meloidogyne* spp.), Tomato (*Solanum lycopersicum*) and Biological control.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops which are grown widely all over the world and used as a commercial for various reasons. It holds various types of R- tocopherol (vitamin E), vitamin C, antioxidant, lycopene, and phenolics which are performing as anticipatory against different kinds of diseases, primarily heart and cancer diseases. This important horticultural crop is susceptible to different types of diseases, causes by various fungi, bacteria, viroid, virus and parasitic nematodes resulting in severe yield loss.

According to Upadhyay and Dwivedi (2008), *Meloidogyne incognita*, an essential endoparasite can cause 30 to 50% yield damage of tomato in farmers's field per annum. In addition to *M. incognita*, some other species like *M. javanica*, *M. hapla*, and *M. arenaria* are also responsible for causing diseases among over 50 species (Wang *et al.*, 1999). These plant parasitic nematodes are able to change their cuticle

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for this reason called them multicellular animals under the group of Ecdysozoa. The nature of the most important part of nematodes is free existing parasites of animals (invertebrate associated species and about 44% vertebrate), as well as plants (15% of the specified species). They are motile, able to move through the soil less than a meter within their lifetime. Nematode can move through infected plants, seeds, plant tissue, and bulbs. It is hard to see the juvenile nematodes with the naked eye. Root-knot nematode juveniles are dynamic in juvenile stages, which is around 0.5 mm long, threadlike worms. The RKN (*Meloidogyne* spp.) are not only dangerous pathogens for tomato, but in fact also cause around 5% annual crop losses in total (Sasser and Carter, 1985). Different types of bacteria, fungi and protozoans are used as a source for their feed. Maintaining of root-knot nematode is very challenging due to their wide host range as well as the rate of reproduction is very high.

Root-knot nematodes are controlled by using different types of methods, namely chemical control, soil solarization, resistant varieties, organic amendments and biological control (Randhawa *et al.*, 2001). Since maximum of the pesticides that are normally used deliver harmful effect on the environment and human health through impurity of ground water and soil. Researchers are concentrating their attention on biocontrol for managing plant disease strategies (Jatala, 1986). Biocontrol approaches are economical, efficient, and have no detrimental environmental effects (Mukerji and Sumeet, 2000). Different types of fungal agents and bacteria are used for controlling the natural density of nematode population under diverse environment's condition that helps to reduce production costs as well as save for the environment (Meyer *et al.*, 2001). So, considering this, recently, various types of research were conducted on biocontrol by using different types of biological agents. The major objective of this review paper is to focus the research progresses of different bio-agents namely fungus, bacteria and their products for controlling RKN in tomato.

Materials and Methods

The review was conducted for searching the related information on biological control of root-knot nematode disease of tomato through browsing different website, including Google, Google scholar, Scopus and WUR library by applying keywords biological control, tomato and root-knot nematode (*Meloidogyne* spp.). This related paper also published from Plant Pathology Division, Bangladesh Agricultural Research Institute on Bangladesh Journal of Agricultural Research.

Results and Discussion

Duration of life cycle in Root-knot Nematodes

The life cycle of Root-knot Nematodes is presented in Fig. 1. The life cycle duration of nematodes (*Meloidogyne* spp.) which differed with season such as 6

weeks in summer and 10-15 weeks in winter might be due to temperature difference during this time. The life cycle started with the female nematode which laying her eggs on the surface of galled roots which surrounded by gelatinous glycoprotein matrix. The first stage called, “Juvenile (J1)” which started from the hatching of the eggs. Afterwards, the larvae started moving through the soil to enter or parasitize a new root and consequently they initiate the infection. Following the infection, the infected root tissue produced one kind of substances that helped nematodes for going towards the root tip. Nematodes stylet secreted some chemical substances into the root cell, which started the enlargement of the plant cells, resulting in giant cells that vary in size. Second Juvenile (J2) stage, then developed by forming a flask shaped body, which gradually increased in width and size of female larvae’ body. In the subsequent developmental period, the Juvenile 3, the larvae arrived the moulting phase, during this time the stylet vanished and also the median oesophagus bulb. At the termination of the life cycle, fourth Juvenile (J4), the adult made vagina and uterus (Bengtsson, 2015; Taylor and Sasser, 1978).

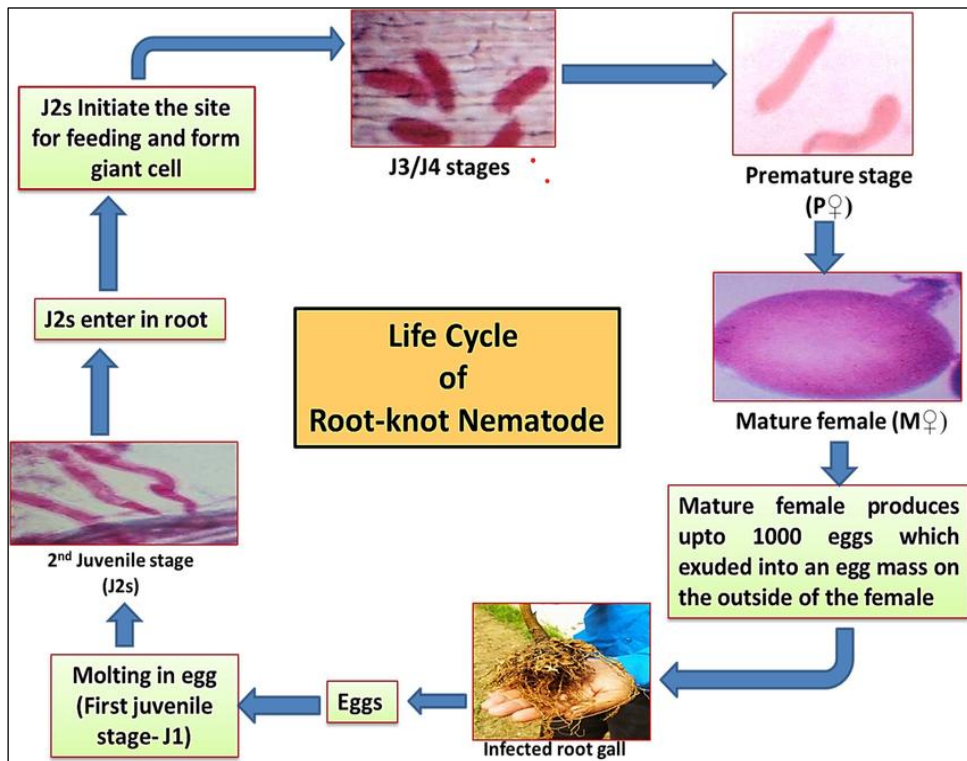


Fig. 1. The Life Cycle of the Root-Knot nematode

Symptoms of infected tomato plants

Due to infection of RKN, different sizes of the galls or lumps developed surrounding the root which varied from 1 to 10 mm in diameter finally, causing root rots in crops. The appearance of the infected plant becomes wasteful and sometimes plants showed the symptoms of chlorosis (yellowing), wilting and stunting. Plants infested immediately after planting resulting in severe symptoms developed. The first infected symptom of the nematode was observed in the root after established. They caused root galls in lower ground tissue of the plant after the infection (Wesemael, *et al.*, 2014)

Biological control and its importance

Biological control was the processes in which different modified or natural organisms and their products were used for control of vegetable crop diseases especially tomato (Yang, *et al.*, 2012). The term biological control had been discovered through trial and now it had been applied in modern agriculture. The durability of biological control was much lengthier than others pest control approaches. It could be more inexpensive than any other strategies in the long run. At present, many investigations were conducted to control root-knot nematode by using biological control as it was safer to the environment and harmless to human being and animals. The large proportion of nematode could be controlled by biological control considering the vast range of environment. Moreover, it would be an environmentally profited prospect for plant safety with unlimited potential for boosting long term agriculture (Sharma, *et al.*, 2013).

Importance of tomato

Among the main vegetable crops, tomato was one of the major important horticultural crops and cultivated everywhere, namely greenhouse, net houses along with fields around the whole world (Singh *et al.*, 2013). Over the last 25 years, the production and consumption of tomato had increased rapidly. It considered as a rich source of some water-soluble vitamins, flavonoids, potassium, vitamin A, E and other trace elements that were beneficial for human health. Tomatoes were good for our eyes, kidneys, hair, heart. It also increased iron absorption that helped to cure various types of bones and teeth diseases. Moreover, these high nutritional values of tomato had increased its utilization all over the world. Thus, this increasing consumer demand of tomato also increased the importance of high yield of tomato in the world (Islam, 2013).

Different Bio-control agents and its efficacy against RKN in tomato

The approaches of biological control could be competently used for maintaining soil borne pathogens in vegetable crops, particularly in tomato (Alabouvette *et al.*,

2006). Recently different research had been done in various conditions by applying several kinds of biological agents to maintain root-knot nematode in tomato. Different types of fungus such as *Trichoderma harzianum*, *T. richoderma*, *T. longibrachiatum*, *Mortierella alpine*, *Arthrobotrys* spp., *Fusarium oxysporum* and Arbuscular Mycorrhizal Fungi (AMF) were used for maintaining root knot nematode. In addition, various experiment was conducted by using bacteria as biocontrol agent namely *Pochonia* spp. *Lysobacter capsici*, *Bacillus* spp. for controlling root-knot nematode in tomato. Several experiments were conducted on *Trichoderma* spp. and *P. chlamydosporia* which indicated the positive impact on the economic threshold level through reducing the root-knot nematode population (Akhtar *et al.*, 2015; Tranier *et al.*, 2014). Furthermore, *Trichoderma* spp. and *P. chlamydosporia* could be used as profit-making bio-nematicides for a sustainable controlling of root-knot nematodes (Singh and Mathur, 2010). Many experiments conducted in different conditions by using different types of organisms for controlling RKN in tomato by utilizing various bacteria, fungus as well as their products that would be briefly discussed below.

The effects of different fungi against *Meloidogyne* spp.

Trichoderma species were used successfully as biocontrol agents for control of soil borne diseases of crops (Whipps, 2001). According to Elgorban *et al.*, (2014), *Trichoderma* had a good potentiality as a biological control organism for reducing population of *Meloidogyne* species even in adverse condition. Furthermore, Sharma and Saxena (1992) found that *T. viride* negatively affected the hatching 2 stage of *M. javanica*. In another report Sharon *et al.* (2001) stated that *T. harzianum* successfully reduced the galls of root-knot nematode caused by *M. javanica* in tomato plants. Moreover, Mokbel (2013) also conducted successful laboratory and field experiments with *Trichoderma* species which significantly reduced the activity J2, and hampered egg hatching leads to decreased infection and severity of *M. arenaria* in tomato plants.

According to Naserinasab, *et al.* (2011). short duration trial of the soil they observed that the galling of root index and per grams egg of nematode (*T. harzianum*) was decreased significantly. The level of biocontrol agents could be improved through the reduction galls number, eggs and nematode masses of egg by using salicylic acid with *T. harzianum* BI while the similar effects were observed by another scientist using *Trichoderma* (Sharon *et al.*, 2001). Elgorban *et al.* (2014) suggested that root-knot diseases in tomato could be reduced by using *Hypocrea lixii* (the Teleomorph of *Trichoderma harzianum*) which might cause lysis of cell wall, inactivation of *M. javanica* eggs as well as J2 population reduction.

Successful research was also accompanied by using *Mortierella alpine* and *T. longibrachiatum* as biocontrol agent against nematode. According to the results

reported by Al-Shammari *et al.* (2013) the *M. javanica* could be controlled by using different biocontrol agents that had detrimental effects on it. Furthermore, infestation of *M. javanica* could be reduced by promoting growth of plants, supplying of nutritional components as well as initiation of systemic resistance in plants. Under greenhouse conditions upto 64.5 % mortality of *M. javanica* juveniles (especially in the second stage J2) were reported by applying *Mortierella alpina* as well as *T. longibrachiatum* with culture filtrates. Consequently, the number of galls per plant, egg masses as well as an egg mass number per gall decreased and finally reduced disease severity with increased plant growth. Another study reported that the infestation of *M. incognita* was significantly decreased (decreasing of community size as well as root galls of nematodes) when *Trichoderma* spp. applied singly or combined with caster cake (Rao *et al.*, 1997). Considering biological control, the nematophagous fungi were essential for agricultural crops (Singh *et al.*, 2006). The *Arthrobotrys strictum* and *Arthrobotrys terreus* had efficiency for controlling of RKN, (*M. incognita*) under *in vitro* condition. These nematophagous fungi could parasitize eggs as well as juveniles resulting in reduced *M. incognita* infestation (Singh and Mathur, 2010). Another advance research reported that *Arthrobotrys oligospora* significantly reduced the larvae of nematode in comparison to control (Mostafanezhad *et al.*, 2014).

According to Bordallo *et al.* (2002) the efficiency of *Arthrobotrys oligospora* plays a vital role in fixing appropriate nematode level in roots of tomato for suppressing the nematode as well as for reducing the inoculum of nematodes in the soil. Moreover, *Arthrobotrys oligospora* increased chlorophyll content, shoot and root length, and total phenolic content (by influencing the activity of phenylalanine ammonia lyase) in plant (Singh *et al.*, 2012). In addition, it was also reported that the plants which treated with *Arthrobotrys oligospora* indicated more effective for suppressing *R. solani* along with *M. incognita*. Moreover, it was not only decreasing the infestation of nematode, but also enhanced the growth of plants as well as enrichment of tomato fruits in terms of nutritional value. According to Stirling and Smith (1998) about 57-96% root-knot nematode was decreased by using *A. dactyloides* under pot condition whereas, 75-80% nematodes reduction was found in field condition. Generally, nematodes could be controlled by using fungus which had detrimental toxic compounds. According to Goswami *et al.* (2008) the population of *M. incognita* could be reduced by using *A. strictum* together with *T. harzianum* due to their toxicity and parasitic eggs that leads to the vigour and growth of tomato plants.

Generally, plant parasitic nematodes could be controlled by using fungus bio-agents through producing detrimental toxic compounds. The population of *M. incognita* could be reduced by using *A. strictum* together with *T. harzianum* that belongs to both properties of toxic as well as parasitic eggs. Generally, the fungus attacked the cuticle of nematode and arrive the nematode body, consequently killed

the nematode. Thus, killing of nematode ultimately increased the vigour of tomato plants (Goswami *et al.*, 2008). Another investigation reported that the production of tomato was increased by dual applications of fungi and rhizosphere. These fungi had wider potentiality and efficacy for killing of nematode. In addition, the second stage juveniles of *M. incognita* was reduced by using combined fungi and rhizosphere, which could be assisted in decreasing the initiate the economic injury level. Another study conducted by Goswami and Singh (2004) and Goswami and Sharma (2001) revealed combined fungal bioagents showed better performance in reduction the reproduction of *M. incognita* resulting in improved health status of tomato plants. The *in vitro* pathogenicity tests showed that the fungal strains could be used for controlling infected root-knot nematode eggs at varying rates between 39% and 95% by using *Pochonia* species (Moosavi *et al.*, 2010). Another research investigated that microbial agents *Paecilomyces lilacinus* played important role for controlling the population density of root-knot nematodes in the soil. Moreover, it promoted the length of the shoot and enhanced root system of the tomato plant (Xiong *et al.*, 2015).

The systemic resistance of tomato plants against root-knot nematode *M. incognita* could be increased by applying one endophytic bacteria strain G12 of *Rhizobium etli*, (Martinuz *et al.*, 2013). The results explained that both Fo162 and G12 had the major contribution to decreasing the penetration of roots that was occurred by *M. incognita*. They also helped to reduce the infestation, development as well as fertility of *M. incognita*. It was reported that the plants of tomato produced less galls and masses of eggs after eight weeks infestation of nematode in comparison to control plants, when the plants were treated with Fo162 and G12 (Reimann *et al.*, 2008).

Effects Arbuscular Mycorrhizal Fungi (AMF) against *Meloidogyne incognita*

It was reported that application of Arbuscular Mycorrhizal Fungi (AMF) mostly showed both carrot and tomato crops were less affected by root galling diseases resulting from reducing the multiplication of nematode root demonstrating that AMF acted as persist and preventor for root-knot nematodes over two life cycles of crops that was conducted in the field experiments (Affokpon *et al.*, 2011). In field conditions, they found that treated plants with AMF as given more yield than control (non-AMF). Furthermore, they revealed that the combination between the crop cultivar and AMF strain helped in controlling root knot nematode destruction in plants. Micorrhizal roots reduced remarkably penetration of *M. incognita* in contrast to control roots as reported by Vos *et al.* (2012). The micorrhizal roots of tomato helped to reduce the nematode penetration as well as it acted incompletely by disturbing the mortality of nematode.

The effects of different bacteria against *Meloidogyne incognita*

Different bacteria were used as biological agents to control nematode in various crops especially in tomato. The gram-positive as well as gram-negative bacteria were used to maintain pathogens of soil-borne especially root-knot nematode (Wulff *et al.*, 2003). Two species of bacteria, namely *Bacillus cereus* and *Bacillus pumilus* had the great potentiality to control root-knot nematode disease in the production of tomato (Ramezani Moghaddam *et al.*, 2014). *Lysobacter* which was acting as a biocontrol agent was used to minimize the various diseases of plants that occurs due to infestation of nematodes, fungi and bacteria (Islam, 2011; Lee *et al.*, 2013). Root-knot nematode was controlled by using *Lysobacter capsici* YS1215 with various concentrations of bacterial culture filtrate (BCF) that was 24 well plates (Lee *et al.*, 2013).

El-Hadad *et al.* (2011) suggested that the infestation of *M. incognita* was significantly reduced due to introduction of *B. megaterium* PSB2 which promoted tomato plant growth. *M. incognita* was considerable decreased by using YBf-10 which possesses systemic nematicidal activity resulting in mortality, lethal activity and preventing egg hatching of root-knot nematode. Moreover, YBf-10 was a very promising nematicidal agent, played vital contribution for controlling the nematodes. The experiment that was conducted in pot suggested that *M. incognita* decreased the damage of tomato plants effectively by applying soil drenching with combination of YBf-10 which reducing masses of nematode egg on roots, decreasing galls and ultimately the population of nematodes in soil. In addition, YBf-10 markedly enhanced host plant growth, whereas another present study revealed that *B. firmus* YBf-10 possesses the systemic nematicidal activity for cog *M. incognita*. In addition, this bacterium helped to reduce the nematode infection through generating nematotoxic metabolites. They also considerable decreased the nematode infection through reducing space, preventing root growth as well as directly killing of nematodes.

M. incognita both in-vitro and in-vivo conditions were suppressed by *Pseudomonas fluorescens* and *Pseudomonas aeruginosa* antagonistic bacteria. These bacteria showed significant mortality of *M. incognita* juvenile up to 100% at 72 hours under *in-vitro* condition. Moreover, the reproduction of *M. incognita* was terminated by using *Pseudomonas fluorescens* under *in-vivo* condition in combination with *Rhizobium leguminosarum*. Besides these, they controlled the infection of nematode not only space competitor, but also stunted the root growth or directly attacking the nematode by introducing nematotoxic metabolites. Siddiqui *et al.* (2009) suggested that *Meloidogyne incognita* control would be possible by using the *Pseudomonas aeruginosa* especially by using the isolates Pa9

and Pa8. Moreover, these isolates enhanced the growth of plants as well as wider reducing the multiplication of nematode in comparison with other isolates. The infestation of *Meloidogyne incognita* was suppressed by using the Isolate I and II of *Pseudomonas aeruginosa* resulting in tomato plants indicated good weight of shoot, better growth in plant height, decreased gall index, enhanced weight of the root, while another experiment suggested that significant growth of plants as well as decreasing multiplication of nematodes and galling was observed by using *Pseudomonas* isolates (Siddiqui *et al.*, 2009). Moreover, *Pseudomonas fluorescens* might efficiently be used for governing *Meloidogyne incognita*. Another study revealed that the three *P. chlamydosporium* strains had varying degrees of abilities to impact *M. incognita* populations (Moosavi *et al.*, 2010).

The effects of different botanicals against *Meloidogyne incognita*

European Journal of Plant Pathology is an international journal presenting relative plant pathology research. Topical mini-reviews on biological control of root-knot nematode in tomato are being published from various organizations of different countries in this Journal. Actually, this journal also includes all plant pathogenic organisms, including viruses, procaryotes, fungi, nematodes, and parasitic plants. Journal of plant pathology which are being publishing of various review papers on biological control of root-knot nematode in different crops. Various Universities and Research Institutions in Germany are working on biological control of root-knot nematode. Indian Phytopathology journal are being published this relative research activities which was done from many Universities and Research Institutions in India.

Conclusion

Over the last few decades uses of chemical nematicides had been decreased due to detrimental impact of human health and the environment. Considering this concept, emphasis was given on biological control of root-knot nematodes (RKNs) in tomato but its application was not fruitful in the field condition. However, further studies on biological control of RKNs might be accompanied by improving the drawback of biological control and application techniques which could create an opportunity to make it more effective than chemical control.

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PRODUCTIVITY AND PROFITABILITY OF MUSTARD AND BORO RICE PATTERNS IN HAOR AREAS OF NETRAKONA

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Abstract

On-farm trial was conducted at the farmers' field of Madan, Netrakona under On-Farm Research Division, Bangladesh Agricultural Research Institute, Mymensingh during 2023-24 and 2024-25 to develop alternate cropping pattern Mustard (var. BARI Sarisha-14)-Boro rice (var. BRRI dhan92)-Fallow and to compare its productivity and profitability against farmers existing cropping pattern, Fallow-Boro (var. BRRI dhan29)-Fallow. The experiment was laid out in a randomized complete block design with six dispersed replications. Two cropping patterns *viz.*, alternate cropping pattern (Mustard-Boro rice-Fallow) and farmers' existing cropping pattern (Fallow-Boro-Fallow) were tested as variables of the experiment. The unit plot size was 1000-1200 m². The result of the study showed that two crops could be grown successfully in sequence in the tested site. Mean rice equivalent yield of alternate cropping pattern was 13.33 t ha⁻¹ which was 111 % higher over existing cropping pattern (6.33 t ha⁻¹). Land utilization index, harvest index and profitability of developed cropping pattern were higher than farmers' existing cropping pattern. The mean gross return (Tk. 2,78,600 ha⁻¹) and gross margin (Tk. 1,27,960 ha⁻¹) were higher in developed cropping pattern compared to farmers' existing cropping pattern. The marginal benefit cost ratio (2.15) also indicated the superiority of the alternate cropping pattern over the farmers' existing cropping pattern.

Keywords: Cropping pattern, Productivity, Profitability, Haor Areas.

Introduction

Bangladesh is almost self-sufficient in rice production but other food production such as oil crops, pulses, and vegetables etc. are still deficient to a large extent. The present cropping intensity of Madan Upazilla of Netrakona district is about 169 % which is lower than the country's cropping intensity 198 %. Mustard (var. BARI Sarisha-14) is a high value cash crop which brings higher economic return. In Fallow-Boro-Fallow cropping patterns, mustard may be introduced after receding flood water. Mustard may be grown easily as an alternative of farmers' one. To align with SDG-2 (Zero Hunger), the Bangladesh Agricultural Research Institute

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(BARI) is focused on boosting cropping intensity. The goal is to maximize land productivity by transitioning from single to double, double to triple, and even triple to quadruple cropping systems.

In this context, not only the modern production technology and complementary inputs are essential but also the diversification of crops throughout the country is foremost. In Bangladesh horizontal expansion is very limited, but increase in crop production could be possible with vertical expansion through increasing crop yield per unit area and by reducing production loss. BARI has developed high yielding mustard variety, BARI Sarisha-14 whose yield potential is 40-45 % higher than Tori-7. Inclusion of this mustard variety can create opportunity to fit in the Fallow-Boro-Fallow cropping sequence. There are seven major cropping patterns which are practiced by the farmers of Madan, under Netrakona district among which Fallow-Boro-Fallow is one of the major cropping patterns under irrigated medium low land. This pattern covers around 40 % of the net cropped area (DAE, 2024). After flood water receded 15-20% land in haor areas is suitable for crop cultivation in last week of September to third week of December. At that time farmers are waiting for cultivating Boro rice by irrigation with deep tube well up to third week of January. As a result, a vast area remains fallow for long time (About 90 to 100 days) before *Boro* rice cultivation. So, there is an opportunity to increase cropping intensity and crop productivity by inclusion of mustard in Fallow-Boro-Fallow cropping pattern. If the farmers will sow mustard by first week of November, then it will be harvested at 3rd week of January. After harvesting of mustard, farmers can easily grow *Boro* rice in proper time which will not be affected by flash flood. Considering the above situation, the present study was carried out to develop two crop-based cropping patterns for haor areas and increase cropping intensity, productivity and income of the farmers.

Materials and Methods

The trial was conducted at the farmers' field of Madan, Netrakona under On-Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Mymensingh during 2023-24 and 2024-25 to increase cropping intensity, productivity and profitability of the farmers by inclusion of mustard (var. BARI Sarisha-14) in the existing cropping system of Fallow -*Boro*-Fallow. The experimental site belongs to Old Brahmaputra Floodplain Agro-ecological Zone (AEZ-9) of Netrakona. The geographical position of the area is between 24°72'N latitude and 90°93' E longitude. The land was medium low and the soil of the study area was clay loam to clay in texture with well drainage system and almost acidic in reaction having pH range of 4.3 to 5.8. The overall soil characteristics are grey clay and silty clay, which are prone to being acidic and organic matter content is medium. In general, fertility level including N, P, K and B was low. Maximum

rainfall was received during the months of April to September. The highest temperature (31.8°C) in August and the lowest in January (12.6°C). The relative humidity was the highest (84.5%) in August and the lowest (75.2 %) in March. Monthly mean maximum and minimum air temperature (31.1 and 23.5°C), total rainfall (2195 mm) and relative humidity (82.7 %) were prevailing during the study period.

The experiment was laid out in a randomized complete block design with six dispersed replications. Two cropping patterns *viz.*, alternate cropping pattern (Mustard-Boro-Fallow) and farmers' existing pattern (Fallow-Boro-Fallow) were the treatment variables of the experiment. The unit plot size was 1000-1200 m². Mustard was grown during *rabi* season and it was the first crop of the sequence. Soil moisture at the time of sowing mustard was prevailing about 65 % at dry weight basis. Major yield contributing characters of mustard are presented in Appendix 1. Fertilizer management was followed by (Ahmmad *et. al.*, 2018) and intercultural operations like weeding, irrigation and pest management were done to support the normal growth and development of the crops. Mustard var. BARI Sarisha-14 was seeded as broadcast method @ 7 kg ha⁻¹. The crop was sown during 14 to 19 November 2023 and 12 to 19 November 2024 in two consecutive years. The crop was harvested during 03 to 09 February 2024 and 02 to 10 February 2025. *Boro* rice was the second crop of the sequence. Major yield contributing characters of BRRI dhan92 are presented in Appendix 2. Seedlings of *Boro* rice were grown in adjacent plot and transplanting was done with 35 to 40 days old seedlings of *Boro* rice var. BRRI dhan92 at a spacing of 20 cm × 20 cm during 10 to 15 February 2024 and 08 to 14 February 2025. The *Boro* rice was harvested during 20 to 27 May 2024 and 19 to 28 May 2025 in two successive years.

Data on yield of different crops in sequences were recorded and converted to ton per hectare. The data of farmer's practice was recorded from adjacent farmers' plots. Agronomic parameters like field duration (FD), turnaround time (TAT), rice equivalent yield (REY), production efficiency (PE), land utilization index (LUI) and harvest index (HI) of cropping patterns were calculated by the following formula.

Rice Equivalent Yield (REY): For comparison between crop sequences, the yield of every crop was converted into rice equivalent yield on the basis of prevailing market price of individual crop (Verma and Modgal, 1983). Rice equivalent yield (REY) was computed as yield of individual crop multiplied by market price of that crop divided by market price of rice.

$$\text{Rice Equivalent Yield (t ha}^{-1}\text{)} = \frac{\text{Yield of individual crop} \times \text{market price of that crop}}{\text{market price of rice}}$$

Productivity: Production efficiency value in terms of $\text{kg ha}^{-1} \text{ day}^{-1}$ was calculated by total main product in a cropping pattern divided by total duration of crops in that pattern (Tomar and Tiwari, 1990).

$$\text{Production efficiency (kg ha}^{-1} \text{ day}^{-1}) = \frac{\sum Y_i}{\sum d_i}$$

Where, Y_i = Yield (kg) of i^{th} crop, d_i = Duration (day) of i^{th} crop of the pattern and $i = 1, 2, 3, 4$

Land utilization index (LUI): It was worked-out by taking total duration of crops in an individual cropping pattern divided by 365 days (Rahman *et al.*, 1989). It was calculated by the following formula:

$$\text{Land Utilization Index (\%)} = \frac{d_1 + d_2}{365} \times 100$$

Where d_1 and d_2 the duration of 1st and 2nd crop of the pattern

Harvest index (HI) was calculated as per following equation (Rahman *et al.*, 1989).

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Economic analysis was done on the basis of prevailing market price of the commodities. The inputs used included seed, fertilizer, labour and insecticides. The MBCR of the farmers' prevalent pattern and any replacement for it can be computed as the marginal value product ((MVP) over the marginal value cost (MVC). The Marginal of prevalent pattern (F) and any potential replacement (E) which was computed as (CIMMYT, 1988).

$$\text{Marginal Benefit Cost Ratio (MBCR)} = \frac{\text{Gross return (E)} - \text{Gross return (F)}}{\text{TVC (E)} - \text{TVC (F)}} = \frac{\text{MVP}}{\text{MVC}}$$

Results and Discussions

Crop management: Crop management practices include date of sowing/transplanting, date of harvesting, fertilizer dose used, field duration and turnaround time etc. of alternate and existing cropping pattern are shown in Table 1. The mean crop field duration of mustard and *Boro* rice under alternate cropping pattern were 83 and 102 days, respectively while, in existing cropping pattern it was 118 days for *Boro* rice. Total field duration of alternate cropping pattern and existing cropping pattern were 183-185 and 117-119 days, respectively in 2023-24 and 2024-25. The crop duration of *Boro* rice under existing cropping pattern was

higher (117-118 days) than that of alternate cropping pattern (101-102 days) due to use of long duration rice var. BRRI dhan29 in farmers' pattern. But in alternate cropping pattern *Boro* rice (BRRI dhan92) was cultivated and it was at least 15 days earlier harvested in both years. Turnaround time for mustard and *Boro* rice were 172-175 and 07-08 days, respectively in alternate cropping pattern whereas in existing cropping pattern it was 246-248 days in both the years.

Seed/Grain and by-product yield: Seed/grain and by-product yield of the study have been presented in Table 2. Seed yield of mustard (var. BARI Sarisha-14) was 1.78 and 1.60 t ha^{-1} and stover yields were 1.34 and 1.26 t ha^{-1} in two successive years, respectively. Two years average seed yield and stover yield of mustard in alternate cropping pattern was 1.69 and 1.30 t ha^{-1} , respectively. Grain yield of *Boro* rice was 7.12 t ha^{-1} in 1st year and 7.40 t ha^{-1} in 2nd year. Two years average grain and straw yields of *Boro* rice were 7.26 and 6.25 t ha^{-1} in alternate cropping pattern, respectively which was 14.69 and 1.46 % higher than existing pattern *Boro* rice (var. BRRI dhan29) due to change of variety along with modern crop production technologies. Similar results were also obtained by Nazrul *et al.* 2013. Farmers' cropping pattern gave lower yield due to imbalance use of fertilizers and poor management practices. It was revealed that the entire component crops of Mustard-*Boro*-Fallow (AP) cropping pattern under improved practices gave higher yield as well as by-product yield in two consecutive years. However, inclusion of mustard (var. BARI Sarisha-14) and *Boro* rice (var. BRRI dhan92) with improved production technologies increased the total yield over the farmers existing practice. Similar results were also obtained by Nazrul *et al.*, 2013.

Table 2. Average Seed/grain yield and by-product yield of alternate cropping pattern and farmers' cropping pattern at Madan, Netrakona MLT site during 2023-24 and 2024-25

Parameters	Years	Improved Cropping Pattern (IP)			Farmers' Existing Pattern (FP)		
		Mustard	<i>Boro</i>	Fallow	Fallow	<i>Boro</i>	Fallow
Seed/Grain yield (t ha^{-1})	2023-24	1.78±0.23	7.12±0.18	-	-	6.46±0.24	
	2024-25	1.60±0.21	7.40±0.22	-	-	6.20±0.27	-
	Average	1.69±0.22	7.26±0.20	-	-	6.33±0.26	
Stover/Straw yield (t ha^{-1})	2023-24	1.34±0.23	6.40±0.28	-	-	6.29±0.21	-
	2024-25	1.26±0.24	6.10±0.24	-	-	6.03±0.27	-
	Average	1.30±0.22	6.25±0.26	-	-	6.16±0.24	-

Rice Equivalent Yield (REY): Total productivity of a cropping system was evaluated in terms of rice equivalent yield (REY) and it was calculated from yield of component crops. Average higher rice equivalent yield (13.33 t ha^{-1})

was recorded with the alternate cropping pattern over farmer's traditional cropping pattern (Table 3). Rice equivalent yield increased by 111% in alternate cropping pattern due to inclusion of mustard (var. BARI Sarisha-14) and new high yielding variety of rice with modern production technologies for the component crops. The lower rice equivalent yield (6.33 t ha^{-1}) was obtained in the farmer's pattern due to single *Boro* rice with traditional management practices. It is evident from the above findings that alternate cropping pattern gave higher yield compared to existing farmers' pattern. Similar results were obtained by Nazrul *et al.* (2017).

Production Efficiency (PE): Mean maximum production efficiency (53.66) in terms of $\text{kg ha}^{-1} \text{ day}^{-1}$ was obtained from farmer's existing cropping pattern which was 10.32 % higher over alternate cropping pattern (Table 3). Production efficiency of alternate cropping pattern was found to be 48.63 and $48.65 \text{ kg ha}^{-1} \text{ day}^{-1}$ in two consecutive years while in existing cropping pattern it was found to be 55.21 and $52.10 \text{ kg ha}^{-1} \text{ day}^{-1}$, respectively. The production efficiency was lower in alternate cropping pattern might be due to inclusion of mustard variety as a result average total duration was (66 days) higher over farmer's existing pattern. The result indicates that the crops remained in the field for longer time leading to lower production per day. On the contrary, crops remain standing in the field for shorter time in farmer's practices, leading to higher production efficiency.

Land utilization index (LUI): Land use efficiency is the effective use of land in a cropping year, which mostly depends on crop duration. The average land utilization index indicated that alternate cropping pattern used the land for 50.41 % period of the year whereas farmer's pattern used the land for 32.33 % period of the year (Table 3). Land utilization index was about 55.92 % higher in alternate cropping pattern than farmer's practice due to alternate cropping pattern occupied the land for longer duration (184 days) than farmer's pattern (118 days) in a year. This higher land use efficiency in alternate cropping pattern is due to cultivation of two component crops in the alternate cropping pattern.

Harvest Index: Alternate cropping pattern mustard (var. BARI Sarisha-14)- *Boro* rice (var. BRRI dhan92) recorded the mean harvest index (54.25%) which was 7.02% higher than existing cropping pattern, Fallow-*Boro* (Var. BRRI dhan29) - Fallow). The harvest index of alternate cropping pattern had higher value due to inclusion of mustard and *Boro* rice varieties which contributed the higher economic and biological yield.

Table 3. Average rice equivalent yield, production efficiency, land utilization index and harvest index of alternate cropping pattern and farmers' practices at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Cropping patterns	REY (t ha ⁻¹)	PE (kg ha ⁻¹ day ⁻¹)	LUI (%)	HI (%)
2023-24	AP	14.12	48.63	50.14	53.49
	FP	6.46	55.21	32.05	50.67
2024-25	AP	12.54	48.65	50.68	55.01
	FP	6.20	52.10	32.60	50.70
Mean	AP	13.33	48.64	50.41	54.25
	FP	6.33	53.66	32.33	50.69

Note: AP= Alternate Pattern and FP=Farmers' Pattern, REY= Rice equivalent yield, PE= Production efficiency, LUI= Land utilization index and HI= Harvest index

Profitability analysis: The cost and return analysis were done on the basis of prevailing market price during the crop season as shown in Table 4. The study revealed that mean gross return of the alternate and farmers' existing cropping pattern was Tk.2,78,600 and Tk. 1,38,920 ha⁻¹, respectively. The mean gross return of alternate cropping pattern was 101 % higher than farmers' existing cropping pattern and it might be due to inclusion of mustard and high yielding *Boro* rice variety. The mean gross margin of alternate and farmers' existing cropping pattern was Tk. 1,27,960 and Tk. 53,298 ha⁻¹, respectively and it was about 140 % higher over farmer's existing cropping pattern. The mean MBCR was found 2.15 which is also indicated the superiority of alternate cropping pattern over farmer's existing cropping pattern.

Table 4. Cost and return analysis of alternate cropping pattern and farmers' existing cropping pattern at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Pattern	Gross return (Tk. ha ⁻¹)	Total variable cost (Tk. ha ⁻¹)	Gross margin (Tk. ha ⁻¹)	MBCR
2023-24	AP	2,82,480	1,50,570	1,31,910	2.17
	FP	1,41,780	85,620	56,160	
2024-25	AP	2,74,720	1,50,710	1,24,010	2.13
	FP	1,36,060	85,625	50,435	
Mean	AP	2,78,600	1,50,640	1,27,960	2.15
	FP	1,38,920	85,623	53,298	

Note: Unit price (Tk. kg⁻¹): Mustard =70/-, *Boro* rice =20/-, Stover=2/-, and Rice straw=2/-

Farmers' opinion: Farmers opined that cultivation of mustard in a year increased cropping intensity and productivity. Harvesting of short duration BARI Sarisha-14 can easily be grown without hampering *Boro* rice.

Conclusion:

The total crop productivity, production efficiency and profitability of alternate cropping pattern Mustard (var. BARI Sarisha-14)-*Boro* rice (var. BRRI dhan92) - Fallow were higher than that of existing cropping pattern, Fallow- *Boro* (var. BRRI dhan29)- Fallow due to inclusion of mustard and *Boro* rice varieties. Thus, alternate cropping pattern Mustard-*Boro*-Fallow is economically as well as agronomically suitable technology for haor area of Netrokona. If early flash flood affected the *Boro* rice than at least mustard crop could be harvested but short duration of *Boro* rice should be developed for this pattern in future to avoid flood.

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Appendix1. Characteristics of BARI Sarisha-14 at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Plant density /m ²	No. of primary branches /plant	No. of siliqua /plant	No. seed / siliqua	1000-seed weight (g)
2023-24	55	3.40	65.70	22.90	2.41
2024-25	57	3.20	67.30	22.10	2.43
Mean	56	3.30	66.50	22.50	2.42

Appendix2. Characteristics of BRRI dhan92 at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Plant density /m ²	No. of effective tillers /hill	No. of filled grain/panicle	1000-grain weight (g)
2023-24	22.14	11.17	170	21.54
2024-25	22.16	11.13	172	21.66
Mean	22.15	11.15	171	21.60

DEVELOPMENT OF BIO-RATIONAL BASED MANAGEMENT TECHNOLOGY AGAINST FOOT AND ROOT ROT AND ROOT-KNOT DISEASES OF CUCUMBER

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Abstract

The experiments were conducted in the field of Plant Pathology Division, BARI during 2022-23 and 2023-24 cropping season to develop eco-friendly integrated management technology against foot and root rot disease caused by *Fusarium oxysporum* and *Sclerotium rolfsii* and root-knot nematode disease caused by *Meloidogyne incognia*. Pathogens infested field soils were treated with different treatment combinations of *Trichoderma* based Tricho-composts, saw dust burning, bio-fungicide Lycomax, poultry refuse, mustard oil cake, chemical fungicide Autostin and nematicide Rugby 10 G. All the treatments gave appreciable reduction of both foot and root rot, and root-knot nematode diseases and thereby enhanced plant growth as well as fruit yield of cucumber. The integration of Tricho-compost with Lycomax effectively reduced the foot and root rot disease upto 85.73% in addition to 44.86% reduction of gall index of root-knot nematodes in cucumber. Combined use of poultry refuses or mustard oil cake with Autostin was also a viable strategy for managing foot and root rot and root-knot nematode diseases in cucumber for enhancing cucumber yield in an eco-friendly manner.

Keywords: Cucumber, foot and root rot, *Fusarium oxysporum*, *Sclerotium rolfsii*, root-knot nematode, *Meloidogyne incognia*, Tricho-composts, Lycomax, poultry refuse and mustard oil cake.

Introduction

Cucumber (*Cucumis sativus* L.) is one of the most important vegetable crops grown worldwide for its nutritional and economic value. Cucumber is largely planted and produced in Asia (87.2%) with China is dominated the word cucumber production (Meng et al., 2018). Owing to the limited availability of agricultural land and high market demand, continuous cucumber cropping has been widely adopted by majority of farmers. However, its production is severely constrained by several soil-borne diseases, particularly foot and root rot caused mainly by *Fusarium solani*, *Rhizoctonia solani* and *Sclerotium rolfsii* and root-knot disease caused by

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Meloidogyne incognita (Noling, 2005; Sikora and Fernandez, 2005). These diseases not only reduce seedling establishment and plant vigour but also cause significant yield losses, often exceeding 30–50% under favourable conditions (Khan *et al.*, 2017; Sikder and Vestergård, 2020). These disease causing pathogens are major soil dweller that leads to severe shortage in cucumber supply under greenhouse condition (Shen *et al.*, 2008). Diseases caused by soil borne pathogens are unique because the causal pathogens, which can survive in soil under the pressure of antagonistic soil microorganisms, can invade plants through soil. Therefore, it is very difficult to eradicate from the infested soil. Traditionally, chemical fungicides and nematicides have been used to manage these diseases. However, indiscriminate chemical use has resulted in environmental pollution, pesticide resistance, and adverse effects on beneficial soil microorganisms (Kumar *et al.*, 2019). Therefore, there is a growing emphasis on developing bio-rational management technologies that are eco-friendly, sustainable, and compatible with integrated disease management practices. Bio-rational approaches include the use of organic amendments (e.g. poultry refuse, mustard oil cake, neem products), biological control agents such as *Trichoderma spp.*, *Pseudomonas fluorescens*, and bio-fertilizers, along with novel products like plant-derived biopesticides and compost-based formulations. These interventions not only suppress soil-borne pathogens but also improve soil health, stimulate plant growth, and enhance systemic resistance in cucumber (Howell, 2003; Harman, 2006; Jaiswal *et al.*, 2020). Recent studies have shown that integration of *Trichoderma harzianum* with organic amendments and reduced doses of chemical inputs significantly reduces the incidence of foot and root rot and root-knot nematode infestation in cucurbits, and thereby increasing fruit yield and quality (Singh *et al.*, 2016; Hossain *et al.*, 2019). Similarly, neem-based products and poultry manure have been reported to improve soil microbial diversity and act synergistically with bio-control agents against root-knot nematodes (Khan *et al.*, 2017; Mukhtar *et al.*, 2021).

The development of bio-rational management technology is particularly relevant in Bangladesh, where cucumber is widely cultivated and growers are facing increasing challenges from foot and root rot as well as root-knot nematode diseases. By integrating locally available organic resources with proven biocontrol agents, it is possible to reduce dependency on chemical inputs, ensure environmental sustainability, and increase cucumber yield. Hence, an attempt was made to develop bio-rational based management packages against these diseases in the field by using Poultry refuse, Mustard oil cake, Tricho-compost, Saw dust, Lycomax, Autostin, and Rugby.

Materials and Methods

The experiment was conducted in the field of Plant Pathology Division, Bangladesh Agricultural Research Institute, Gazipur to develop bio-rational based

management packages against the diseases combining Poultry refuse, Mustard oil cake, Tricho-compost, Saw dust, Lycomax, Autostin, and Rugby during 2022-23 and 2023-24 cropping seasons. There were six treatment combinations viz., (i) Poultry refuse @ 6 kg/pit + Autostin @ 2g/l water (ii) Mustard oil cake @ 1 kg/pit + Lycomax bio-fungicide @ 3g/l water (iii) Tricho-compost @ 2 kg/pit + Lycomax bio-fungicide @ 3g/l water (iv) Saw dust burning + Lycomax bio-fungicide @ 3g/l water (v) Autostin @ 2 g/l water+ Rugby 10 G 15 g/pit and (viii) Control. The unit pit size was 2 m x 2.5 m. The experiment was conducted in randomized complete block (RCB) design with 3 replications. *Trichoderma harzianum* isolate was collected from Plant Pathology Division and was multiplied in the mixture of Grasspea and wheat bran with mustard oilcake substrates. The formulated *Trichoderma* was used to mass multiplication in organic-compost and it is designated as Tricho-compost. Tricho-compost @ 2 kg/pit was added 5 days before seed sowing and mixed properly with soil and kept 5 days for *Trichoderma* establishment in soil. Poultry refuse and mustard oil cake was applied 21 days before seed sowing. After application, poultry refuse and mustard oil cake was properly mixed with the soil and kept moist for proper decomposition. In case of saw dust burning, 6 cm thick layer of dry saw dust cover with pit soil and burned the soil properly. After burning the ash was mixed with the soil. The Bio-fungicide, Lycomax (@ 3 g/l water) and chemical fungicide Autostin was applied (@ 2 g/l water) was applied 3 times at 10 days interval started from 20 days after seed sowing. The Nematicide, Rugby 10 G was added at the time of seed sowing. Seeds of cucumber (Lalteer) were sown in the pit soils and each pit received ten seeds. Fertilizers, weeding and irrigation were applied as per recommendation of the crop. After 50-55 days of seed sowing, 3 seedlings were kept in each pit and the rest of the seedlings were uprooted carefully without disturbing the root system and those were used for data recording.

Determination of foot and root rot disease

The experimental plots were routinely inspected to observe the initiation of foot and root rot disease of cucumber in the field. In case of any complexity to identify the disease, the infected plants were collected from the field and brought to the laboratory for further study. From the infected plants, the pathogens were isolated following tissue planting methods (Baxter *et al.*, 1999). After incubation, the fungi that grew over potato dextrose agar (PDA) medium were purified by the hyphal tip culture method. The isolated fungus was identified as *F. oxysporum* and *S. rolfisii* according to reference mycology books and manuals (Barnett and Hunter, 1972; Booth, 1971).

Data collection and analysis

The root-knot disease severity was recorded at 50-55 days after seed germination. The additional seedlings from each pit were carefully uprooted and the root

systems were cleaned with running tap water. Data on length and weight of shoot and root were recorded. The severity of root gall was recorded in terms of gall index based on a 0-10 scale (Zeck, 1971). The incidence of foot and root rot disease was recorded upto 55 days after seed germination and yield of cucumber were also taken. The percent data were converted into arcsine transformation values before statistical analysis. Data were analyzed statistically by using the MSTATC program. The treatment effects i.e. mean values were compared by applying the least significant different (LSD) test at $P \leq 0.05$ level.

Results and Discussion

Shoot growth: Average shoot length of cucumber under control was 70.67 cm plant⁻¹ in first year and 104.0 cm/plant in second year. Integrated soil treatment with poultry refuse (PR)+ Autostin, mustard oil cake (MOC) + Autostin, Tricho-compost + Lycomax bio-fungicide, Saw dust burning (SDB)+ Lycomax bio-fungicide and Rugby 10 G + Autostin increased the shoot length ranging from 97.67 to 116.70 cm plant⁻¹ in first year and 125.3-164.7 cmplant⁻¹ in second year trial. In both the years, integration PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide gave the higher shoot length followed by SDB + Lycomax bio-fungicide treatment (Table 1). The least effective treatments to increase shoot length was Rugby 10 G + Autostin (Table 1).

Table 1. Effect of soil treatment with Tricho-compost, organic amendments, saw dust burning and chemical pesticides on shoot growth of cucumber

Treatments	Average shoot length (cm plant ⁻¹)		Average shoot weight (g plant ⁻¹)	
	2022-2023	2023-2024	2022-2023	2023-2024
Poultry refuse + Autostin	116.70	161.7	159.00	236.0
Mustard oil cake + Autostin	116.30	163.7	160.70	243.3
Tricho-compost + Lycomax bio-fungicide	115.70	164.7	164.30	248.7
Saw dust burning + Lycomax bio-fungicide	106.30	145.0	137.00	217.7
Autostin+ Rugby 10 G	97.67	125.3	107.30	171.3
Control	70.67	104.0	77.67	135.0
LSD (0.05)	7.716	9.907	12.47	19.58

In first year, the shoot weight of cucumber was only 77.67 g plant⁻¹ under control treatment. It increased to 107.3-164.3 g plant⁻¹ due to treatments with PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide, SDB+ Lycomax bio-fungicide and Rugby 10 G + Autostin. Integrated soil treatment with PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide

gave the higher shoot weight followed by SDB + Lycomax bio-fungicide treatment (Table 1). In second year, the shoot weight of cucumber was 135.0 g plant⁻¹ when both the organic amendments and pesticides were not applied (control). Application of PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide gave higher shoot weight over control within the range of 236.0-248.7 g plant⁻¹. The least effective treatment to increase shoot weight was Rugby 10G + Autostin followed by SDB + Lycomax (Table 1).

Root growth: Integrated soil amendment with PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide showed positive effects on root growth of cucumber as compared to control. In first year, the minimum root length of 11.87 cm plant⁻¹ was recorded under control treatment. Integration of PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide gave higher root length by 17.47 cm plant⁻¹, 17.37 cm plant⁻¹ and 17.80 cm plant⁻¹, respectively followed by the treatments with SDB+ Lycomax and Rugby 10 G + Autostin giving 14.67 and 13.87 cm plant⁻¹ of root length. In second year, the minimum root length of 11.3 cm plant⁻¹ was recorded from control treatment. The highest root length of 23.3 cm plant⁻¹ was achieved with Tricho-compost + Lycomax bio-fungicide followed by the treatment with PR + Autostin and MOC + Autostin giving 22.0 and 22.0 cm plant⁻¹ root length. Other treatments also increased root length over control within the range of 11.3-18.0 cm plant⁻¹ (Table 2).

Root weight was 2.77 g plant⁻¹ in the first year and 2.5 g plant⁻¹ in control plot. Integration of PR+ Autostin, MOC + Autostin, Tricho-compost + Lycomax bio-fungicide gave higher root weight by 4.37 g plant⁻¹, 4.10 g plant⁻¹ and 4.40 g plant⁻¹ in the first year where 4.39 g plant⁻¹, 4.33 g plant⁻¹ and 4.33 g plant⁻¹ in the second year, respectively. Other treatments also increased the root weight to some extent over control showing 3.12-3.60 g plant⁻¹ in the first year and 2.90-3.43 g plant⁻¹ in the second year (Table 2).

Table 2. Effect of soil treatment with Tricho-compost, organic amendments, saw dust burning and chemical pesticides on root growth of cucumber

Treatments	Average root length (cm plant ⁻¹)		Average root weight (g plant ⁻¹)	
	2022-2023	2023-2024	2022-2023	2023-2024
Poultry refuse + Autostin	17.47	22.0	4.37	4.39
Mustard oil cake + Autostin	17.37	22.0	4.10	4.33
Tricho-compost + Lycomax bio-fungicide	17.80	23.3	4.40	4.33
Saw dust burning + Lycomax bio-fungicide	14.67	18.0	3.60	3.43
Autostin+ Rugby 10 G	13.87	13.0	3.12 c	2.90
Control	11.87	11.3	2.77 c	2.50
LSD (0.05)	1.878	5.33	0.418	0.606

Foot and root rot disease incidence: In both the years, the incidence of foot and root rot disease was drastically reduced over control due to integrated application of different treatments (Table 3). In the first year, the highest foot and root rot disease of 38.33% was recorded in the untreated control plot. The percent incidence of foot and root rot disease of cucumber was 10.00% - 11.67% due to application of different treatments (Table 3). Integration of mustard oil cake with chemical fungicide and only application of chemical fungicide Autostin reduced 73.91% foot and root rot disease incidence over control followed by the integration of Tricho-compost and saw dust burning with Lycomax bio-fungicide and poultry refuse with Autostin where the reduction of disease incidence was 69.55%, 69.55% and 69.55%, respectively compared to control.

In the second year, foot and root rot disease incidence was higher 23.33% was recorded in the untreated control plot. The foot and root rot disease incidence of cucumber was 3.33% to 6.67% due to application of different treatments. Integration of mustard oil cake with Autostin, poultry refuse with Autostin and Tricho-compost with Lycomax bio-fungicide reduced foot and root rot disease upto 85.73% followed by the integration of saw dust burning with Lycomax and only Autostin treatment where the reduction of disease incidence was 71.41% compared to control.

Table 3. Effect of soil treatment with Tricho-compost, organic amendments, saw dust burning and chemical pesticides on the foot and root rot disease of cucumber

Treatments	Foot and root rot disease incidence (%)		Reduction of foot and root rot disease (%)	
	2022-2023	2023-2024	2022-2023	2023-2024
Poultry refuse + Autostin	11.67 (19.88)	3.33	69.55	85.73
Mustard oil cake + Autostin	10.00 (18.05)	3.33	73.91	85.73
Tricho-compost + Lycomax bio-fungicide	11.67 (19.88)	3.33	69.55	85.73
Saw dust burning + Lycomax bio-fungicide	11.67 (19.88)	6.67	69.55	71.41
Autostin+ Rugby 10 G	10.00 (19.88)	6.67	73.91	71.41
Control	38.33 (38.19)	23.33	-	-
LSD (0.05)	3.541	-	-	-

Vvalues within the parenthesis are the Arcsin Transformed values.

Severity of root gall: In both the years, the severity of root gall of cucumber was drastically reduced over control due to treatment of soil with mustard oilcake (MOC)+Autostin, poultry refuse (PR)+ Autostin, Tricho-compost+ Lycomax, Saw dust burning (SDB)+ Lycomax and application of Rugby 10G + Autostin. In the first year, the maximum average gall index value of 4.27 was recorded in the control plot. The gall index ranged from 1.60 to 2.33 due to treatments with two organic amendments, Tricho-compost, Saw dust burning and Rugby 10G (Table 4). Soil treatment with poultry refuse (PR)+ Autostin gave the highest reduction of root-knot severity 62.53% compared to control followed by MOC + Autostin, Rugby 10G + Autostin, Tricho-compost+ Lycomax and Saw dust burning (SDB)+ Lycomax where the reduction of root-knot disease severity was 60.89%, 51.52%, 50.12%, and 45.43%, respectively over control. In the second year, the highest gall index value of 3.50 was found in control plot and the values were 1.67 to 2.00 due to application of different treatments. The reduction in disease severity was significant compared to control. The maximum reduction root-knot nematode disease severity was obtained with poultry refuse (PR)+ Autostin 52.29% compared to control followed by MOC + Autostin, Tricho-compost+ Lycomax, Rugby 10G+ Autostin and Saw dust burning (SDB)+ Lycomax where the reduction of root-knot disease severity was 48.57%, 44.86%, 42.86%, and 42.86%, respectively compared to control (Table 4).

Table 4. Effect of soil treatment with Tricho-compost, organic amendments, saw dust burning and chemical pesticides on the root knot nematode disease of cucumber

Treatments	Gall index (0-10 scale)		Reduction of gall index value (%)	
	2022-2023	2023-2024	2022-2023	2023-2024
Poultry refuse + Autostin	1.60	1.67	62.53	52.29
Mustard oil cake + Autostin	1.67	1.80	60.89	48.57
Tricho-compost + Lycomax bio-fungicide	2.13	1.93	50.12	44.86
Saw dust burning + Lycomax bio-fungicide	2.33	2.00	45.43	42.86
Autostin+Rugby 10 G	2.07	2.00	51.52	42.86
Control	4.27	3.50	-	-
LSD (0.05)	0.530	1.81	-	-

Crop yield: The yield of cucumber was significantly increased by integration of mustard oil cake and Tricho-compost with Lycomax bio-fungicide and poultry refuse with fungicide Autostin compared to control (Table 5). In first year, the lowest yield of cucumber (15.90 t ha⁻¹) was recorded from control plot followed by saw dust burning with Lycomax and only Autostin treatments but all those

treatments were statistically similar. The maximum yield of 29.13 t ha⁻¹ was obtained with Tricho-compost + Lycomax treatment followed by MOC + Autostin and PR + Autostin with the yields of 29.10 t ha⁻¹ and 28.53 t ha⁻¹, respectively. Efficacy of three treatments to increase yield was statistically similar. Yield of cucumber was higher (45.42%) compared to control due to application of Tricho-compost + Lycomax bio-fungicide where as it were 45.36% and 44.27% due to integration MOC + Autostin, PR + Autostin, respectively. Integrated application of saw dust burning + Lycomax bio-fungicide and Rugby 10 G + Autostin gave 23.56% and 18.34% higher yield over control. In 2nd year, average fruit yield was 18.52 t ha⁻¹ under control and 27.93 t ha⁻¹ to 34.74 t ha⁻¹ under treated plots. The yield of cucumber was significantly increased by 27.93 t ha⁻¹ to 34.74 t ha⁻¹ due to integration of Tricho-compost + Lycomax, PR + Autostin, MOC + Autostin, saw dust burning + Lycomax and Rugby 10 G + Autostin. The maximum yield of 34.74 t ha⁻¹ was obtained with MOC + Autostin, which was statistically similar to Tricho-compost + Lycomax and PR + Autostin. Yield of cucumber was higher upto 46.69% compared to control due to integrated application of mustard oil cake + Lycomax bio-fungicide where as it was 46.46% and 43.69% due to integration of Tricho-compost + Lycomax bio-fungicide and poultry refuse + Autostin, respectively. Integrated application of saw dust burning + Lycomax bio-fungicide and Rugby 10 G + Autostin gave 33.69% and 20.89% higher yield over control.

The present study was designed to determine the potentiality of integration of different eco-friendly disease management approaches like integration of Tricho-compost + Lycomax bio-fungicide, mustard oil cake + Autostin, poultry refuse + Autostin, saw dust burning + Lycomax bio-fungicide and Rugby 10 G + Autostin against foot and root rot disease and also root-knot nematode diseases for increasing plant growth parameters as well as yield of cucumber. The results demonstrated that integration of different eco-friendly disease management approaches like integration of Tricho-compost + Lycomax bio-fungicide, mustard oil cake + Autostin and poultry refuse + Autostin were effective in reducing foot and root rot disease and also root-knot nematode diseases and thereby increasing plant growth parameters as well as yield of cucumber.

These results were supported by the findings of other researchers. It was reported that poultry refuse significantly reduced the population of *Fusarium* and *Pythium* species, as well as nematodes in cucumber-growing soils (Akhtar and Malik, 2000; Kaskavalcı, 2007). According to Singh *et al.* (2011), poultry manure reduced *Fusarium oxysporum* population in cucumber rhizosphere, decreasing foot and root rot severity by up to 45%. Chatterjee *et al.* (2006) observed that poultry manure incorporated into soil reduced incidence of root rot in cucurbits by 40–

60%. Mustard oil cake, a by-product of mustard seed oil extraction, contains glucosinolates that hydrolyze to form allyl isothiocyanate, a natural biofumigant toxic to many soil pathogens and nematodes. When applied to soil, mustard oil cake significantly reduced *Meloidogyne incognita* infestation and improved cucumber plant growth and yield (Chahal *et al.*, 2005; Rao *et al.*, 2014). The integration of poultry refuse, mustard oil cake, and chemical fungicide was a viable strategy for managing foot and root rot and root-knot nematode diseases in cucumber. This integrated approach did not only reduced pathogen pressure but also enhanced soil health and crop productivity in an eco-friendly manner. Das *et al.* (2017) reported that integrated application of poultry refuse + Carbendazim and mustard oil cake + fungicide increased cucumber yield by 52% and 45–50%, respectively compared to untreated control. Kaskavalci (2007) observed improved plant height, fruit length, and total marketable yield in cucumber treated with poultry manure and *Trichoderma*. Gogoi and Ali (2012) demonstrated that poultry manure + fungicide reduced disease severity index (DSI) and increased cucumber yield and fruit quality under field conditions. Rai *et al.* (2010) found that application of MOC with Carbendazim reduced disease severity index (DSI) by 70% and improved cucumber yield by 40% over control.

Different workers reported the role of Tricho-compost having bio-control agent *Trichoderma*, different composts against soil-borne and air borne plant pathogens and increasing plant growth and yield of different crops (Hossain and Naznin, 2005; Shaban and El-Bramawy, 2011; Olabiyi and Oladeji, 2014). For instance, *T. harzianum* significantly reduced disease incidence of foot rot and improved plant vigour and root architecture in cucumber (Elad *et al.*, 2000). Harman *et al.* (2004) and Yedidia *et al.* (2001) reported that *Trichoderma* application enhanced cucumber root and shoot biomass, chlorophyll content, and fruit yield under both controlled and field conditions. Rai *et al.* (2011) showed that Tricho-compost reduced root rot incidence by up to 60% and increased cucumber yield significantly. Hossain *et al.* (2016) demonstrated suppression of *M. incognita* and improved soil health with Tricho-compost application in cucurbits. Islam *et al.* (2018) reported that Lycomax-treated cucumber plants showed better vegetative growth and resistance to root stress, resulting in up to 35% yield increase. Begum *et al.* (2020) found that combined use of biocompost and Lycomax improved cucumber root development and plant vigour under nematode-infested conditions. Akter *et al.* (2021) found that cucumber plants treated with both Tricho-compost and Lycomax had 45% greater plant height and *Fusarium* wilt was reduced by 55% and increased cucumber yield by 48% compared to untreated plots.

Table 5. Effect Effect of soil treatment with Tricho-compost, organic amendments, saw dust burning and chemical pesticides on the yield of cucumber

Treatments	Yield (t ha ⁻¹)		Yield increased over control (%)	
	2022-2023	2023-2024	2022-2023	2023-2024
Poultry refuse + Autostin	28.53	32.89	44.27	43.69
Mustard oil cake + Autostin	29.10	34.74	45.36	46.69
Tricho-compost + Lycomax bio-fungicide	29.13	34.59	45.42	46.46
Saw dust burning + Lycomax bio-fungicide	20.80	27.93	23.56	33.69
Autostin+ Rugby 10 G	19.47	23.41	18.34	20.89
Control	15.90	18.52	-	-
LSD (0.05)	4.999	2.228	-	-

Conclusion

The integration of Tricho-compost and Lycomax was a highly effective strategy for the management of foot and root rot and root-knot nematodes in cucumber. The integration of poultry refuses or mustard oil cake with the chemical fungicide Autostin was also seemed to be a viable strategy for managing foot and root rot and root-knot nematode diseases in cucumber. These integrated approaches not only reduced foot and root rot and root-knot nematode diseases but also enhanced crop yield in an eco-friendly manner.

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GROWTH PATTERNS AND INSTABILITY OF CHICKPEA CULTIVATION IN BANGLADESH

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Abstract

Chickpea plays an important role in Bangladesh's agriculture due to its nutritional value and contribution to food security. This study examines the growth patterns and instability of chickpea cultivation in Bangladesh over four decades (1984–2023). Using secondary data, the period was divided into four sub-periods (1984–1993, 1994–2003, 2004–2013, and 2014–2023) to analyze trends. Exponential growth functions were applied to estimate growth rates, while the Cuddy–Della Valle index measured instability. The results indicate a sharp decline in the cultivated area, particularly after 1999/2000. However, yield improvements since the mid-2000s have partly offset production losses. Growth decomposition analysis shows that yield growth (96.02%) was the main driver of production, whereas area changes (3.62%) had only a minor effect. Instability indices reveal greater variability in yield compared to area and production, underscoring challenges in achieving stable productivity. Strategic measures to stabilize and expand cultivation area, alongside continuous yield improvement, are essential to ensure the sustainability of chickpea production in Bangladesh.

Keywords: Chickpea, growth rate, instability, Bangladesh.

Introduction

Pulses hold significant importance in the agricultural landscape of Bangladesh, serving as essential sources of nutrition for human consumption (Das *et al.*, 2016). Their rapid growth, provision of fodder for livestock, and profitable returns for farmers underscore their multifaceted value (Miah *et al.*, 2009). In addition, pulses enhance agricultural and environmental sustainability through nitrogen fixation, carbon sequestration, and organic matter enrichment (Senanayake *et al.*, 1987; Zapata *et al.*, 1987; Sarker and Kumar, 2011). The favorable climatic conditions across Bangladesh support the cultivation of diverse pulse varieties, making pulses, often referred to as the “poor man’s meat”- a vital component of diets, particularly for low-income populations. Among these, lentils are one of the oldest and most widely consumed legumes in Bangladesh. Their ability to grow in marginal environments, combined with their rich and balanced protein supply, has ensured their long-standing role in food security.

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Chickpea (*Cicer arietinum* L.) is another important pulse crop in Bangladesh due to its high consumer demand and widespread consumption. Traditionally grown under rainfed conditions, chickpea is mainly cultivated in Jessore, Faridpur, Rajshahi, Kushtia, Pabna, Chapainawabganj, and Dinajpur districts. In 2022–23 season, chickpea was cultivated on about 4.04 thousand hectares, producing around 4.67 thousand tonnes, with an average yield of 1.16 t/ha (BBS, 2023). However, domestic production remains insufficient, and to meet demand Bangladesh imported 354.14 thousand tonnes of dry chickpeas valued at USD 210.94 million in 2021 (FAOStat, 2021).

Instability is a common feature of agriculture, as production depends heavily on weather conditions and other external factors. Consequently, the area, production, and yield of chickpeas have experienced considerable variation over time. Despite the crop's importance, there is a scarcity of research focusing specifically on the growth and instability of chickpea cultivation in Bangladesh. While several studies (Das *et al.*, 2016; Miah *et al.*, 2009; Rashid *et al.*, 2014) have examined pulse production, most emphasized lentils or pulses in general, with limited attention to chickpeas. Moreover, earlier studies often lacked long-term analysis and detailed decomposition of the drivers of production changes.

This study seeks to fill that gap by analyzing growth patterns and instability in chickpea cultivation over four decades (1984–2023). By applying growth decomposition techniques and instability indices, the research provides updated insights that are directly relevant for agricultural policy and planning in Bangladesh. The findings are expected to guide researchers, policymakers, and planners in formulating strategies for sustainable chickpea development.

The specific objectives of the study are:

- (i) to determine the growth rates of area, production, and yield of chickpeas in Bangladesh;
- (ii) to measure the changes and instability in area, production, and yield of chickpeas; and
- (iii) to propose policy guidelines for the development of chickpea cultivation in Bangladesh.

Materials and Methods

Data and its Sources

The study was based on secondary data obtained from various published sources. Time series data on the area, production, and yield of chickpea for a 40-year period (1984–2023) were collected from different issues of the *Yearbook of Agricultural Statistics of Bangladesh*.

Analytical Procedures

Various statistical measures were used to analyze the data to examine the nature of change, instability, and the degree of relationship in the area, production, and yield of chickpea in Bangladesh.

Trend analysis: Trend analysis aims to find out the extent and causes of instability in the area and production of chickpeas over time. This information may lead research managers as well as policymakers to prepare appropriate policy documents for the improvement of chickpeas in the country. A simple line graph and bar diagram were used to show the trends in area, production, and yield of chickpeas in Bangladesh.

Index number: The relative changes in the area, production, and yield of chickpeas over a specified period can be quantified using an index number. For this purpose, the entire study period was divided into four sub-periods: 1984–1993, 1994–2003, 2004–2013, and 2014–2023. The division was made to analyze the changes in area, production, and yield of chickpeas within each 10-year period. The average values of area, production, and yield for the first sub-period (1984–1993) were used as the base values for comparison.

Annual growth rates: Growth rates are *the percent change of a variable over time*. It is important because it can help researchers and policymakers predict future growth. For simplicity and widely used even in the recent past (Das and Mishra, 2020; Chaudhary *et al.*, 2016), the compound growth rates of area, production, yield, and price of chickpeas were worked out by fitting an exponential function of the following type (Equation 1):

$$Y = ae^{bt} \quad \text{or} \quad \text{Ln}Y = \text{Lna} + bt \text{-----} (1)$$

Where Y is the area/production/yield of chickpea, 't' is the time in a year, and 'a' is the constant, $e^b - 1$ be the compound growth rate, which is expressed in percentage.

The component analysis model has been used to measure the relative contributions of area and yield toward the overall output change with regard to individual crops. The growth performance of the crops has been studied using this model (Equation 2) by numerous researchers in the literature (Gupta and Saraswat, 1997; Singh and Ranjan, 1998; Siju and Kombairaju, 2001; Kakali and Basu, 2006).

$$\Delta P = A \circ \Delta Y + Y \circ \Delta A + \Delta A \Delta Y \text{-----} (2)$$

Change in production = Yield effect + Area effect + Interaction effect

Thus, the total change in production is attributed to area and yield that can be decomposed into three effects viz, yield, area, and interaction effects.

Instability index: Instability means the quality or state of being unstable or a lack of stability. Agricultural instability can be measured by different methods, such as the coefficient of variation (CV), dispersion, Cuddy Della Valle Index (CDI), Coppock Instability index, etc. The present study applied the Cuddy and Valle (1978) Index (Equation 3) for examining the nature and degree of instability in the area, production, and yield of chickpeas in Bangladesh. The use of CV as a measure to show the instability in any time series data has some limitations. It does not explain properly the trend component inherent in the time series data. If the time series data exhibit any trend, the variation measured by CV can be overestimated, i.e., the region that has growing production at a constant rate will score high in instability of production if the CV is applied for measuring instability. As against that, CDI first attempts to detrend the CV by using the coefficient of determination (R^2). Thus, it is a better measure to capture instability in agricultural production. A low value of this index indicates low instability in farm production and vice versa. The estimable form of the equation is as follows:

$$CV_t = (CV) \times \sqrt{1 - R^2} \text{ ----- (3)}$$

Where CV_t is the coefficient of variation around the trend; CV is the coefficient of variation around the mean in percent; and R^2 is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom. The formulas of CV and R^2 are given below.

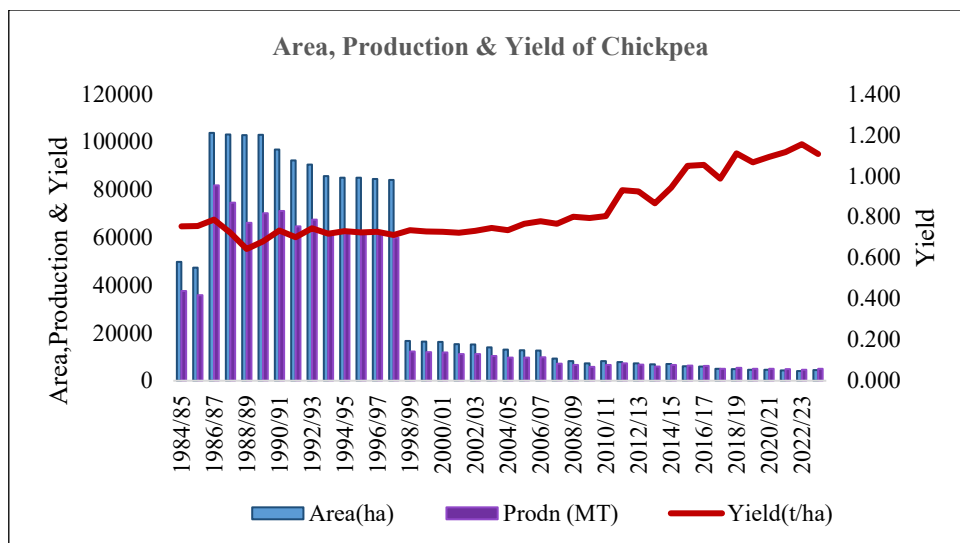
$$CV = \frac{\text{Standard deviation}}{\text{Mean}} \times 100$$

$$R^2 = 1 - \frac{\text{Unexplained variation}}{\text{Total variation}}$$

Results and Discussion

Trends of Area and Production of Chickpea in Bangladesh

Fig. 1 shows that the area and production of chickpeas for the period from 1984/85 to 1985/86 were very low compared to the succeeding years. After that chickpea cultivation is gaining popularity among farmers. Therefore, both area and production of chickpeas were very high for the period of 1986/87-1997/98 due to the higher adoption of improved varieties (BARI Chola-2, -3, -4, -5 & -6) and technologies of chickpeas at the farm level (Kabir *et al.*, 2009). Again, the overall area and production of chickpeas in the country were found to decrease for the period from 1998/99 to 2023/24. The reason for decreasing trend was to put high emphasis on increasing the area and production of cereals like rice, wheat, maize, and other short-duration oilseed crops throughout the country (Rashid *et al.*, 2014).



Source: Using data from various issues of the BBS in different years

Fig. 1. Trend of area, production, and yield of chickpea, 1984/85-2023/24.

The overall indices show that the area and production of chickpea show a decreasing trend from its base period during 2014-2023. On the other hand, the productivity indices revealed an increasing trend during the period from 1984-1993 to 2014-2023 (Table 1). Despite the decrease in area, the yield of chickpeas has gone up in those periods, which was mainly due to the adoption of improved varieties along with management technologies of chickpeas.

Table 1: Index of area, production, and yield of chickpea

Period	Area (%)	Production (%)	Yield (%)
1984-1993	100 (87506)	100 (63048.5)	100 (0.724)
1994-2003	49.4	49.7	100.7
2004-2013	10.7	11.9	112.8
2014-2023	5.8	8.6	147.5

Note: Figures within parentheses indicate a 10-year average value in the base year of the indices. Source: Various issues of BBS

Annual Growth of Chickpea Production

The overall annual growth rates scenario reveals that the area and production of chickpea registered highly significant negative growth rates during 40-year period (1984-2023). The growth rates registered in area and production from 1984 to 1993 were found positive and significant (Table 2). Both area and production growth

rates were found significantly negative during 1994-2023 due to putting a high emphasis on increasing the area and production of cereals like rice, wheat, maize, and other short-duration oilseed crops (Rashid *et al.*, 2014). However, the growth rates of yield were positive and highly significant for all periods except the period 1984-1993 and 1994-2003 (-0.619 and 0.18). The highly significant growth rates of yield were mainly due to the adoption of improved chickpea variety and technology. This indicates that more adoption of the modern varieties of chickpea is needed for the expansion of this crop throughout the country.

Table 2: Annual growth rates of area, production, and yield of chickpea, 1984-2023

Period	Area	Production	Yield
1984-1993	5.24***	4.62***	-0.619
1994-2003	-25.33***	-25.15***	0.18
2004-2013	-7.59***	-5.27***	2.31***
2014-2023	-5.36***	-3.74***	1.62***
1984-2023	-9.6***	-8.34***	1.25***

Note: '***', '**' & '*' represent 1%, 5% and 10% level of significant

Sources of Growth of Chickpea Production

The decomposition of chickpea production growth reveals that both area and yield contributed differently across the periods (Table 3). During 1984–1993, the major contribution came from yield improvement (123.20%), while the effect of area was negative (–15.81%). Similarly, in 1994–2003, yield contributed 103.06% to production growth, whereas the area effect was almost negligible (–0.02%).

In 2004–2013, yield improvement (126.63%) remained the dominant factor, though the area effect (–26.51%) negatively influenced production. The most striking result was observed in 2014–2023, where yield accounted for as high as 250.23% of the change in production, while the area effect again showed a strong negative contribution (–141.28%).

When the entire period (1984–2023) is considered, yield effect (96.02%) overwhelmingly dominated chickpea production growth, while the area effect (3.62%) played a relatively minor role. The interaction and residual effects were very small and inconsistent across the periods.

Overall, this analysis clearly shows that the improvement in yield was the principal driver of chickpea production growth in Bangladesh, while area under cultivation generally declined and negatively contributed to production growth.

Table 3: Growth decomposition in the production of chickpea during 1984-2023

Period	Effect (%)				
	Area (A)	Yield (Y)	Interaction	Residual	Total
	$\Delta A * Y$	$A * \Delta Y$	$\Delta A * \Delta Y$	$\Delta COV(A, Y)$	ΔQ
1984-1993	-15.81	123.20	7.39	-14.78	100
1994-2003	-0.02	103.06	3.04	-6.09	100
2004-2013	-26.51	126.63	0.12	-0.23	100
2014-2023	-141.28	250.23	8.95	-17.89	100
1984-2023	3.62	96.02	-0.36	0.72	100

Source: Author's calculation using BBS data of different years

Instability of Chickpea Cultivation

The estimates of instability in area, production, and yield of chickpeas are presented in Table 4. The instabilities of the chickpea area (4.35%) and production (4.65%) at the national level were not so high, but the instability of production was a little bit higher than the area instability. On the other side, the instability related to productivity was about -43.08% during 1984-2023, meaning that chickpea productivity was almost stable over the stipulated period.

Table 4: Instability indices for area, production, and yield of chickpea, 1984-2023

Period	Instability (%)		
	Area (ha)	Production (t)	Yield (t/ha)
1984-1993	2.24	2.21	-16.90
1994-2003	4.06	4.16	-3.32
2004-2013	1.14	1.41	-19.41
2014-2023	0.81	0.76	56.96
1984-2023	4.35	4.65	-43.08

The results clearly show that yield growth (96.02%) was the principal driver of chickpea production, compensating for the continuous decline in cultivation area. This finding is consistent with Kabir *et al.* (2009), who emphasized the role of BARI-developed chickpea varieties. The strong negative contribution of area reflects a national policy shift toward rice, wheat, and maize (Rashid *et al.*, 2014), which discouraged chickpea expansion. Instability patterns indicate that while productivity remained stable in earlier decades, the last decade (2014–2023) experienced high variability in yield (56.96%). This rise can be attributed to climatic fluctuations, including erratic rainfall and drought events, as well as limited adoption of climate-resilient practices—challenges that have also been

observed in pulse production across South Asia (Sarker and Kumar, 2011). Thus, while yield improvements are promising, their sustainability remains vulnerable to environmental risks and management inefficiencies.

Conclusions

The analysis of chickpea cultivation in Bangladesh over 1984–2023 highlights significant structural changes in area, production, and yield. Since the late 1990s, the cultivated area has declined sharply, largely due to the expansion of cereals such as rice, wheat, and maize, along with short-duration oilseed crops. Despite this contraction, production losses were partly offset by substantial yield improvements, driven by the adoption of improved varieties and modern cultivation technologies.

Growth decomposition analysis shows that yield effect (96.02%) was the principal contributor to production gains, whereas area effect (3.62%) was marginal and often negative in sub-periods. This indicates that productivity improvements have compensated for land reduction, but declining area remains a critical constraint to sustaining output growth.

Instability analysis further reveals that production instability (4.65%) has been slightly higher than area instability (4.35%), while yield instability fluctuated considerably—remaining stable in earlier decades but increasing sharply in recent years (56.96% during 2014–2023). These findings suggest that although yield growth has been the main driver of production, it is also increasingly vulnerable to environmental variability and management challenges.

In conclusion, yield improvements have been the key determinant of chickpea production growth in Bangladesh; however, the persistent decline in cultivation area and rising yield instability pose serious challenges for long-term sustainability. Strategic interventions are required to stabilize cultivation area, promote wider adoption of improved varieties, and strengthen crop management practices. Without such measures, dependence on chickpea imports will continue to grow, threatening national pulse security.

Recommendations

Based on the study findings, the following recommendations are proposed to promote sustainable growth in chickpea production in Bangladesh:

1. **Strengthen varietal improvement and seed dissemination:** Since yield contributed 96.02% to production growth, future strategies should prioritize the development and dissemination of climate-resilient, high-yielding chickpea varieties. Ensuring timely access to quality seed for farmers is essential.

2. **Reintroduce chickpea on marginal and fallow lands:** The sharp decline in cultivated area highlights the need for policy incentives—such as input support, minimum price guarantees, or intercropping schemes—to encourage farmers to allocate land for chickpea cultivation.
3. **Reduce yield instability through risk management:** The high variability in yield during 2014–2023 underscores the importance of adaptive measures, including crop insurance schemes, supplemental irrigation, improved soil management, and integrated pest and disease management practices.
4. **Strengthen extension and value chain linkages:** Collaboration among BARI, extension services, NGOs, and private seed companies should be enhanced to scale up technology adoption. Developing efficient marketing and value chain systems can also reduce import dependence and stabilize domestic chickpea prices.

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