

ISSN 0258 - 7122 (Print)  
2408 - 8293 (Online)



**Volume 49 Number 1**

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**Bangladesh  
Journal of**

**Agricultural  
Research**

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**Bangladesh**  
**Journal of**  
**AGRICULTURAL**  
**RESEARCH**  
**Volume 49 Number 1**

## BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

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**Bangladesh Agricultural Research Institute (BARI)**  
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## BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

Vol. 49

March 2024

No. 1

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## EVALUATION OF OKRA GENOTYPES FOR MORPHOLOGICAL CHARACTERISTICS, YIELD AND RESISTANCE TO YELLOW VEIN MOSAIC VIRUS

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### Abstract

The experiment was conducted during the *kharif* season of 2020 and 2021 in the experimental field of RARS, Cumilla in a randomized complete block design with three replications. A total thirteen genotypes of okra were collected from different locations of the Cumilla region to evaluate morphological characteristics, yield and resistance to Okra Yellow Vein Mosaic Virus (OYVMV). The experimental results revealed that number of pods per plant was varied significantly among the okra germplasm and it was maximum in AE Cum-004 (32.82) whereas AE Cum-009 produced the maximum individual fruit weight (18.01 g) with the highest fruit yield (28.82 t/ha). Among the thirteen okra germplasm, AE Cum-004 was also found highly resistant (10.00 and 10.00%) to OYVMV whereas the high yielding genotype AE Cum-009 was found moderate resistant (12.41 and 14.00 %) to OYVMV in both years (2020 and 2021), respectively. Considering fruit yield and resistance to OYVMV, it is concluded that the genotypes AE Cum-009 and AE Cum-004 perform best and may be selected for further verification for their suitability as okra varieties.

Keywords: Okra, OYVMV, Resistant, Susceptibility, Tolerant, Yield.

### Introduction

Okra (*Abelmoschus esculentus* L.) is a valuable vegetable crop cultivated in tropical and sub-tropical regions. Okra cultivation area is steadily increasing in Bangladesh, but production per hectare remains unchanged or is decreasing gradually (Anon., 2019). Bangladesh produced approximately 54,183 metric tons of okra from 11,606 hectares of land which is very low compared to that of other developed countries (Anon., 2019). Okra is a vital vegetable crop that offers a variety of nutritional benefits and health advantages. The production and marketing of the crop have been severely limited by several challenges including a lack of improved high-yielding okra yellow vein mosaic virus (OYVMV)-resistant varieties. Okra OYVMV belonging to the family Geminiviridae are the most devastating plant pathogen which causes huge crop losses. Symptoms of OYVMV, spread by whitefly (*Bemisia tabaci* Genn), include varying levels of

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chlorosis, yellowing of veins and veinlets, reduced leaf size, diminished fruit yield, and stunted growth (Venkataravanappa *et al.*, 2012). Infected plants showed 24.9% reduction in plant height, 15.5% decrease in root length, and 32.1% in number of fruits per plant, whereas compared to healthy plants stem girth was reduced by 16.3% (Sheikh *et al.*, 2013). If plants are infected within 20 days after germination, their growth is retarded; few leaves and fruits are formed and loss may be about 94%. The extent of damage declines with a delay in infection of the plants. BARI has developed two okra varieties, namely BARI Dherosh-1 and BARI Dherosh-2. These varieties were tolerant to OYVMV for a few years after release. But in recent times, it has been nearly susceptible to OYVMV. It is necessary to develop a new variety of okra for high-yielding as well as resistance to OYVMV. Therefore, the study was undertaken to evaluate the collected thirteen okra genotypes to select high yielding genotype (s) resistant to OYVMV.

### **Materials and Methods**

This experiment was conducted in the experimental field of RARS, Bangladesh agricultural Research Institute (BARI), Cumilla during the *kharif* seasons of 2020 and 2021 to screen out the collected 13 okra genotypes including BARI Dheros-2. The seeds of thirteen genotypes, viz. AE Cum-001, AE Cum-002, AE Cum-003, AE Cum-004, AE Cum-005, AE Cum-006, AE Cum-007, AE Cum-008, AE Cum-009, AE Cum-010, AE Cum-011, AE Cum-012 and AE Cum-013 were collected from different locations of Cumilla and BARI Dheros-2 seeds were collected from the Olericulture Division of Horticulture Research Centre (HRC) of BARI. The experiment was executed in a randomized complete block design with three replications. The seeds were sown on 4 and 17 April 2020 and 2021, respectively. The unit plot size was 4.0 m × 1.2 m and the plants were spaced at 60 cm × 40 cm. Cowdung was applied @ 15 tons per hectare. Fertilizers were applied in the form of urea, TSP, and MoP @ 72-30-75 kg ha<sup>-1</sup> of N-P-K. The entire amount of cow dung and TSP and two-thirds of MoP were applied at the time of final land preparation. The remaining MoP was applied after 30 days of seed sowing (DAS). Urea was top dressed in three equal installments at 30, 45, and 60 DAS. Other necessary intercultural operations such as irrigation, weeding, and plant protection measures were done properly as and when necessary. Data on yellow vein mosaic virus (OYVMV)-infected plants were recorded at 80 DAS. The number of plants showing OYVMV disease from 10 randomly plants was counted. The disease on each test entry was assessed according to the disease rating scale by Ali *et al.* (2005a,b) presented in the following Table 1. Based on the severity of OYVMV incidence, the germplasm accessions were grouped into different categories based on a 0-6 scale mentioned in Table 1. (Data on yield and yield attributes were recorded by harvesting fresh fruits from 7 plants in the plot at weekly intervals over a month and were sorted out into marketable and unmarketable fruits per hectare. In addition, the color of the flower, stem, and pod as well as the shape of

the leaf were recorded. Yield and yield attributes data were analyzed using Statistix10 software and the means were separated by LSD test at 5% level of significance.

**Table 1: Disease rating scale of Okra Yellow Vein Mosaic Virus (OYVMV) disease**

Rating scale	Type	Severity Range (%)
0	Immune	0
1	Highly resistant	1-10
2	Moderate resistant	11-25
3	Tolerant	26-50
4	Moderate susceptible	51-60
5	Susceptible	61-70
6	Highly susceptible	71-100

Source: Ali *et al.* (2005a,b)

## Results and Discussion

### Morphological characteristics

Morphological characteristics in terms of the color of the flower, stem, pod, and leaf shape of different germplasms of okra were recorded and shown in Table 2. There were no differences in flower color and shape of leaf among okra genotypes. The flower color and leaf shape were light yellow and palmate shape, respectively. Based on their stem and pod color, germplasms were grouped into 3. There was light green, dark green, and reddish green were similar to the results reported by Alam and Hossain (2008). Among thirteen genotypes, seven (AE Cum-001, AE Cum-002, AE Cum-003, AE Cum-006, AE Cum-010, AE Cum-012 and AE Cum-013) were grouped into light green, four (AE Cum-005, AE Cum-007, AE Cum-008, AE Cum-009) were grouped into dark green, whereas the rest 2 germplasm (AE Cum-004, AE Cum-011) were categorized into reddish green (Table 2). The leaves arrangement was alternate and single leaf in one section. The tip of the leaf was acute and its' rim was serrated. Similar results reported by (Lamont, 1999; Rashwan, 2011).

### Yield attributes

In case of okra, main yield attributing characters are Plant height, fruit length, fruit breadth, number of fruits per plant and individual fruit weight. Yield contributing characters of okra germplasm varied significantly (Table 3).

**Table 2: Morphological characteristics of various okra germplasm**

Treatment	Flower color	Stem color	Pod color	Leaf shape
AE Cum-001	Light yellow	Light green	Light green	Palmate
AE Cum-002	Light yellow	Light green	Light green	Palmate
AE Cum-003	Light yellow	Light green	Light green	Palmate
AE Cum-004	Light yellow	Reddish green	Reddish green	Palmate
AE Cum-005	Light yellow	Dark green	Dark green	Palmate
AE Cum-006	Light yellow	Light green	Light green	Palmate
AE Cum-007	Light yellow	Dark green	Dark green	Palmate
AE Cum-008	Light yellow	Dark green	Dark green	Palmate
AE Cum-009	Light yellow	Dark green	Dark green	Palmate
AE Cum-010	Light yellow	Light green	Light green	Palmate
AE Cum-011	Light yellow	Reddish green	Reddish green	Palmate
AE Cum-012	Light yellow	Light green	Light green	Palmate
AE Cum-013	Light yellow	Light green	Light green	Palmate
BARI Dheros-2	Light yellow	Light green	Light green	Palmate

### Plant height

The plant height is usually a good index of plant vigor which may contribute towards higher productivity (Pandey *et al.*, 2017). The mean values of plant height of different genotypes showed significant variations, ranging from 100.68 to 174.67 cm. Maximum plant height was observed in AE Cum-002 (174.67 cm) followed by BARI Dherosh-2 (170.54 cm) and AE Cum-006 (166.56) whereas minimum in AE Cum-006 (100.68). The increase in plant height might be due to longer intermodal length. Similar observations were also reported by Saifullah *et al.* (2009) and Pandey *et al.* (2017).

### Fruit length

The results indicated a notable difference in fruit length among the various Okra genotypes (Table 3). Fruit length of ranged from 11.00 to 15.60 cm where the longest fruit was observed in AE Cum-007 (15.60 cm) followed by AE Cum-005 (15.52 cm), AE Cum-004 (15.40 cm), AE Cum-003 (15.34 cm), and the shortest in AE Cum-013 (11.00 cm). This outcome might be due to environmental factors and varietal traits. Pandey *et al.* (2017) and Rahman *et al.* (2012) also found similar results in the varietal evaluation of okra. In the experiment by Dash *et al.* (2013) pod length varied significantly among the varieties. Saha *et al.* (2016) also highlighted a notable impact of variety on fruit length, suggesting genetic diversity and environmental factor among the evaluated okra varieties.

### **Fruit breadth**

Significant differences in fruit breadth were observed among all the genotypes (Table 3). Fruit breadth ranged from 1.63 to 2.38 cm where the widest fruit was found from AE Cum-012 (2.38 cm) followed by AE Cum-009 (2.08 cm) and BARI Dherosh-2 (2.08 cm). The variation in fruit size may result from genetic variations among the okra genotypes and their reactions to the current environmental factors. This is further corroborated by the earlier study conducted by Saha *et al.* (2016) which highlighted a notable impact of variety on fruit size, suggesting genetic diversity among the evaluated okra varieties. A similar result was reported in okra by Dash *et al.* (2013) and Sarker (2014).

### **Number of fruits per plant**

The number of fruits per plant is one of the most important yield contributing character of okra. The data shows that the quantity of fruits per plant directly impacts on the yield, meaning that a higher number of fruits per plant results in higher yield per plant. The number of fruits per plant was also statistically varied among the okra germplasms (Table 3). Maximum fruits per plant were produced by AE Cum-004 (32.82) followed by AE Cum-005 (32.67) and AE Cum-009 (32.00) and minimum fruits per plant by AE Cum-003 (10.80). Variations in the number of fruits per plant might be due to the greater plant height, a larger number of branches per plant may get more space for fruit development. Similar reports are also quoted by Singh *et al.* (2018) and Pandey *et al.* (2017). Rahman *et al.* (2012) also reported significant differences among the okra varieties for the number of pods per plant and this variation might be due to their genetic makeup of the variety and environmental effects.

### **Individual fruit weight**

Individual fruit weight was maximum in AE Cum-009 (18.01 g) followed by AE Cum-004 (16.95 g), AE Cum-002 (16.32) and the lowest in AE Cum-012 (12.58 g). Pandey *et al.* (2017) and Singh *et al.* (2018) also found similar results. Saha *et al.* (2016) corroborates this finding that crop yield is influenced by various factors such as individual fruit weight. Rahman *et al.* (2012) also highlighted notable variations in different okra varieties and suggesting that genetic differences and environmental factors may impact pod weight per plant.

### **Fruit Yield**

The mean values of green fruit yield per hectare exhibited significant variations among the genotypes with the range of 7.97 to 28.82 t/ha (Table 3). AE Cum-009 produced the maximum yield (28.82 t/ha) followed by AE Cum-004 (27.81 t/ha) and the lowest yield by AE Cum-003 (7.97 t/ha). The genotypes showed superior performance for pod yield due to their higher ranking for the number of pods per plant, weight of pods per plant, pod length, plant height, and less infection of

yellow vein mosaic virus, which caused greater assimilation of photosynthates. Masarapu *et al.* (2014) also found that a single OYVMV infection could lead to yield reductions ranging from 20 to 30%. Variation in yield among different okra cultivars was reported by other workers (Amjad *et al.*, 2001; Halim *et al.*, 2009; Saifullah and Rabbani, 2009).

**Table 3. Fruit yield and yield attributes of okra germplasm (pooled of 2020 and 2021)**

Treatment	Plant height (cm)	Pod length (cm)	Pod breadth (cm)	No. of pods/plant	Individual pod wt. (g)	Fruit yield (t/ha)
AE Cum-001	148.56	13.60	1.91	23.06	14.80	17.06
AE Cum-002	174.67	14.50	1.83	31.40	16.32	25.62
AE Cum-003	117.23	13.05	1.72	10.80	14.75	7.97
AE Cum-004	138.89	15.40	1.76	32.82	16.95	27.81
AE Cum-005	166.56	15.52	1.94	32.67	15.51	25.34
AE Cum-006	100.68	12.06	1.85	29.23	14.67	21.44
AE Cum-007	152.34	15.60	1.91	29.80	14.72	21.93
AE Cum-008	123.79	13.61	1.94	26.00	16.08	20.90
AE Cum-009	147.45	13.40	2.08	32.00	18.01	28.82
AE Cum-010	134.67	13.07	1.98	29.65	15.43	22.42
AE Cum-011	128.73	15.34	1.83	21.00	15.12	16.20
AE Cum-012	138.81	11.05	2.38	19.46	12.58	12.24
AE Cum-013	109.27	11.00	1.63	21.98	15.31	16.83
BARI Dherosh -2	170.54	13.05	2.08	30.33	16.00	24.26
LSD (0.05)	2.74	3.62	1.22	4.78	2.89	4.78
CV(%)	6.56	8.45	7.21	10.12	8.43	10.12

### Okra Yellow Vein Mosaic Virus (OYVMV) disease

Mean percentages of OYVMV infestation were higher in 2021 than that of 2020 but their rating scale of severity was similar in both years (2020 and 2021) (Table 4). Based on the disease rating scale of OYVMV shown in Table 1, AE Cum-004 was found highly resistant in both years (2020 and 2021), and only 10.00 % plant infected by OYVMV was found on this genotype. AE Cum-005 (12.67 and 16.44% in 2020 and 2021, respectively), AE Cum-009 (12.41 and 14.00% in 2020 and 2021, respectively) and BARI Dherosh -2 (16.34% and 25.00% in 2020 and 2021, respectively) were categorized into moderate resistant against OYVMV. AE Cum-002 (27.41% in 2020 and 33.89% in 2021) and AE Cum-010 (39.23% in 2020 and 43.33% in 2021) showed tolerant to OYVMV infection. AE Cum-001 (52.62 and 56.78%) and AE Cum-011 (57.19 and 60.00%) were

found moderate susceptible whereas AE Cum-006 (62.32 and 67.63% in 2020 and 2021, respectively), AE Cum-007 (65.22 and 67.95% in 2020 and 2021, respectively) and AE Cum-012 (55.11 and 66.67% in 2020 and 2021, respectively) were found susceptible and the others genotypes AE Cum-003 (100 and 100% in 2020 and 2021, respectively), AE Cum-008 (77.23 and 79.63% in 2020 and 2021, respectively) and AE Cum-013 (72.23 and 100% in 2020 and 2021, respectively) were highly susceptible. In the case of hybrid plant, OYVMV disease incidence ranged between 19.26 and 69.13% whereas, on parent plants, it ranged from 19.95 to 51.16% reported by Chaudhary *et al.* (1992). A study revealed that the infection rate of OYVMV disease could reach 100% when field yield loss falls between 50 and 94% (Ali *et al.*, 2012). Batra and Singh (2000) screened eight okra varieties against OYVMV, Okra No.6, LORM-1, VRO-3, and P-7 were found free from disease whereas VRO-4 showed a mild reaction. Ali *et al.* (2005b) reported Safal, Subz Pari and Surkh Bhindi varieties against OYVMV in a field trial (3.36-24.40%). Benchasri (2011) and Venkataravanappa *et al.* (2013) also reported similar results.

**Table 4. Okra Yellow Vein Mosaic Virus (OYVMV) disease reaction of 13 okra germplasm during the *kharif* seasons of 2020 and 2021**

Treatment	2020		2021	
	OYVMV infestation %	Rating scale of severity	OYVMV infestation %	Rating scale of severity
	(80 DAS)		(80 DAS)	
AE Cum-001	52.62	MS	56.78	MS
AE Cum-002	27.41	T	33.89	T
AE Cum-003	100	HS	100	HS
AE Cum-004	10.00	HR	10.00	HR
AE Cum-005	12.67	MR	16.44	MR
AE Cum-006	62.32	S	67.63	S
AE Cum-007	65.22	S	67.95	S
AE Cum-008	77.23	HS	79.63	HS
AE Cum-009	12.41	MS	14.00	MS
AE Cum-010	39.23	T	43.33	T
AE Cum-011	57.19	MS	60.00	MS
AE Cum-012	55.11	S	66.67	S
AE Cum-013	72.23	HS	100.00	HS
BARI Dherosh -2	16.34	MR	25.00	MR

S = Susceptible, MS = Moderate susceptible, HS = Highly susceptible, T = Tolerant, MR = Moderate resistant, R = Resistant; DAS = Days after sowing

### Conclusion

Among all the genotypes, AE Cum-002, AE Cum-004, AE Cum-005, and AE Cum-009 exhibited higher yield than the average yield of BARI Dherosh -2. Among them, the genotypes AE Cum-009 performed best for its yield whereas the genotypes AE Cum-004 showed highly resistance to OYVMV. Considering the mean performance of the thirteen okra germplasm against OYVMV reaction and yield attributes, it might be concluded that the genotypes AE Cum-004 and AE Cum-009 were best performer and could be selected for further verification.

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## VALUE CHAIN ANALYSIS OF BARI SUMMER TOMATO IN THE SOUTH-WEST REGION OF BANGLADESH

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### Abstract

Summer tomato, a high-value crop with significant market demand faces challenges such as disease susceptibility, inadequate seed, poor market management, and increased product losses. A study was conducted from July to December 2023 in the areas of Jashore, Khulna, and Satkhira to assess the value chain of BARI Summer tomato production and marketing, evaluate value addition at different stages, examine profitability, and assess marketing efficiency. A total of 180 producers and 45 market actors taking 60 producers and 15 actors from each district of Jashore, Satkhira and Khulna was randomly selected following a purposive and multistage random sampling approach by using primary data. Relevant secondary data were also collected from government publications, annual reports, seminar papers, journals, books and websites. The study analyzed it as profitable with a BCR of 2.89 and yields of 35.85 t/ha and Tk. 44.90/kg. Major actors included input suppliers, producers, traders, processors, and consumers. Also identified seven marketing channels, with Channel IV having the highest gross marketing margin at 28.00, and Channel III having the lowest at 18.20. Channel II had the highest net marketing margin at Tk. 10.75/kg, followed by Channel IV and Channel VI. Channel III had the highest marketing efficiency at 2.58, followed by Channel VII, Channel I, and Channel V. Channel VII offered the highest price for tomato producers at Tk. 50.25/kg, enhancing summer tomato production and improving the value chain. Factors such as insect infestation, limited seed supply, high raw material costs, lack of minimum price fixing, intermediaries, capital shortages, standardization, and illegal revenue collection major hindered summer tomato production and marketing.

Keywords: BARI summer tomato, BCR, marketing channel, marketing margin, value chain map, value addition, marketing efficiency.

### Introduction

Bangladesh is one of the world's most populated countries with a population of 173.95 million (WPP, 2024). A total of 40% of the labour force depends directly or indirectly on agriculture for their livelihoods (Sen, 2024). Crops, vegetables, forestry, fisheries, and livestock are all included in it while vegetables are a significant source of income for small and marginal farmers. Vegetables also help consumers fulfill their nutritional requirements (Begum *et al.*, 2011). According to the FAO of the United Nations, Bangladesh is now 3<sup>rd</sup> in the world vegetables

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production (Islam, 2021 and Maruf *et al.*, 2021). Tomato is one of the most important vegetables in Bangladesh, the third largest tomato-producing country in South Asia (Sarma and Ali, 2019).

Tomato (*Solanum lycopersicum* L.) belongs to the Solanaceae family and is one of the most popular and nutritious vegetable crops cultivated worldwide including Bangladesh. Tomato and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body (Arab and Steck, 2000). Tomato contains a higher amount of lycopene, a type of carotenoid with antioxidant properties which is beneficial in reducing the incidence of some chronic diseases (Basu and Imrahn, 2007) like cancer and many other cardiovascular disorders (Freeman and Reimers, 2011). Tomato production has increased tremendously growth in last ten years due to adoption of high-yielding varieties, timely used of pesticides, training, and extension facilities (Mitra and Yunus, 2018). Despite it being a winter vegetable, Bangladesh Agricultural Research Institute (BARI) has released three new popular hybrid summer tomato varieties, namely BARI Hybrid Tomato-4, -8 and -11, which have yield potentiality of 40, 35-40, and 48-50 t/ha, respectively (Azad *et al.*, 2020). The hybrid summer tomato (var. BARI Hybrid Tomato-3, -4, and -8) has an average production of 50.41 tons per hectare (Hajong *et al.*, 2018). The benefit-cost ratio of hybrid tomato production for small and medium farmers were 4.22 and 4.16 on the basis of full cost, 5.17 and 5.01 on the basis of cash cost, respectively (Das and Jahan, 2022).

Total production of tomato was 469204.49 MT over an area of 31151.07 ha in 2022-2023 (Anon., 2024). Now-a-days land area for tomato cultivation has been extended day by day due to the increasing demand for domestic consumption. Compared with other field crops, tomato is known as a profitable, less risky, labor-intensive, and relatively short-duration cash crop with a growing season of 90-120 days (Das and Jahan, 2022 and Azad *et al.*, 2020). Tomato was selected for the value chain analysis because it is a significant high-value crop in Bangladesh. It has significant post-harvest losses (Khatun and Rahman, 2020) in addition to (i) strong market demand, (ii) excellent production potential and (iii) including a huge number of small and underprivileged farmers (Sarma and Ali, 2019). Limitations encompass unfavorable local and export markets, varietal susceptibility to diseases, inadequate seed, insufficient services, inadequate technological expertise, poor market management, and value decrease via increased product losses at each stage in the tomato value chain (Sarma and Ali, 2019).

Tomato value chains are creating shared value to enhance marketing success. This study provided valuable information on the tomato value chain that would help the appropriate organizations decide when and how to intervene in the process of developing the tomato value chain and creating suitable strategies and policies. The outcomes of this study would be helpful to governmental and non-governmental organizations that are implementing programs aimed at developing the value chain subsector. The main focus of the research was to conduct a value

chain analysis of tomato in the south-west region, to supply useful information to support the growth of the tomato sector's share. The specific objectives of the study were as follows:

- i. To draw a value chain map of BARI summer tomato production and marketing;
- ii. To assess value addition at various stages of the summer tomato marketing channels;
- iii. To examine the marketing efficiency of different marketing channels; and
- iv. To identify constraints faced by the producers and market actors.

## **Materials and Methods**

### **Study area selection**

The study was conducted at summer tomato growing areas in Jashore, Khulna, and Satkhira in the south-west region of Bangladesh from July to December, 2023 and data were purposively selected

for the collection of primary level data for this study. Again, three major markets were selected from the aforesaid districts for the collection of primary-level marketing data. The studied markets were Basundia in Jashore Sadar, Sunadanga at Koyra Upazila in Khulna, and Sultanpur Boro Bazar in Satkhira Sadar.

### **Selection of sample and sampling technique**

Both primary and secondary data were used in this study. Primary data were collected from tomato producers and tomato traders at different levels. A total of 180 producers and 45 market actors taking 60 producers and 15 actors from each selected district were randomly selected for the collection of primary data. Again, relevant secondary data were collected from government publications, annual reports, seminar papers, journals, books, and websites.

### **Data analysis**

Survey data were coded where relevant, loaded into a database system through Microsoft Excel and were analyzed using STATA-15. Descriptive statistics were used to define the variables and broad marketing costs were calculated by following approach defined by Dawe (2008).

For the calculation of total production cost, both variable and fixed costs were taken into consideration. Variable costs included the costs for seed, human labour, land preparation, fertilizers, manure, irrigation, pesticides, canopies preparations, interest on operating capital and depreciation. The fixed costs included mainly land use cost, family labour. The following equation was used to calculate the net return of summer tomato producer in the study areas.

Net return of the producer (Eq. 1) (Sharma *et al.*, 2023).

$$\Pi = P_F \cdot Q_F - (TVC + TFC) \text{ ----- (1)}$$

Where  $\Pi$  = Net return of producer (Tk./ha);  $P_F$  = Price of tomato (Tk./kg);  $Q_F$  = Quantity of tomato (t/ha); TVC = Total variable cost of tomato cultivation; TFC = Total fixed cost of tomato cultivation.

Gross return was calculated by multiplying the total volume of output by per-unit price of the commodity at the time of harvest. The following equation was used to estimate gross return (GR) (Eq. 2) (Shahriar, 2024).

$$GR = \Sigma P_b \cdot Q_b \text{ ----- (2)}$$

Where  $P_b$  = Price of tomato (Tk./ha);  $Q_b$  = Quantity of tomato (t/ha)

The following equation was used to assess the gross margin (Eq. 3) (Biswas *et al.*, 2022).

$$GM = TR - VC \text{ ----- (3)}$$

Where GM = Gross margin; TR = Total return; VC = Variable cost

Undiscounted BCR was estimated by following formula (Eq. 4) (Shahriar, 2024).

$$\text{Benefit cost ratio (BCR)} = \frac{GR}{TC} \text{ ----- (4)}$$

Where GR = Gross return; TC = Total cost of production.

Depreciation cost: Around 40% of the materials used for canopies preparation (such as transparent polythene, pieces of bamboos like ‘makhal’ and ‘barak’, bow, clamp, pope, jute twine, etc) in the first year for summer tomato cultivation can be reused in e next year. Therefore, 40% value was considered as depreciation in the present study.

Interest on operating capital was calculated according to Sharma *et al.* (2023).

Interest on operating capital (IOC) = {Operating capital × Interest rate (I) × Time required (t)} / 2

Where I = interest rate (%) and t = length of tomato crop period in years

Note: Variable cost of production was considered as operating capital.

### Value chain analysis

Analysis of the value chain included identifying all the functions performed in a specific commodity sector, organizing them into the sequence, and analyzing each function about both the preceding steps and subsequent ones (Rayhan *et al.*, 2021; Sarma and Ali, 2019; McCormick and Schmitz, 2005). The total marketing cost incurred by the farmers and market actors in a channel was estimated by Eq. 5 (Lamba *et al.*, 2023).

$$C = C_f + C_{m1} + C_{m2} + C_{m3} + \dots + C_{mi} \quad \text{----- (5)}$$

Where C = Total cost of tomato marketing in a channel; C<sub>f</sub> = Cost paid by the producer when the commodity moves; C<sub>mi</sub> = Cost incurred by the i<sup>th</sup> intermediary in the process of buying and selling of tomato in a channel, (i = 1, 2, 3, ... n).

The gross marketing margin and net marketing margin of different value chain actors were estimated by Eq. 6 & 7 (Acharya and Agarwal, 2004).

$$\text{GMM} = \text{Sales price} - \text{Purchase price} \quad \text{----- (6)}$$

$$\text{NMM} = \text{GMM} - \text{MC} \quad \text{----- (7)}$$

Where GMM = Gross marketing margin (Tk./kg); NMM = Net marketing margin; MC = Marketing cost (Tk./kg)

$$\text{Value Addition (\%)} = \frac{\text{Sales price} - \text{Purchase price}}{\text{Purchase price}} \times 100$$

Acharya's method of marketing efficiency is an optimum measure of marketing efficiency, especially for judging the efficiency of alternate marketing channels. Marketing efficiency was estimated by applying Acharya's index, which is defined by the following Eq. 8 (Acharya, 2004; Lamba *et al.*, 2023).

$$\text{ME} = \frac{FP}{MC + MM} \quad \text{----- (8)}$$

Where ME = Marketing efficiency; FP = Net price received by producers (purchase price); MC = Marketing cost; MM = Total marketing margin of intermediaries. A higher value of ME denotes a higher level of efficiency and vice versa.

**Results and Discussion**

**Cost and return**

Costs act as a major consideration in the producers' decision-making process. Production costs include both variable costs and fixed costs. In Jashore district, the total production cost of summer tomato was Tk. 654328/ha, for which the total variable cost (TVC) was Tk. 479923/ha, and the total fixed cost (TFC) was Tk. 174425/ha. (Table 1). Based on total cost of production, among variable costs canopies preparation cost accounted for the largest share (26.79%) followed by depreciation cost (10.71%), hired labour (9.96%) and hormone & pesticides (9.55%) and irrigation cost accounted for the lowest share (1.34%) and, for fixed cost family labour and land use contributed 19.22% and 7.43%, respectively in this district. In the context of Satkhira district, the total production cost was Tk. 643705/ha, for which TVC and TFC were Tk. 452413/ha and Tk. 191292/ha, respectively. In terms of TVC, the cost of canopies preparation covered maximum 26.73% of the total cost of production followed by hormone & pesticides cost (9.11%), fertilizer cost (8.44%) and depreciation cost (10.60%); whereas, family

labour cost contributed 24.22% and land use cost contributed 5.49% to total cost of cultivation among TFC in Satkhira district. In the study site of Khulna district, the total production cost was Tk. 381816/ha, for which TVC was Tk. 221874/ha and TFC was Tk. 159942/ha. Among TVC, cost of canopies preparation was the major cost of production cost (16.35%) followed by hormones & pesticides (9.27%), fertilizer cost (8.25%), hired labour cost (6.55%), and depreciation cost (6.54%), whereas, in terms of TFC, family labour cost covered 35.47% and land use cost covered 6.42% of total production cost of summer tomato production in Khulna district. Based on above results, it is evident that the Jashore district had the highest total cost of production followed by Satkhira district and the lowest total cost of production was in the district of Khulna. The low production cost was in Khulna district because besides, shrimp cultivation, vegetables like tomato, brinjal, watermelon and bitter gourd were grown in this district as additional crops in those edge places surrounding the water bodies where shrimp was produced. On average, the total production cost of summer tomato was Tk. 559949.7/ha, for which TVC and TFC were Tk. 384736.7/ha and Tk. 175219.7/ha, respectively (Table 1). The average cost of canopies preparation and hormone & pesticides covered 24.39% and 9.32% of total average cost of summer tomato cultivation, respectively.

The average depreciation cost contributed 9.72%, fertilizer cost 7.88%, hired labour cost 7.88%, family labour 24.83%, land use 6.46%, seed cost 2.22%, manure cost 2.20%, land cleaning & preparation cost 1.99%, irrigation cost 1.24%, IOC cost contributed 1.87% to the total cost production (Table 1).

In the districts of Jashore, Satkhira, and Khulna, summer tomato yields were 42.53, 39.54, and 25.48 t/ha, respectively, and in those 3 districts, tomato price were 46.70, 45.45, and 42.55 tk./kg, respectively (Table 2). The maximum gross return was observed in Jashore district (Tk. 1986151/ha) followed by Satkhira district (Tk. 1797093/ha) and the lowest margin was in Khulna district (Tk. 1084174/ha). Gross margin was also found highest in Jashore (Tk. 1506228/ha) followed by Satkhira (Tk. 1344680/ha) and the lowest gross margin was recorded in Khulna (Tk. 862300/ha). In three districts, a similar trend in net return was also observed. The highest net return was recorded in Jashore (Tk. 1331823/ha) followed by Sathkira (Tk. 1153388/ha) and the lowest was in Khulna (Tk. 702358/ha). In the districts of Jashore, Satkhira and Khulna, benefit-cost ratio (BCR) was 3.03, 2.79, and 2.84, respectively. On average, the yield of summer tomato over yields of Jashore, Satkhira and Khulna was 35.85 t/ha and total average cost of production was Tk. 559949.7/ha. So, the average cost of summer tomato production per kg was Tk. 15.62. The average gross return, average gross margin, and average net return were Tk.1622472.7/ha, Tk. 1237736/ha, and Tk. 1062523/ha, respectively. On average, benefit-cost ratio (BCR) was found to be 2.89 (Table 2). Hajong *et al.* (2018) reported that they obtained gross return of Tk. 1542300 /ha and BCR of 2.64 (full cost basis) and 3.04 (cash cost basis). Parvin (2017) obtained net return of Tk. 311755.7/acre and BCR of 1.84 from BARI summer tomato cultivation.

Table 1. Cost of summer tomato production (Tk/ha) in the study areas

Cost items	Jashore	Satkhira	Khulna	Average
<b>A. Variable cost</b>				
Hired labour	65200 (9.96)	42100 (6.54)	25000 (6.55)	44100 (7.88)
Land cleaning & preparation	9800 (1.50)	10152 (1.58)	13500 (3.54)	11150.7 (1.99)
Seed	15000 (2.29)	13500 (2.10)	8750 (2.29)	12416.7 (2.22)
Fertilizer	46569 (7.12)	54310 (8.44)	31500 (8.25)	44126.3 (7.88)
Manure	14500 (2.22)	12000 (1.86)	10540 (2.76)	12346.7 (2.20)
Hormone & pesticides	62500 (9.55)	58650 (9.11)	35410 (9.27)	52186.7 (9.32)
Irrigation	8750 (1.34)	9540 (1.48)	2500 (0.65)	6930 (1.24)
Canopies preparation	175270 (26.79)	172054 (26.73)	62400 (16.35)	136574.7 (24.39)
Interest on operating capital (IOC)	12226 (1.87)	11885 (1.85)	7314 (1.92)	10475 (1.87)
Depreciation	70108 (10.71)	68222 (10.60)	24960 (6.54)	54430 (9.72)
<b>Total variable cost (TVC)</b>	<b>479923 (73.35)</b>	<b>452413 (70.28)</b>	<b>221874 (58.11)</b>	<b>384736.7 (68.71)</b>
<b>B. Fixed cost</b>				
Land use	48645 (7.43)	35400 (5.49)	24500 (6.42)	36182 (6.46)
Family labour	125780 (19.22)	155892 (24.22)	135442 (35.47)	139038 (24.83)
<b>Total fixed cost (TFC)</b>	<b>174425 (26.66)</b>	<b>191292 (29.72)</b>	<b>15994 (41.89%)</b>	<b>175219.7 (31.29)</b>
<b>C. Total production cost (TC)</b>	<b>654328 (100)</b>	<b>643705 (100)</b>	<b>381816 (100)</b>	<b>559949.7 (100)</b>

Note: Figures in the parenthesis are the percentage of total cost of production.

Source: Author's calculation from the Field Survey, 2023.

**Table 2. Yield, gross return, and net return of summer tomato in the study areas**

Particulars	Jashore	Satkhira	Khulna	Average
Yield (t/ha)	42.53	39.54	25.48	35.85
Price (Tk./kg)	46.70	45.45	42.55	44.90
Gross return (Tk./ha)	1986151	1797093	1084174	1622472.7
Total variable cost (Tk./ha)	479923	452413	221874	384736.7
Total fixed cost (Tk./ha)	174425	191292	159942	175219.7
Total production cost (Tk./ha)	654328	643705	381816	559949.7
Gross margin (Tk./ha)	1506228	1344680	862300	1237736
Net return (Tk./ha)	1331823	1153388	702358	1062523
Benefit-cost ratio (BCR)	3.03	2.79	2.84	2.89

Source: Author's calculation from the Field Survey, 2023.

### Value chain mapping

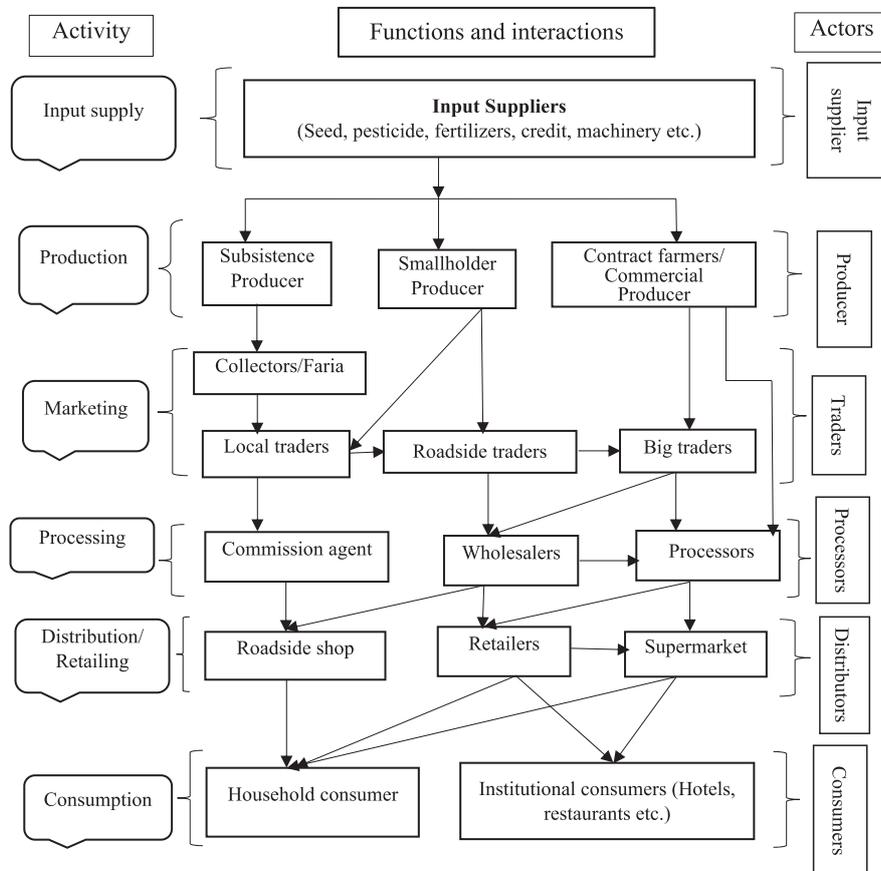
Value chain mapping makes it possible to see how a product moves via different players from production to the final consumer (McCormick and Schmitz, 2005). Studying all of the actors in the summer tomato value chain and being aware of their connections and functions are also important. The summer tomato's present value chain map in the study areas is shown in Figure 1.

It presents a visual representation of a tomato as it passes through multiple stages and processors on its way from manufacturing to customers. The links that follow are displayed vertically, starting on the left and moving rightward. Major-chain functions are enumerated in the top head. The supply of inputs, production, marketing, processing, distribution/retailing, and consumption were the activities in this instance given vertically on the left side of Figure 1. The actors who were engaged in performing the various roles are shown in a horizontal flow from the left to the right. The key actors in summer tomato value chain were input suppliers, producers, traders, processors, distributors and consumers given vertically in the right side of the Figure 1. The people pictured on the left are known as enablers, and they help the actors perform their roles. The majority of the facilitators are the formal, informal, and private institutions. Several participants and tasks in the value chain may fall under the purview of the enablers' roles. As the Figure 1 illustrates, some performers are limited to performing a single function, while others can fulfill multiple roles. For instance, the local traders deliver the goods to the wholesalers or processors after collecting them from the farmers.

**Input suppliers:** Input suppliers are manufacturers of agricultural inputs like seeds, fertilizers, manure, hormone, pesticides, polythene, bamboos, mulch sheets, etc for summer tomato production. They sell their products through company dealers and provide technical guidance. They maintain good relationship with producers and act as informal sources of finance. Public and private extension

services, banks and microfinance institutions provide extension services, credit and information about tomato production schemes. Input suppliers include fertilizer, seed and agribusiness companies, government distributors, small wholesalers and retail shops.

**Producers:** In the summer tomato value chain, the producer is the first link, collecting and transporting products to the second agent. They make the decisions on what to grow, produce and sell. Production systems can be classified into three categories: large-scale commercial production, small-scale commercial production and subsistence production. Subsistence farming involves producing small-scale of crops production for household consumption, whereas commercial farmers, both large and small, sell their produce to middlemen. Big farmers now have greater availability to market information due to communication technology during the last two to three years.



Source: Field Survey (Focus Group Discussion), 2023

**Figure 1. Linkage and flow of summer tomato value chain in the study area.**

**Primary collector:** Farmers transport their summer tomatoes to particular areas in the community, where sellers collect to transport them to marketplaces. Tomatoes and other vegetables are collected from producers by local or outside retailers and transported to urban markets. Without a road system, producers use hired labor or family members for transportation. The tomatoes are purchased by wholesalers or collectors, who then transport them to markets.

**Commission agent:** A commission agent is a person who, acting on behalf of an owner and receiving compensation for each transaction, provides the goods of the owner in his care and sells them, incurring liability for both the transportation of the goods to the buyer and the payment of the purchase price to the person who sold them.

**Traders:** Summer tomatoes from different remote cities or markets are directly purchased and sold by local traders, who then redistribute them to wholesalers at a profit. They frequently work as commission representatives for commercial processors or distributors. Producers who collect tomatoes from other producers at the farm gate to distribute them to the customers and shops are known as roadside traders. About 25% of the produce (tomato) grown in the study areas is sold by producers to roadside retailers, who then resell it to wholesalers, retailers, and consumers. They must be essential and have a thorough understanding of excess regions. Just a few roadside sellers who represent a threat to wholesalers. They hire traders to collect tomatoes on behalf of them as compensation for a commission when they are not to meet their demand in quantity.

**Wholesalers:** Wholesalers are market participants who buy large quantities of summer tomatoes and resell them to other traders. They purchase tomatoes from roadside traders and producers in the study area and spend their full time in wholesale buying throughout the year. They use vehicles for transportation when the amount supplied is large or purchase other crops to fill the vehicle. They play a role in influencing buyers and they set daily prices based on information from friends and mass media in Jashore, Khulna and Satkhira.

**Processors:** In Bangladesh, processors are secondary industries that create tomato-based products/foods including ketchup, sauce and paste. During market overproduction and peak seasons, they purchase fresh tomatoes from wholesalers and retailers. Through contract farming, large processors such as PRAN buy tomatoes directly from farmers. The two most processed foods in Bangladesh are ketchup and tomato sauce, of which PRAN is the biggest manufacturer. Processed tomato products are also made by other processors as Square, Golden Harvest, BD Foods, Sajeeb and Aftab Foods.

**Distributors:** Distributors generally purchase processed tomato products from producers to supply supermarkets and small grocery stores. Generally, they offer foods/products from different suppliers with different retailing types.

**Supermarkets:** Although supermarket culture is still relatively young in Bangladesh, it is expanding quickly. Together with other fruits and vegetables, some of them are also in the retail sale of processed and fresh tomato products. For the transportation of fresh tomatoes, some producers get in contact with supermarkets directly in big cities like Dhaka, Jashore, and Khulna, while some retailers buy fresh tomatoes directly from the wholesalers.

**Retailers:** Supermarkets and other large-scale shops are among the retailers who distribute huge supplies of foods to customers in small quantities, mostly for large breakdowns. Through a variety of channels, including supermarkets, upscale fruit and vegetable stores, and local grocery stores, they offer tomatoes to consumers. Retailers usually purchase products in smaller amounts with larger profit margins from the wholesalers, selling both processed and fresh products. They meet the requirements and desires of consumers and generate possibilities for value addition through promotional strategies. They represent an essential last connection in the summer tomato supply chain.

**Consumers:** The vegetable market chain ends with a business-to-consumer (B2C) channel model, in which buyers purchase products for their personal use. Producers to wholesalers and retailers to wholesalers are common intersections in the market chain. The retail price reduces with chain length. Customs, purchasing power and consuming habits all have significant effects on the potential market for agricultural commodities. Major marketing channels identified in the study areas are given below:

#### Major marketing channels

- I. Producer → Collector/Faria → Local trader → Commission agent → Roadside shop → Consumer
- II. Producer → Collector/Faria → Local trader → Roadside trader → Wholesaler → Retailer → Consumer
- III. Producer → Roadside trader → Wholesaler → Retailer → Consumer
- IV. Producer → Roadside trader → Wholesaler → Processor → Retailer → Consumer
- V. Producer → Big trader → Processor → Super market → Consumer
- VI. Producer → Big trader → Processor → Retailer → Super market → Consumer
- VII. Producer → Processor → Super market → Consumer

Around 75% of summer tomatoes reach the final consumer through Channel I and Channel III.

Table 3. GMM (Tk./kg), net marketing margin (Tk/kg), and marketing efficiency

Channel	Actors	Purchase Price	Sales Price	GMM	Marketing Cost	NMM	Value addition (%)	ME
<i>I</i>	2	3	4	5=4-3	6	7=5-6	8=5/3	9=3/(6+7)
Channel I	Faria	45.20	50.77	5.57	3.05	2.52	12.32	
	Trader	50.77	56.45	5.68	3.79	1.89	11.19	2.18
	Commission agent	56.45	58.40	1.95	1.10	0.85	3.45	
	Roadside shop	58.40	65.92	7.52	4.05	3.47	12.88	
	Total			20.72	11.99	8.73		
Channel II	Faria	45.00	48.90	3.90	1.72	2.18	8.67	
	Local trader	48.90	52.64	3.74	2.35	1.39	7.65	1.82
	Roadside trader	52.64	58.19	5.55	3.02	2.53	10.54	
	Wholesaler	58.19	61.20	3.01	2.04	0.97	5.17	
	Retailer	61.20	68.85	7.65	3.91	3.74	12.5	
		Total			23.85	14.03	10.75	
Channel III	Roadside trader	47.00	53.98	6.98	4.90	2.08	14.85	
	Wholesaler	53.98	57.50	3.52	2.25	1.27	6.52	2.58
	Retailer	57.50	65.20	7.7	4.65	3.05	13.39	
		Total			18.2	11.80	6.4	
Channel IV	Roadside trader	42.50	45.75	3.25	2.28	0.97	7.65	
	Wholesaler	45.75	50.00	4.25	2.90	1.35	9.29	1.47
	Processor	50.00	62.10	12.10	10.25	1.85	24.2	
	Retailer	62.10	70.50	8.4	3.45	5.95	13.53	
	Total			28.00	18.88	10.12		

Channel	Actors	Purchase Price	Sales Price	GMM	Marketing Cost	NMM	Value addition (%)	ME
<i>I</i>	2	3	4	5=4-3	6	7=5-6	8=5/3	9=3/(6+7)
Channel V	Big trader	48.50	53.28	4.78	3.08	1.70	9.86	
	Processor	53.28	61.05	7.77	5.25	2.52	14.58	2.16
	Super market	61.05	71.00	9.95	6.53	3.42	16.30	
	Total			22.50	14.86	7.64		
Channel VI	Big trader	48.09	53.00	4.91	3.69	1.22	10.21	
	Processor	53.00	58.85	5.85	4.89	0.96	11.04	1.98
	Retailer	58.85	63.25	4.40	3.05	1.35	7.48	
	Super market	63.25	72.40	9.15	6.33	2.82	14.47	
	Total			24.31	17.96	6.35		
Channel VII	Processor	50.25	60.04	9.79	7.74	2.05	19.48	
	Super market	60.04	71.52	11.48	6.35	4.13	19.12	2.48
	Total			21.27	14.09	6.18		

GMM= Gross marketing margin; NMM = Net marketing margin; ME= Marketing efficiency  
 Source: Author's calculation from the Field Survey, 2023.

A significant indicator of efficiency is the amount and makeup of the marketing margin. Table 3 shows the gross marketing margins (GMM), marketing costs (MC), net marketing margin (NMM) margins, value addition and marketing efficiency (ME) for the respective channels. The effectiveness of different marketing channels were carried out based on different performance indicators in different channels using a composite index formula. Maximum GMM was noted in Channel IV (28 Tk./kg) followed by Channel VI (24.31 Tk./kg), Channel II (23.85 Tk./kg), Channel V (22.50 Tk./kg), Channel VII (21.27 Tk./kg) and Channel I (20.72 Tk./kg) and the lowest GMM was in Channel III (18.20 Tk./kg). The highest NMM was recorded in Channel II (10.75 Tk./kg) closely followed by Channel IV (10.12 Tk./kg) and then followed by Channel I (8.73 Tk./kg), Channel V (7.64 Tk./kg), Channel III (6.40 Tk./kg), Channel VI (6.35 Tk./kg) and the lowest was found in Channel VII (6.18 Tk./kg). Maximum ME was recorded in Channel III (2.58) closely followed by Channel VII (2.48) and then followed by Channel I (2.18), Channel V (2.16), Channel VI (1.98), Channel II (1.82), and the lowest ME was noted in Channel IV (1.47). The findings showed that common marketing routes are traders→ wholesalers→ retailers→ consumers. The above results confirmed that, in the summer tomato-producing areas, the marketing Channel II, IV, and VI were not especially effective. From the Channels II and IV, producers received lower prices (45 Tk./kg in Channel II and 42.50 Tk./kg in Channel IV) than other channels. Producers obtained the highest price of summer tomato from the Channel VII (50.25 Tk./kg) which was closely followed by Channel V (48.50 Tk./kg), Channel VI (48.09 Tk./kg), and Channel III (47 Tk./kg). Channels VII, III, I, and V were revealed as the efficient marketing channels due to their highest ME (2.48, 2.58, 2.18, and 2.16, respectively). Channel VII had the highest value addition in processor (19.48%)→supermarket (19.12%) followed by Channel III (roadside trader: 14.85%→ wholesaler:6.52%→ retailer:13.39%), Channel I (farmer:12.32%→ trader:11.19%→ commission agent: 3.45%→roadside shop:12.88%), and channel V (big trader:9.86%→ processor: 14.58%→ supermarket: 16.30%). Selling directly to the processors to the consumer was the producers' response to marketing Channel VII and it was revealed to be the most appealing (Table 3). Based on the data mentioned above, it can be established that producers' shares were very low in Channels II and IV. The government should prioritize the development of channels I, III, V, and VII to support the increased marketing efforts in these study areas and so raise the proportion of producers. The research findings of Rayhan *et al.* (2021) and Gunwant *et al.* (2012), which found that the fewer the market actors involved, the higher the marketing efficiency, further support this results. They reported that the producer→ processor→ consumer channel is shown to have the highest marketing efficiency.

### **Constraints faced by producers and market actors**

In the study following constraints were identified through a questionnaire survey and open discussion with tomato producers and relevant stakeholders. The constraints were stated below:

**Table 4. Constraints faced by the producers and market actors in the study areas**

Constraints	% of respondent	Rank
<i>i. Producers' level:</i>		
1) Lack of good quality summer tomato seeds in the market	90	1
2) High cost of tomato farming inputs	75	2
3) Very poor access to low-interest credit facilities	68	3
4) Prevalence of tomato diseases and pests	65	4
5) Lack of modern technical knowledge	59	5
6) Lack of storage facilities	51	6
7) Lack of proper supervision	49	7
8) Labour shortage	38	8
<i>ii. Actors' level:</i>		
1) High cost of transportation	89	1
2) Lack of granted sale channel/ Unstable price	85	2
3) Illegal revenue collection on the roads by the police, touts, and other security agencies	84	3
4) Lack of training on modern marketing systems	75	4
5) Post-harvest loss	73	5
6) Poor packaging of tomato	60	6

At producers' level, among the constraints lack of good quality summer tomato seeds in the market ranked 1<sup>st</sup>, high cost of tomato farming units rank 2<sup>nd</sup> and very poor access to low interest credit facilities ranked 3<sup>rd</sup> and so on (Table 4). At market actors' level, high cost of transportation, lack of granted sale channel and illegal revenue collection on the roads by the police, touts and other security agencies ranked 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup>, respectively.

### Conclusion and Recommendations

The study explores value chain analysis in Jashore, Satkhira, and Khulna districts of Bangladesh. The findings reveal that the production of BARI hybrid summer tomato was profitable endeavor. Channel VII had the highest price paid to the producers of summer tomato, at Tk. 50.25/kg and the highest marketing efficiency of this channel was 2.48. Channels I, III, V, and VII were the most desired and effective marketing channels. These are- Channel I: Producer→ Faria→ Local trader→ Commission agent→ Roadside shop→ Consumer; Channel III: Producer→ Roadside trader→ Wholesaler→ Retailer→ Consumer; Channel V: Producer→ Big trader→ Processor→ Super market→ Consumer and Channel VII: Producer→ processor→ Super market→ Consumer. According to the findings of the study, a lot of opportunities to improve summer tomato production and develop

the tomato value chain. The cultivation and marketing of tomatoes involved a huge number of labour. Therefore, an established framework for summer tomato production and its sale may undoubtedly benefit producers and actors financially. Given the high profitability, the government may decide to implement awareness-raising campaigns and provide training through the Department of Agricultural Extension (DAE) and Department of Agricultural Marketing (DAM) to facilitate the growth of high-value vegetable like tomato in the south-west region. Channel III was comparatively well-established in the study areas. Therefore, the government should prioritize the development of channels V and VII situations to support the increased marketing efforts in these areas to increase the proportion of the summer tomato producers. To develop an improved and more dynamic marketing channel that benefits producers and market actors, further research should be done in those areas to provide ideas and information.

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## EFFECT OF POLYTHENE MULCH ON WEED MANAGEMENT AND YIELD OF CHILLI

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### Abstract

The field experiment was conducted during *Kharif* seasons of 2021 and 2022 in the research field of Regional Spices Research Centre, Bangladesh Agricultural research Institute (BARI), Gazipur to evaluate the performances of different polythene mulches on weed management efficiency and fruit yield of chilli var. BARI Morich-2. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments comprised five polythene mulches (30 $\mu$  thickness), viz. black polythene mulch, transparent polythene mulch, silver on black polythene mulch, blue polythene mulch and unweeded. The two years' pooled results revealed that almost all the yield and yield contributing parameters were significantly influenced by polythene mulches to produce fruit yield of chilli. The maximum weed control index (94.61%), weed control efficiency (89.2%), fresh red fruit yield (20.3 t ha<sup>-1</sup>), dry fruit yield (7.8 t ha<sup>-1</sup>) and seed yield (482.3 kg ha<sup>-1</sup>) were recorded from silver on black polythene mulch, whereas the minimum fresh red fruit yield (5.6 t ha<sup>-1</sup>), dry fruit yield (2.3 t ha<sup>-1</sup>) and seed yield (118.7 kg ha<sup>-1</sup>) were found in unweeded plot. It may be suggested that silver on black polythene mulch could be effective in weed control and fruit yield as well as seed yield of chilli.

Keywords: Chilli, polythene mulch, weed management, fruit yield, seed yield.

### Introduction

Chilli (*Capsicum annum* L.), a member of the Solanaceae family, is popularly known as 'morich' in Bangladesh. It is the second most important commercial spices crop in Bangladesh in terms of production and its diversified uses. In 2021-2022, Bangladesh produced 6.25 lakh tons chilli (*kharif chilli*: 1.29 lakh tons and winter chilli: 4.96 lakh tons) with an average yield of 6.35 t ha<sup>-1</sup> (*kharif chilli*: 6.33 t ha<sup>-1</sup> and winter chilli: 6.36 t ha<sup>-1</sup>) covering 0.98 lakh hectares (*kharif*: 0.20 ha and winter: 0.78 ha) of land (Anon., 2023). Chilli is often consumed as fresh (green), dry and processed products (powder) for its aromatic odor, flavor, coloring substance, medicinal and seasoning properties being rich in proteins, lipids, carbohydrates, fibers, minerals (Ca, P, Fe, K), vitamins (A, D, E, C, K, P, B<sub>2</sub> and B<sub>12</sub>) and anti-oxidant (Sathiyamurthy *et al.*, 2017). The crops are cultivated both in *rabi* (winter) season for dry chilli and *Kharif* for green chilli in Bangladesh.

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Among the yield limiting factors, weeds pose a significant challenge reducing 45-70% fruit yield by competing with plants for resources (plant nutrients, soil moisture, active sunlight and land) and also acting as co-host and vectors of insects, mites and diseases (Kumar *et al.*, 2021). Sustainable weed management is crucial particularly during the initial stage of chilli plants because weeds germinated fast and grow rapidly (Wickramarathne *et al.*, 2021). There are several weed management practices, namely manually, mechanical, herbicide and mulching. Hand weeding is a famous traditional weed management practices which is the most time consuming, accounts 30-40% of production (Kharwal and Yadav, 2023). Application of herbicide is a better supplement to conventional method considering weed emergence pattern, application time and crop growth stage. Mulching is covering materials on the surface of soil to cost effective and eco-friendly technology alternative to conventional and herbicides, which keeps the field in weed free, conserve soil moisture, regulate soil temperature, reduce salinity, control soil erosion, moves soil microbes and improve soil health with minimizing nutrient losses (Iqbal *et al.*, 2020). Polythene and plastic (polyvinyl chloride) mulches are the most popular inorganic mulch, altering the soil microclimates (increasing soil temperature & air and reducing evaporation), impacting soil ecosystems (prevent soil compaction, increasing nutrient and dioxide concentration) and microbial community (ensure convenient environment for beneficial microbes and suppressing soil borne pathogens) which significantly influence on growth (especially root growth) and quality fruit yield of chilli, reducing leaching loss of plant nutrients and reducing the degree of weed infestation (Kefelegn and Desta, 2021; Wickramarathne *et al.*, 2021). There are different kinds and colors of polythene mulch such as white, black, white on black, silver on black, grey, infrared transmitted brown (IRT-brown), IRT-green etc. used in agriculture (Ibarra-Jiménez *et al.*, 2008). Black polythene mulch does not allow to pass photosynthetic active radiations (PAR) which inhibits emergence and growth of weeds beneath the mulches and helps to control 100% weeds (Iqbal *et al.*, 2020). Though black polythene mulch is applied generally in worldwide which had adverse effect on environment. To prevent this problem silver on black polythene mulch is used as alternatives (Wickramarathne *et al.*, 2021). Therefore, the present study was conducted to evaluate the performance of polythene mulch in managing weeds and satisfactory fruit and seed yield of chilli.

### **Materials and Methods**

The field experiment was conducted during *Kharif* seasons of 2021 and 2022 at the research field of Regional Spices Research Center, Bangladesh Agricultural Research Institute (BARI), Gazipur, situated at 23<sup>0</sup>59' North Latitude and 90<sup>0</sup>24' East Longitude with an altitude of 8.4 m above the mean sea level. The experimental site featured belonging to Chhiata Soil series categorized as Grey Terrace Soil within Inceptisol in Taxonomy under the AEZ-28 (Madhupur Tract) was described by Brammer (1971). The collected soil samples (0-30 cm depth) of the experimental field were analyzed in the Soil Science Laboratory, BARI, Gazipur using standard

methods (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments. The treatments were: T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (no mulch as Control), replicated three times. The thickness of used polythene mulch being 30 $\mu$ . The seeds of chilli (var. BARI Morich-2) were sown on 25 January 2021 and 28 January 2022 for the first and second year, respectively in 3 m x 1 m sized seedbed with a line-to-line distance of 10 cm prior to raise seedling. Before sowing, the seeds were treated with Autostin (carbendazim) @ 2 g kg<sup>-1</sup> for preventing primary seed borne as well as soil borne diseases. The seedlings (40 days old) were transplanted in 3 m x 3 m sized main plots maintaining 50 cm x 50 cm spacing on 7 March 2021 and 10 March 2022, respectively. During transplanting, the root zone of seedlings was dipped in Autostin @ 0.2% solution for controlling foot and root disease of chilli. The recommended dose chemical fertilizer on soil test basis, 120-60-100-30-1.5-1.5 kg ha<sup>-1</sup> of N- P -K -S -Zn- B with 5 t ha<sup>-1</sup> of cowdung (FRG, 2018). The total amount of well decomposed cowdung, 1/4<sup>th</sup> of urea for N, TSP for P, 1/3<sup>rd</sup> of MoP for K, gypsum for S, ZnSO<sub>4</sub> for Zn and boric acid for B were applied in broadcast and incorporated to the soil during final land preparation. Top-dressings were done using ring method of N and K fertilizer at 40, 65 and 90 days after transplanting (DAT) of chilli in both the years with equal amount. The polythene mulch was cut into pieces of 3.5 m long to cover the entire plot and anchored 25 cm in to the soil. A scissor was used to cut the holes as per inter and intra row spacing where chilli seedlings were then transplanted. Irrigation was done immediately and equal amount after transplanting by watering can with fine meshed nozzle. Guard rows were established around the entire plot for insect reflecting and also for gap filling purpose. While final land preparation Ecofuran 5G (carbofuran) @ 10 kg ha<sup>-1</sup> was applied in broadcast for controlling soil and foliar-feeding insects such as, stem borer, top shoot borer, wireworms, boll worm, weevil, white grubs and nematode. Throughout the entire cropping season, spraying insecticide Ripcord (Cypermethrin), miticide Vertimec (Abamectin) and fungicide Indofil M-45 (Mancozeb) along with two irrigations were done for proper growth and development of the crop. The well ripened chillies from selected plants were collected four times by hand between 15 May to 01 November in both the years. Before sundried the harvested chillies were cured in a shady place for 3 days. When dried enough, then the chillies were kept in double layer polythene bag into a jute bag for storing. To collect seeds, the dried fruits keeping inside jute bags were beaten by bamboo sticks. Then, the seeds were separated and sieved using BSS 8 x 8 sieves and seeds were dried well to maintain seed moisture less than 10% and weighed. Seed yield was calculated from the plot yield. Soil temperature was monitored using a gardener's soil thermometer (Brannan brand) at 5 to 10 cm beneath the soil in the experimental plot twice in every month. Soil moisture content was determined using digital soil moisture meter (Field Scout, TDR 300, Spectrum technology, Inc, USA) at 10-30 cm beneath the soil in every 10 days intervals.

### Weed density and weed biomass per square meter

Immediate after final harvesting the crops, the weeds were collected from 1m<sup>2</sup> area at the center place of the plot and dried to obtained dry biomass (kg ha<sup>-1</sup>). The uprooted weeds were air-dried in the laboratory and finally oven-dried for 72 hours at 70°C to estimate dry biomass production. The dry biomass of weeds was calculated by the following formula (Yadav *et al.*, 2015):

$$BM = \{(DY \times 10000)\}/1000$$

Where,

$$BM = \text{Dry biomass (kg ha}^{-1}\text{)}$$

$$DY = \text{Total dry yield of weeds per square meter (g)}$$

**Weed control index (WCI)** was estimated by following formula (Das *et al.*, 2016):

$$WCI = [ \{ \text{Dry biomass of weeds in control plot (g m}^{-2}\text{)} - \text{Dry biomass of weed in treated plot (g m}^{-2}\text{)} \} / \text{Dry biomass of weed in control plot (g m}^{-2}\text{)} ] \times 100$$

**Weed control efficiency (WCE)** was estimated by following formula (Das *et al.*, 2016):

$$WCE = [ \{ \text{Weed density in control plot (number m}^{-2}\text{)} - \text{Weed density in treated plot (number m}^{-2}\text{)} \} / \text{Weed density in control plot (number m}^{-2}\text{)} ] \times 100$$

The recorded data on different parameters were statistically analyzed by using R version 3.5.0 software to find out the significant variation results from different treatments. The difference between treatments means were judged by Least Significant Difference (LSD) test at 5% level of significance.

**Table 1. Average physical and chemical properties of initial soil of the experimental field**

Soil characteristics	Analytical value	Analytical method
Soil Textual class	Silty clay loam	Hydrometer method
Bulk density (g cm <sup>-3</sup> )	1.41	Core sampling method
Particle density (g cm <sup>-3</sup> )	2.66	Pycnometer method
Soil pH	5.98	Soil: water=1:2.5
Total N (%)	0.08	Modified Kjeldhal Method
Organic C (%)	0.9	Wet oxidation method
Available P (ppm)	7.05	Bray and Kurtz method
Exchangeable K (meq100g <sup>-1</sup> soil)	0.07	N NH <sub>4</sub> OAc extraction method
CEC (meq 100g <sup>-1</sup> soil)	9.31	N NH <sub>4</sub> OAc extraction method
Available B (ppm)	0.11	Calcium chloride extraction method
Available Zn (ppm)	0.36	DTPA Extraction method
Available Cu (ppm)	0.18	DTPA Extraction method
Available Mn (ppm)	0.61	DTPA Extraction method
Available S (ppm)	6.0	Calcium dihydrogen phosphate extraction method

### Weather parameters

Throughout the experimental periods, monthly average maximum and minimum temperature, relative humidity and rainfall data were diligently recorded and depicted in Figure 1a and 1b, respectively. The monthly average of maximum temperature range (25.02°C to 45.18°C in the year of 2021 and 24.77°C to 34.73°C in the year of 2022) and minimum temperature (13.36°C to 26.96°C and 14.12°C to 31.29°C). The total annual rainfall (1626 mm and 1557 mm) and humidity range (71.2 to 89.16% and 77.73 to 88.17%) both the year of 2021 and 2022, respectively. Yearly average soil temperature and soil moisture content were categorized through treatment wise were also meticulously documented and illustrated in Figure 2. The yearly soil temperature and soil moisture range varied (17.5°C to 32.1°C and 18.1°C to 33.3°C) and (17.5 to 30.5% and 18.5 to 33.8%) at different mulching treatments, both the year of 2021 and 2022, respectively.

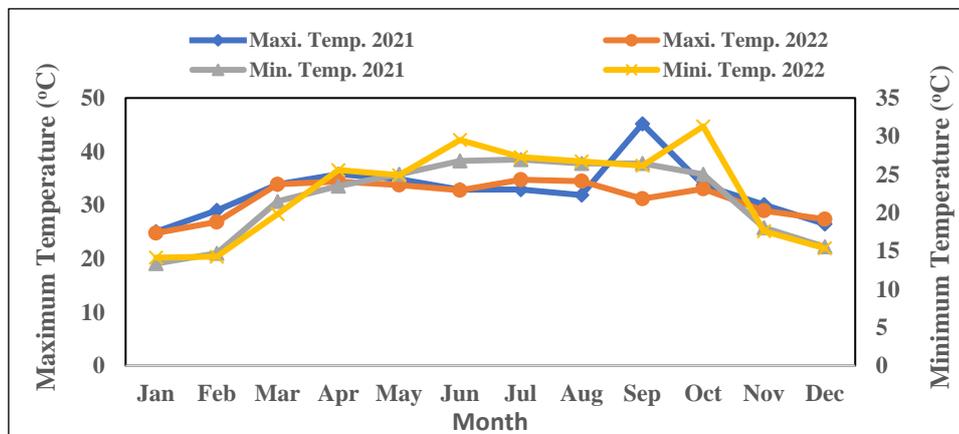


Fig. 1a. Monthly average maximum and minimum temperature of the BARI experimental farm during 2021 and 2022.

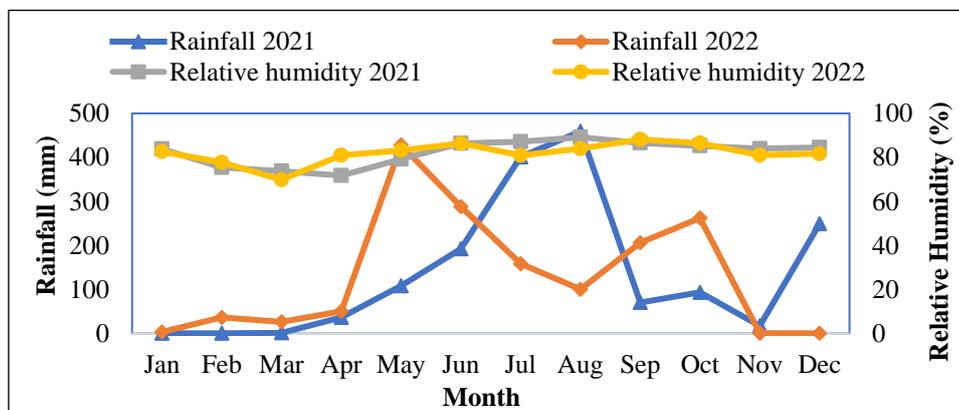
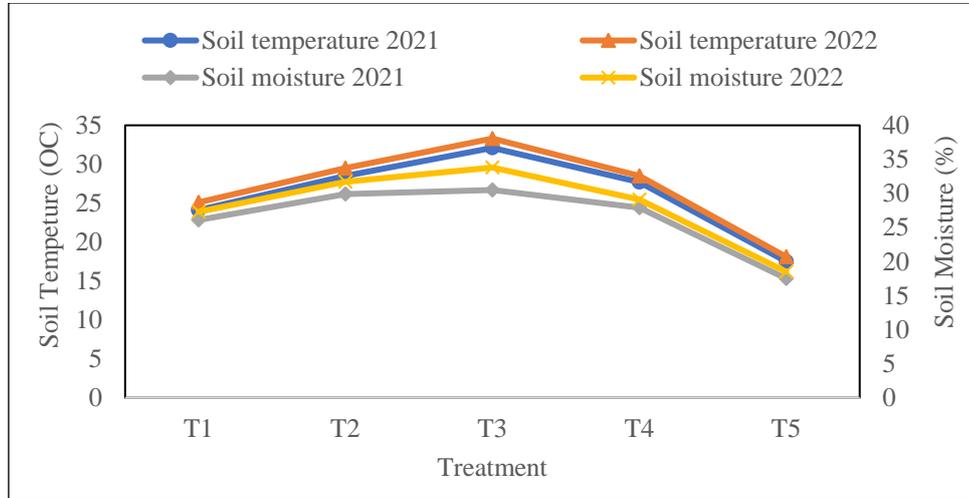


Fig. 1b. Monthly rainfall with monthly average relative humidity of the BARI experimental farm during 2021 and 2022.



**Fig. 2. Yearly average Soil temperature and Soil moisture of different treatment during 2021 and 2022.**

### Results and Discussion

The experimental field exhibited varying densities of broadleaved, grass and sedge weeds as summarized in Table 2. Notably, *Cyperus rotundus* (60%) *Cynodon dactylon* (11%), *Eleusine indica* (10%) and *Echinochloa crussgalli* (6%) emerged as the predominant weed genotypes within the field. When no weeding was done, the number of weeds increased, leading to higher weed density. Conversely, areas covered with polythene mulch shown a significant reduction in weed population, attributed to decreased light transmission beneath the soil surface, hindered weed seed germination as well as growth and development (Wickramarathne *et al.*, 2021).

**Table 2. Weed community recorded in unweeding plot at the experimental field of chilli**

Common name	Scientific name	Family	Weed density in control plot (% m <sup>2</sup> )
Barnyard grass	<i>Echinochloa crussgalli</i>	Poaceae	6
Bermuda grass	<i>Cynodon dactylon</i>	Poaceae	11
Goose grass	<i>Eleusine indica</i>	Poaceae	10
Nut grass	<i>Cyperus rotundus</i>	Cyperaceae	60
Harkuch	<i>Enhydra fluctuans</i>	Asteraceae	1
Prostate spurge	<i>Euphorbia parviflora</i>	Euphorbiaceae	3
Pig weed	<i>Amaranthus viridis</i>	Amaranthaceae	2
Creeping water primrose	<i>Jussiaea repens</i>	Onagraceae	1
Common purslane	<i>Portulaca oleracea</i>	Portulacaceae	5
Cocklebur	<i>Xanthium indicum</i>	Asteraceae	1

### Weed density, fresh and dry weight of weeds

The effect of various polythene mulches on weed density, weed biomass in chilli field were found as illustrated in Table 3. The silver on black polythene mulch exhibited the lowest weed density (1.7 in  $\text{m}^{-2}$  2021, 9.0  $\text{m}^{-2}$  in 2022 and 5.4  $\text{m}^{-2}$  as pooled), the minimum fresh weight of weed (36.3g  $\text{m}^{-2}$  in 2021, 125g  $\text{m}^{-2}$  in 2022 and 80.7g  $\text{m}^{-2}$  as pooled) and as well as the minimum dry weight of weed (32.7g  $\text{m}^{-2}$  in 2021, 6.3g  $\text{m}^{-2}$  in 2022 and 19.3g  $\text{m}^{-2}$ ). Conversely, the unweeded treatment (control) showed the highest weed density (47.7  $\text{m}^{-2}$  in 2021, 52.3  $\text{m}^{-2}$  in 2022 and 50.0  $\text{m}^{-2}$  as pooled), the maximum fresh weight of weed (1135.3g  $\text{m}^{-2}$  in 2021, 1076.7g  $\text{m}^{-2}$  in 2022 and 1106.0g  $\text{m}^{-2}$  as pooled) and maximum dry weight of weed (351.7g  $\text{m}^{-2}$  in 2021, 365g  $\text{m}^{-2}$  in 2022 and 358.4g  $\text{m}^{-2}$  as pooled). This disparity could be attributed to the ability of polythene mulches to restrict weed emergence solely through the punched holes, with no weed was found underneath the polythene mulch. By reducing the weed growth and density in the field, polythene mulch performs to access resources and flourish without competition, ultimately leading to optimal growth and yield of chilli. The findings are in consonance with the results of Kanthaswamy and Venkadeswaran (2020) and Sathiyamurthy *et al.* (2017).

**Table 3. Effect of polythene mulch on weed density, weeds fresh and dry weight of chilli**

Treatment	Weed density (No. $\text{m}^{-2}$ )			Fresh weight of weeds (g $\text{m}^{-2}$ )			Dry weight of weeds (g $\text{m}^{-2}$ )		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T <sub>1</sub>	8.0	4.7	6.4	152.7	159.0	155.9	50.3	31.0	40.7
T <sub>2</sub>	5.7	6.3	6.0	122.7	140.7	131.7	41.0	20.3	30.7
T <sub>3</sub>	1.7	9.0	5.4	36.3	125.0	80.7	32.7	6.3	19.3
T <sub>4</sub>	9.3	11.3	10.3	172.3	210.0	191.2	66.3	37.3	51.8
T <sub>5</sub>	47.7	52.3	50.0	1135.3	1076.7	1106.0	351.7	365.0	358.4
CV (%)	7.45	7.84	9.72	14.11	5.08	9.83	2.26	2.31	3.73
LSD (0.05)	2.39	3.11	1.84	86.69	32.72	39.71	9.03	4.61	4.54

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

T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (Control)

### Weed control index and weed control efficiency

Weed control index and weed control efficiency of chilli were influenced by the application different polythene mulch as depicted in Table 4. The silver on black polythene mulch treatment achieved the maximum weed control index (94.61%)

and weed control efficiency (89.2%) followed by black polythene mulch having weed control index (91.43%) and weed control efficiency (88.0%) while the blue polythene mulch treatment exhibited the lowest weed control index (85.55%) and weed control efficiency (79.4%). The black polythene mulch inhibits weed germination, growth & development and weed infestation by preventing the transmittance of photosynthetic light (Shehata *et al.*, 2019).

**Table 4. Effect of polythene mulch on weed control index and weed control efficiency of chilli (Pooled of two years)**

Treatment	Weed control Index (%)	Weed control efficiency (%)
T <sub>1</sub> (Transparent polythene mulch)	88.64	87.2
T <sub>2</sub> (Black polythene mulch)	91.43	88.0
T <sub>3</sub> (Silver on black polythene mulch)	94.61	89.2
T <sub>4</sub> (Blue polythene mulch)	85.55	79.4
T <sub>5</sub> (Unweeded)	-	-

#### **Plant height, number of brunches and number of fruits per plant**

The results demonstrated a significant impact of polythene mulches on various growth parameters of chilli compared to the unweeding as depicted in Table 5. The treatment silver on black polythene mulch gave the tallest plant (118.8 cm in 2021 and 104.7 cm in 2022 and 111.5 cm as pooled), the highest number of branches per plant (14.7 in 2021, 13.3 in 2022 and 14.0 as pooled) and maximum number of fruits per plant (583.3 in 2021, 478 in 2022 and 530.7 as pooled). This was closely followed by the treatment black polythene mulch having plant height (113.7 cm in 2021, 98 cm in 2022 and 105.8 cm as pooled), number of branches per plant (11.3 in 2021 and 11.7 in 2022 and 11.5 as pooled) and number of fruits per plant (548.3 in 2012, 468 in 2022 and 508.2 as pooled). On the contrary, the unweeded plot showed the shortest plant (77 cm in 2021, 69 cm in 2022 and 73.0 cm as pooled), fewer number of branches per plant (5.7 in 2021, 5.3 in 2022 and 5.5 as pooled), the lowest number of fruits per plant (131.3 in 2021, 128.7 in 2021 and 130.0 as pooled). This difference can be attributed to the favorable soil moisture (90-100% field capacity) conditions facilitated by the use of polythene mulches, which enhanced to lead the higher availability of nutrients (around 15% increase) for improved growth, minimized evaporation losses (25-50% total amount of water) and maintaining favorable temperature (around 10°C reduced in desert and increasing cool) (Iqbal *et al.*, 2020). Additionally, weed suppression may have contributed to these observed effects (Shehata *et al.*, 2019). Similar conclusions were drawn in previous studies by Wickramarathne *et al.* (2021) and Mahadeen (2014).

**Table 5. Effect of polythene mulch on plant height, number of branches and number of fruits per plant of chilli**

Treatment	Plant height (cm)			No. of branches per plant			No. of fruits per plant		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T <sub>1</sub>	103.0	92.7	97.8	8.7	8.3	8.5	507.7	476.3	492.0
T <sub>2</sub>	113.7	98.0	105.8	11.3	11.7	11.5	548.3	468.0	508.2
T <sub>3</sub>	118.8	104.7	111.5	14.7	13.3	14.0	583.3	478.0	530.7
T <sub>4</sub>	100.7	80.7	90.7	7.7	10.0	8.8	482.7	377.0	429.8
T <sub>5</sub>	77.0	69.0	73.0	5.7	5.3	5.5	131.3	128.7	130.0
CV (%)	2.37	2.31	2.60	5.38	13.06	12.02	4.04	8.61	6.69
LSD (0.05)	7.68	2.50	4.67	0.97	2.39	1.41	34.31	62.5	33.92

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test. T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (Control).

### Fruit size and individual fruit weight

The impact of various polythene mulches on fruit size and individual fruit weight per plant of chilli were summarized in Table 6. Higher fruit size (7.81 cm X 1.26 cm in 2021, 7.04 cm x 0.62 cm in 2022 and 7.42 cm X 0.94 cm as pooled) and maximum individual fruit weight (3.90 g in 2021, 3.20 g in 2022 and 3.6 g as pooled) were obtained from silver on black polythene mulch followed by black polythene mulch having fruit size (7.58 cm x 1.16 cm in 2021, 7.04 cm x 0.59 cm in 2022 and 7.31 cm X 0.87 cm as pooled) and individual fruit weight (3.60 g in 2021, 3.07 g in 2022 and 3.3 g as pooled). The smallest fruit (5.43 cm x 0.69 cm in 2021, 5.45 cm x 0.39 cm in 2022 and 5.44 cm X 0.54 cm as pooled) and the lowest fruit weight (2.0 g in 2021, 2.07 g in 2022 and 2.0 g as pooled) were recorded in unweeded plot. This variance can be attributed to the beneficial effects (maintain optimum soil moisture, temperature and aeration) of polythene mulches on soil physical properties (modification of soil texture, bulk density, temperature and aeration) in rhizospheric zone of the chilli plants (Santosh *et al.*, 2022).

**Table 6. Effect of polythene mulch on fruit size and single fruit weight of chilli**

Treatment	Fruit length (cm)			Fruit width (cm)			Single fruit weight (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T <sub>1</sub>	7.14	6.35	6.74	1.01	0.58	0.79	3.13	2.87	3.0
T <sub>2</sub>	7.58	7.04	7.31	1.16	0.59	0.87	3.60	3.07	3.3
T <sub>3</sub>	7.81	7.04	7.42	1.26	0.62	0.94	3.90	3.20	3.6
T <sub>4</sub>	6.97	6.22	6.59	0.99	0.55	0.77	3.03	2.47	2.8
T <sub>5</sub>	5.43	5.45	5.44	0.69	0.39	0.54	2.0	2.07	2.0
CV (%)	2.06	3.53	3.34	9.04	10.32	8.43	8.14	3.09	6.13
LSD (0.05)	0.27	0.43	0.27	0.17	1.06	0.08	0.48	1.59	0.22

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test. T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (Control)

### Fruit yield

The effect of different polythene mulches on the fresh fruit yield per plant, fresh red fruit and dry fruit yield of chilli were statistically significant as presented in Table 7. Notably, silver on black polythene mulch treatment exhibited the maximum number of fruits per plant (1048.3 g in 2021, 939.3 g in 2022 and 987.0 g as pooled), fresh red fruit yield (22.4 t ha<sup>-1</sup> in 2021, 18.1 t ha<sup>-1</sup> in 2022 and 20.3 t ha<sup>-1</sup> as pooled) and dry fruit yield (8.13 t ha<sup>-1</sup> in 2021, 7.40 t ha<sup>-1</sup> in 2022 and 7.77 t ha<sup>-1</sup> as pooled) followed by the treatment black polythene mulch which gave number of fruits per plant (988 in 2021, 925.7 in 2022 and 963.7 as pooled), fresh red fruit yield (20.8 t ha<sup>-1</sup> in 2021, 17.9 t ha<sup>-1</sup> in 2022 and 19.4 t ha<sup>-1</sup> as pooled) and dry fruit yield (7.50 t ha<sup>-1</sup> in 2021, 7.13 t ha<sup>-1</sup> in 2022 and 7.32 t ha<sup>-1</sup> as pooled). On the other hand, the unweeded treatment produced the minimum number of fruits per plant (203.3 in 2021, 205.3 in 2022 and 204.0 as pooled), the lowest fresh red fruit yield (6.6 t ha<sup>-1</sup> in 2021, 7.2 t ha<sup>-1</sup> in 2022 and 5.9 t ha<sup>-1</sup> as pooled) and dry fruit yield (2.23 t ha<sup>-1</sup> in 2021, 2.30 t ha<sup>-1</sup> in 2022 and 2.27 t ha<sup>-1</sup> as pooled). The applied silver on black polythene mulch led to a remarkable increase in dry fruit yield (242.29%) followed by black polythene mulch (222.47%) over the unweeded treatment. This improvement can be attributed to the ability of polythene mulches to create a micro-climate conducive to crop growth while inhibiting weed growth & development and favorable environmental condition for crop cultivation (Iqbal *et al.*, 2020).

**Table 7. Effect of polythene mulch on fruit yield of chilli**

Treatment	Fruit yield per plant (g)			Fresh red fruit yield (t ha <sup>-1</sup> )			Dry fruit yield (t ha <sup>-1</sup> )			% dry fruit yield (pooled) increases over control (pooled)
	Y <sub>1</sub>	Y <sub>2</sub>	Pooled	Y <sub>1</sub>	Y <sub>2</sub>	Pooled	Y <sub>1</sub>	Y <sub>2</sub>	Pooled	
T <sub>1</sub>	936.3	837.0	886.7	18.7	16.5	17.6	6.77	6.27	6.51	186.78
T <sub>2</sub>	988.0	925.7	963.7	20.9	17.8	19.4	7.50	7.13	7.32	222.47
T <sub>3</sub>	1048.3	939.3	987.0	22.4	18.1	20.3	8.13	7.40	7.77	242.29
T <sub>4</sub>	907.3	781.3	844.3	18.5	16.6	17.6	6.70	6.20	6.45	184.14
T <sub>5</sub>	203.3	205.3	204.0	6.6	7.2	5.9	2.23	2.30	2.27	-
LSD (0.05)	17.66	60.19	33.48	2.93	0.73	1.51	0.77	0.54	0.42	-
CV (%)	1.15	4.33	3.55	8.91	2.53	6.07	6.53	4.88	5.67	-

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test. T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (Control); Y<sub>1</sub> = 2021, Y<sub>2</sub> = 2022.

### Number of seeds per fruit, 1000-seed weight and seed yield

The results of various polythene mulches on the number of seeds per fruit, 1000 seed weight and seed yield of chilli were found significant (Table 8). The utilization of silver on black polythene mulch on chilli resulted in the maximum number of seeds per fruit (49.0 in 2021 and 47.5 in 2022 and 48.25 as pooled), higher 1000-seed weight (4.27 g in 2021, 4.48 g in 2022 and 4.38 g as pooled) and maximum seed yield (478.6 ha<sup>-1</sup> in 2021, 486.3 ha<sup>-1</sup> in 2022 and 482.3 kg ha<sup>-1</sup> as pooled) which were followed by the treatment black polythene having number of seeds per fruit (46.0 in 2021 and 45.0 in 2022 and 45.5 as pooled), 1000-seed weight (3.97 g in 2021, 4.0 g in 2022 and 3.99 g as pooled) and seed yield (467.3 kg ha<sup>-1</sup> in 2021, 472.7 kg ha<sup>-1</sup> in 2022 and 470.0 kg ha<sup>-1</sup> as pooled). Conversely, the unweeded treatment exhibited the lowest number of seeds per fruit (34.3 in 2021, 35.5 in 2022 and 34.92 as pooled), the lowest 1000- seed weight (2.87 g in 2021 and 3.07 g in 2022 and 2.97 g as pooled) and seed yield (114.3 kg ha<sup>-1</sup> in 2021, 127.0 kg ha<sup>-1</sup> in 2022 and 118.7 kg ha<sup>-1</sup>). Notably, the silver on black polythene mulch maximum treatment demonstrated a substantial increase in seed yield (306.3%) compared to unweeding treatment. This enhancement can be attributed to the ability of polythene mulches to establish a favorable hydrothermal soil regime and maintaining a weed free environment.

**Table 8. Effect of polythene mulch on no. of seed per fruit, 1000 seed weight and seed yield of chilli**

Treatment	No. of seeds per fruit			1000 seed weight (g)			Seed yield (kg ha <sup>-1</sup> )			% seed yield increase over control
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	
T <sub>1</sub>	42.0	43.5	42.75	3.75	3.71	3.73	399.7	419.7	409.7	245.2
T <sub>2</sub>	46.0	45.0	45.5	3.97	4.0	3.99	467.3	472.7	470.0	295.9
T <sub>3</sub>	49.0	47.5	48.25	4.27	4.48	4.38	478.6	486.0	482.3	306.3
T <sub>4</sub>	40.7	42.0	41.33	3.53	3.57	3.55	412.3	433.0	422.7	256.1
T <sub>5</sub>	34.3	35.5	34.92	2.87	3.07	2.97	114.3	123.0	118.7	-
LSD (0.05)	0.88	3.95	1.25	0.26	0.39	0.66	9.78	21.22	11.76	-
CV (%)	1.09	2.87	2.43	3.74	5.50	4.65	1.39	2.91	2.54	-

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test. T<sub>1</sub> = Transparent polythene mulch, T<sub>2</sub> = Black polythene mulch, T<sub>3</sub> = Silver on black polythene mulch, T<sub>4</sub> = Blue polythene mulch and T<sub>5</sub> = Unweeded (Control)

### Conclusion

Based on the two years' pooled findings of the present study, it is concluded that silver on black polythene mulch (30μ thickness) can be effectively used in chilli field to obtain the maximum fresh red fruit yield (20.30 t ha<sup>-1</sup>) as well as dry fruit

yield (7.77 t ha<sup>-1</sup>) along with the highest seed yield (482.30 kg ha<sup>-1</sup>) of chilli. Additionally, this treatment also showed the highest weed control index (94.61%) and weed control efficiency (89.2%) in Grey Terrace Soil of Madhupur Tract (AEZ-28). Therefore, uses of silver on black polythene mulch can be considered as the optimal weed management approach for enhancing chilli production in the study area.

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## GROWTH, YIELD AND STORABILITY OF ONION VARIETIES AS INFLUENCED BY INTEGRATED NUTRIENT MANAGEMENT

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### Abstract

A Field experiment on onion (*Allium cepa* L.) was conducted at Regional Spices Research Centre, BARI, Gazipur (23°59' North Latitude and 90°24' East Longitude) during *rabi* season of 2021-2022 and 2022-2023. The objectives were to find out promising onion variety, to develop a balanced nutrient management package for higher bulb yield with longer storability and to make a nutrient balance sheet for revealing the condition of soil fertility. The experiment was designed in Factorial Randomized Complete Block Design having three replications and nine treatments comprising three winter onion varieties: BARI Piaz-1 (V<sub>1</sub>), BARI Piaz-4 (V<sub>2</sub>) and BARI Piaz-6 (V<sub>3</sub>) and three nutrient management packages i.e., 100% RDF (120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup>) + Cowdung @ 5 t ha<sup>-1</sup> (N<sub>1</sub>), 100% RDF + Vermicompost @ 3 t ha<sup>-1</sup> (N<sub>2</sub>) and 100% RDF + Poultry manure @ 3 t ha<sup>-1</sup> (N<sub>3</sub>) kg ha<sup>-1</sup>. The highest bulb yield (30.65 and 32.06 t ha<sup>-1</sup>), marketable bulb yield (29.24 and 31.03 t ha<sup>-1</sup>) was recorded from var. BARI Piaz-4 cultivated with 100% RDF + Vermicompost @ 3 t ha<sup>-1</sup> in both the year. The net nutrient balance of N (-38 to -146 kg ha<sup>-1</sup>), K (-10.92 to -21.06 kg ha<sup>-1</sup>) and S (-0.70 to -2.68 kg ha<sup>-1</sup>) showed negative balance but P (0.3 to 0.8 kg ha<sup>-1</sup>) was positive. The highest total physiological loss of weight (PLW) of onion (19.5 and 21.7% in both the year) was recorded when onion var. BARI Piaz-6 was fertilized with 100% RDF + Poultry manure @ 3 t ha<sup>-1</sup> during 120 days of storage. Among the onion varieties, BARI Piaz-6 was more susceptible to PLW. Hence, BARI Piaz-4 appeared as high yield potential onion variety and a combination of 120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup> + Vermicompost @ 3 t ha<sup>-1</sup> was found to be the most suitable package in augmenting yield and sustaining soil health in the studied location of Madhupur Tract (AEZ-28).

Keywords: Onion varieties, nutrient management, bulb yield, storability and nutrient balance sheet.

### Introduction

In Bangladesh, onion ranks first in production among the spice crops covering 1.94 lakh hectares of land and produced 22.69 lakh Metric tons bulb production with an average yield of 11.7 t ha<sup>-1</sup> (BBS, 2022), which is lower in comparison to the world average yield of 19.7 t ha<sup>-1</sup> (FAO, 2022). Plant nutrient elements are essential as a constituent of chlorophyll, amino acids, proteins and nucleic acids, those are responsible for photosynthesis leading to formation of protoplasm and new cells

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for growth, development and improve the storability (Bangali *et al.*, 2012 and Walle *et al.*, 2018). Farmers usually do not use balanced dose of fertilizers and manure, which hampers growth, yield and storability of onion (Yayeh *et al.*, 2017). Selection of suitable variety, soil moisture and nutrient management are most essential factors which, with optimum application, increase bulb yield and storability caused huge yield reduction (Gnanasundari *et al.*, 2022; Kumara *et al.*, 2018). Moreover, Kumar *et al.* (2007) reported that the growth and yield parameters such as plant height, number of leaves per plant, biomass, individual bulb weight and bulb yield increased significantly with appropriate nutrient management. Bangladesh Agricultural Research Institute (BARI) has developed three high yielding winter onion varieties like, BARI Piaz-1, BARI Piaz-4 and BARI Piaz-6 (Khan *et al.*, 2023) having higher yield potentiality but its lower yield in farmer's field are due to improper use of fertilizers and manures (Hasan and Mozumder, 2023) Hence, the present study was undertaken to find out the promising onion variety and to develop a balanced nutrient management package for higher bulb yield with longer storability and to develop a nutrient balance sheet for revealing the condition of soil fertility

### Materials and Methods

The present study was conducted at the research field of Regional Spices Research Center, BARI, Gazipur, during two consecutive growing seasons of 2020-2021 and 2021-2022. The experimental site was situated at 23<sup>0</sup>59' North Latitude and 90<sup>0</sup>24' East Longitude, at an altitude of 8.4 m above the mean sea level. The soil of the experimental site belongs to Chhiata Soil series classified as Grey Terrace Soil of Inceptisol under the AEZ-28 (Madhupur Tract) reported by Brammer (1971). The initial soil samples of the experimental field were collected (0-15 cm depth) and analyzed in the Soil Science Laboratory, BARI, Gazipur following standard and recommended methods (Table 1). The experiment was laid out in Factorial Randomized Complete Block Design with nine treatment combinations were: Factor A:- three onion varieties [BARI Piaz-1 (V<sub>1</sub>), BARI Piaz-4 (V<sub>2</sub>) and BARI Piaz-6 (V<sub>3</sub>)] and Factor B:- three nutrient management packages i.e., 100% RDF (120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup>) + Cowdung @ 5 t ha<sup>-1</sup> (N<sub>1</sub>), 100% RDF + Vermicompost @ 3 t ha<sup>-1</sup> (N<sub>2</sub>) and 100% RDF + Poultry manure @ 3 t ha<sup>-1</sup> (N<sub>3</sub>) having three replications. The recommended dose of chemical fertilizer (RDF) was measured by soil test basis (STB) using FRG, 2018. Seeds were soaked in water for 12 hours and treated with Autostin (*Carbendazim*) @ 2 g kg<sup>-1</sup> before sowing to control primary seed-borne diseases. The seeds were sown @ 30 g per seed bed (3 m x 1 m) on 15 October 2022. Healthy seedlings of 40 days were transplanted into the main field maintaining 10 cm x 10 cm spacing on 25 November 2022. The unit plot size was 3.0 m x 1.2 m with 30 cm deck around the plot. Cowdung, vermicompost, poultry manure and chemical fertilizers such as triple super phosphate, gypsum, zinc sulphate and boric acid as a source of P, K, S, Zn and B, respectively as per treatment were applied as basal before final land

preparation. Nitrogen and potassium in the form of urea and muriate of potash, respectively were applied at two equal splits where, the 1<sup>st</sup> split was top dressed at 25 days after transplanting (DAT) and the second at 50 DAT. The intercultural operations like hand weeding were done thrice to control weed, spraying of Ridomil Gold (*Mancozeb + Metalaxyl*) @ 2.5 g l<sup>-1</sup> and Ruvral (*Iprodione*) @ 2.5 g l<sup>-1</sup> in alternation with Admire (*Imidacloprid*) @ 2.0 ml l<sup>-1</sup> were done at 12 days interval for controlling disease and insect pest. The bulbs were harvested 10 days after 80% neck fall on 22 March 2023. Data on plant height, number of leaves per plant, neck thickness, days to maturity, bulb size, individual bulb weight and bulb yield were recorded for each treatment from randomly selected 10 plants before harvest. The harvested bulbs were cured for three days in a well aerated shady place to make the bulb firm, dried and colored. Marketable bulb yield was determined by discarding bulb size smaller than 1.5 cm in diameter, injured, thick necked, bolted and rotten to total number of normal bulbs per plot. To enhance the shelf-life after curing, bulbs were cut at 5-7 cm above neck region for storing. The physico-chemical properties of soil in the experimental site are presented in Table 1. Nutrient contents of organic manures used in the experiment are shown in Table 2. About 10 kg of cured bulbs were stored in a plastic rack at room temperature to observe shelf-life of onion on 27 March 2022. The data on physiological loss in weight were recorded at 30 days interval up to 120 days of storage. After harvesting 10 (ten) selected onion plants from each plot were uprooted, air-dried in the laboratory and finally oven-dried for 72 hours at 65°C to estimate dry matter production. The dry matter was calculated by the following formula (Yousuf, 2005):

$$DM = [(DY / 10) \times NP] \times 10000 / 1000$$

Where, DM = Dry matter (kg ha<sup>-1</sup>)

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

NP = Total number of plants per m<sup>2</sup>

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

$$\text{Nutrient uptake} = \% A \times Y / 100 \text{ kg ha}^{-1}$$

Where, % A = Nutrient content of plant in percent; Y = Total dry matter production of plant (kg ha<sup>-1</sup>)

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

$$\text{Nutrient balance (N, P, K, S)} = \Sigma \text{Input (N, P, K, S)} - \Sigma \text{Output (N, P, K, S)}$$

Where,

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

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

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

For measuring the TSS, bulb tissue (20.0g) was homogenized in a blender and centrifuged for 20 min at 12000 rpm under 4°C, the supernatant was analyzed at room temperature with a hand refractometer, expressed as °Brix. The recorded data on different parameters were statistically analyzed by using the software, R 3.5.5 to find out the significance of variation resulting from different treatments. The difference between treatment means were judged by Least Significant Difference (LSD) test at 5% level of significance.

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

Soil Chemical Properties	Analytical value	Analytical method
Textural class	Clay loam	Hydrometer method
Bulk density (g cm <sup>-3</sup> )	1.38	Core sampling method
Particle density (g cm <sup>-3</sup> )	2.65	Pycnometer method
Soil pH	6.2	Soil: water=1:2.5
Organic carbon (%)	0.89	Wet oxidation method
Total N (%)	0.09	Micro Kjeldhal Method
Available P (ppm)	7.78	Bray and Kurtz method
Exchangeable K (meq 100 g <sup>-1</sup> soil)	0.08	N NH <sub>4</sub> OAc Extraction method
Available S (ppm)	6.57	Calcium dihydrogen phosphate extraction method
Available B (ppm)	0.18	Calcium chloride extraction method
Available Zn (ppm)	0.57	DTPA Extraction method
Available Cu (ppm)	0.17	DTPA Extraction method
Available Mn (ppm)	0.75	DTPA Extraction method
CEC (meq 100 g <sup>-1</sup> soil)	9.3	N NH <sub>4</sub> OAc Extraction method

**Table 2. Nutrient contents in different organic manure used in the experiment**

Organic manure	pH	OC	N	P	K	S
		(% )				
Cowdung	7.3	13.9	1.1	0.5	0.6	0.06
Vermicompost	7.6	11.7	1.8	1.1	0.9	0.03
Poultry manure	7.7	14.9	1.9	0.9	0.8	0.04

## Results and Discussion

The interaction effects of onion variety and nutrient management packages were significant for plant height, number of leaves per plant and bulb size of onion

(Table 3). The maximum plant height (58.7 and 66.0 cm), number of leaves per plant (14.3 and 18.3) and biggest bulb (5.93 x 6.07 and 6.07 x 6.43 cm<sup>2</sup>) were recorded with BARI Piaz-4 and application of 100% RDF + Vermicompost @ 3 t ha<sup>-1</sup> (V<sub>2</sub>N<sub>2</sub>) during 2021-2022 and 2022-2023, respectively. The minimum plant height (35.0 and 42.3 cm), number of leaves per plant (7.3 and 9.3) and bulb size (3.73 x 4.13 and 4.77 x 5.23 cm<sup>2</sup>) were observed in BARI Piaz-1 fertilized with 100% RDF (120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup>) + Cowdung @ 5 t ha<sup>-1</sup> (V<sub>1</sub>N<sub>1</sub>) in both the years. Plant nutrients favored vegetative growth of onion plants by enhancing physiological and metabolic activities (Asgele *et al.*, 2018).

**Table 3. Effects of onion variety and nutrient management on plant height, no. of leaves per plant and bulb size of onion**

Treatment	Plant height (cm)		No. of leaves per plant		Bulb length (cm)		Bulb diameter (cm)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
V <sub>1</sub> N <sub>1</sub>	35.0f	42.3e	7.3d	9.3f	3.73d	4.13d	4.77c	5.23b
V <sub>1</sub> N <sub>2</sub>	39.3e	49.0c	7.7d	12.0de	3.87d	4.43cd	5.0c	5.27b
V <sub>1</sub> N <sub>3</sub>	38.3e	45.0de	8.0d	10.3ef	3.83d	4.33cd	5.07bc	5.20b
V <sub>2</sub> N <sub>1</sub>	55.7b	64.0a	13.0b	16.3b	5.43ab	5.97a	5.53abc	6.07a
V <sub>2</sub> N <sub>2</sub>	58.7a	66.0a	14.3a	18.3a	5.93a	6.07a	5.77a	6.43a
V <sub>2</sub> N <sub>3</sub>	57.0ab	60.7b	13.7ab	15.7b	5.87a	5.97a	5.6ab	6.23a
V <sub>3</sub> N <sub>1</sub>	41.7d	46.0d	9.7c	13.0cd	4.0d	4.60c	5.03bc	5.27b
V <sub>3</sub> N <sub>2</sub>	45.0c	49.0c	10.3c	14.7bc	4.93bc	5.13b	4.87c	5.43b
V <sub>3</sub> N <sub>3</sub>	42.0d	46.0d	9.3c	12.3de	4.67c	4.7c	4.87c	5.23b
CV (%)	2.57	3.18	7.07	2.12	7.19	4.15	6.71	5.58

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

The combined effects of onion variety and nutrient management packages were significant for single bulb weight, neck thickness, TSS and days to maturity of onion (Table 4). The maximum bulb weight (82.67 and 86.1 g), neck thickness (1.63 and 1.57 cm), TSS (14.7 and 15.93<sup>0</sup>Brix) and maximum day required to mature bulb (111 and 115 days) and were recorded from plot subjected to BARI Piaz-4 with application of 100% RDF + Vermicompost @ 3 t ha<sup>-1</sup> (V<sub>2</sub>N<sub>2</sub>) in both the years. The minimum bulb weight (42.43 and 55.7 g), neck thickness (0.79 and 0.87 cm) and TSS (12.4 and 13.07<sup>0</sup>Brix) were recorded under BARI Piaz-1 with application of 100% RDF (120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup>) + Cowdung @ 5 t ha<sup>-1</sup> (V<sub>1</sub>N<sub>1</sub>). But the minimum day required to mature bulb (71 and 73 days) was noted in treatment V<sub>3</sub>N<sub>3</sub> in both the years. It is assumed that the IPNS based nutrient management supplied sufficient macro & micro nutrients, which favored growth promoting and enzymatic activities of plants.

**Table 4. Effects of onion variety and nutrient management on yield contributing components of onion**

Treatment	Single bulb weight (g)		Neck thickness (cm)		TSS ( <sup>0</sup> Brix)		Days to maturity	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
V <sub>1</sub> N <sub>1</sub>	45.43c	55.7b	0.79c	0.87b	12.4b	13.07b	88	90b
V <sub>1</sub> N <sub>2</sub>	52.50bc	56.2b	1.16b	1.08b	12.5b	13.63b	86b	89b
V <sub>1</sub> N <sub>3</sub>	50.77bc	54.1b	1.14b	0.88b	12.6b	13.60b	87b	88b
V <sub>2</sub> N <sub>1</sub>	76.47a	80.3a	1.60a	1.53a	14.6a	15.90a	111a	114a
V <sub>2</sub> N <sub>2</sub>	82.67a	86.1a	1.63a	1.57a	14.7a	15.93a	111a	115a
V <sub>2</sub> N <sub>3</sub>	81.90a	85.3a	1.60a	1.56a	14.6a	15.83a	110a	113a
V <sub>3</sub> N <sub>1</sub>	54.0b	60.3b	0.97bc	1.0b	12.8b	13.17b	72c	73c
V <sub>3</sub> N <sub>2</sub>	52.67bc	59.8b	1.01bc	1.05b	12.7a	13.17b	73c	74c
V <sub>3</sub> N <sub>3</sub>	53.87b	57.1b	0.94bc	1.10b	12.7b	13.17b	71c	73c
CV (%)	7.04	6.54	16.97	15.69	3.73	6.59	3.00	2.26

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

Total bulb yield, marketable bulb yield and biomass yield of onion were significantly influenced by variety and nutrient management (Table 5). The maximum bulb yield (30.65 and 32.06 t ha<sup>-1</sup>), marketable bulb yield (29.24 and 31.03 t ha<sup>-1</sup>) and biomass yield (4.07 and 4.13 t ha<sup>-1</sup>) of onion were obtained from V<sub>2</sub>N<sub>2</sub> treatment in both the years. The lowest bulb yield (17.29 and 18.92 t ha<sup>-1</sup>), marketable bulb yield (15.65 and 17.63 t ha<sup>-1</sup>) and biomass yield (2.4 and 2.43 t ha<sup>-1</sup>) were recorded from treatment V<sub>1</sub>N<sub>1</sub> in both the years. Biomass production depends on the synthesis, accumulation and translocation of photosynthates which depend upon efficient photosynthetic structure as well as source sink relationship. The biomass yield is mostly controlled by nutrient mobility and translocation of photosynthates by plant. This may be due to nutrient availability in the root zone, leads to enhance plant growth and development (Yayeh *et al.*, 2017 and Kumar *et al.*, 2007).

**Table 5. Effects of onion variety and nutrient management on bulb yield, marketable yield and biomass yield of onion**

Treatment	Total bulb yield (tha <sup>-1</sup> )		Marketable yield (tha <sup>-1</sup> )		Biomass yield (tha <sup>-1</sup> )	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
V <sub>1</sub> N <sub>1</sub>	17.29e	18.92d	15.65e	17.63d	2.40b	2.43c
V <sub>1</sub> N <sub>2</sub>	17.84de	19.19d	16.48de	18.53d	2.77b	2.91bc
V <sub>1</sub> N <sub>3</sub>	17.41e	19.13d	15.67e	17.83d	2.77b	2.87bc
V <sub>2</sub> N <sub>1</sub>	27.06b	29.38b	24.74b	28.47b	3.97a	4.03a
V <sub>2</sub> N <sub>2</sub>	30.65a	32.06a	29.24a	31.03a	4.07a	4.13a
V <sub>2</sub> N <sub>3</sub>	29.66a	30.87ab	28.44a	30.2ab	4.03a	4.10a
V <sub>3</sub> N <sub>1</sub>	20.85c	22.28c	19.42c	21.0c	3.03b	3.10bc
V <sub>3</sub> N <sub>2</sub>	21.15c	22.58c	19.71c	21.43c	3.13b	3.27bc
V <sub>3</sub> N <sub>3</sub>	19.9cd	21.55c	18.24cd	20.57c	2.90b	3.0bc
CV (%)	5.48	4.49	5.40	4.99	13.60	13.35

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

### Storability

Onion is non climacteric perishable crop producing low endogenous ethylene during storage and encounters 35-40% post-harvest losses during storage owing to decay, sprouting and physiological weight loss (Anbukkarasi *et al.*, 2013). The storability of onion depends on variety, bulb size, shape with content of TSS, maturity at harvest, production technologies, storage condition and climatic condition. The effects of both variety and nutrient management on physiological loss of weight (PLW) of onion was observed in up to 120 days of storage (Figure 1 and 2). However, PLW increased at faster rate recorded higher loss during storage in initial stage, which was the highest in BARI Piaz-6. The maximum PLW was (19.5 and 21.7%) recorded in  $N_3 V_3$ , the minimum PLW (10.4 and 12.7%) was noted in the treatment of BARI Piaz-1 with application of 120-60-100-20-3-1.5 kg NPKSZnB  $ha^{-1}$  + Cowdung @ 5 t  $ha^{-1}$  in both the years. Onion variety under higher yield potentiality had accumulated higher moisture and nutrients, where nitrogen might have played major role in producing higher bulb size with higher moisture content and tends to lose more weight and enhanced susceptibility to diseases and early sprouting during storage. On the other hands, onion variety having smaller bulb size utilized lower soil moisture and nutrient showed less physiological weight loss to keep well during the 120 days storage. Similar result was reported by Kumar *et al.* (2007).

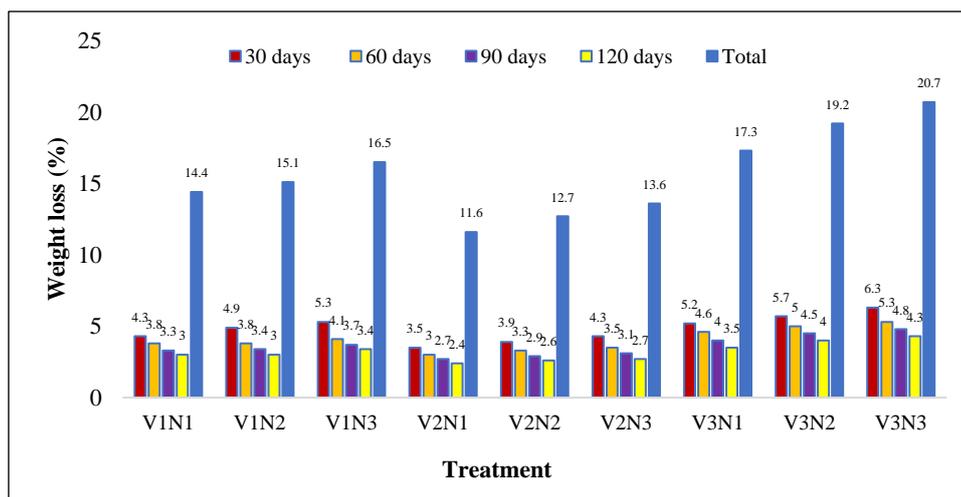
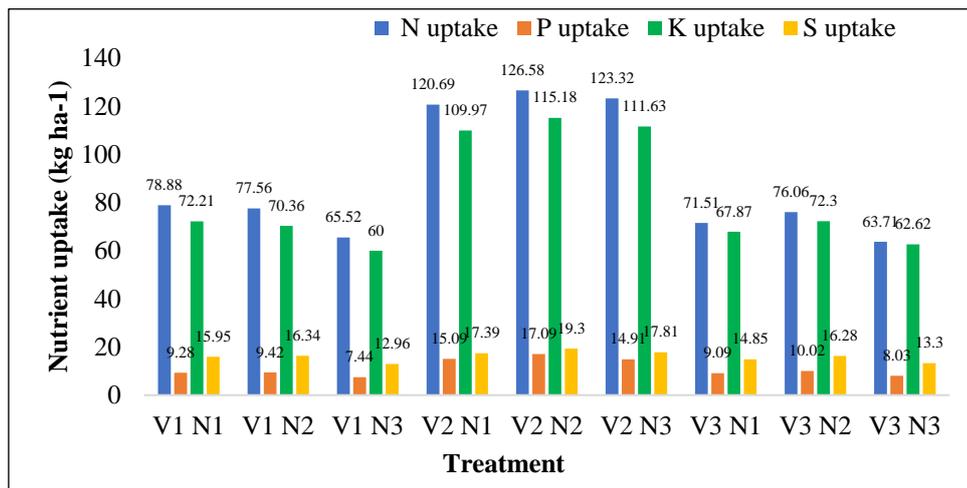


Fig. 1. Effect of variety and nutrient management packages on storability of onion.

### Uptake of N, P, K and S

N, P, K and S uptake by onion plants under different nutrient management packages were studied (Figure 2). It was observed that the maximum uptake of N, P, K and S were 126.58, 17.09, 115, 18 and 19.30  $kg ha^{-1}$ , respectively in treatment  $V_2N_2$  in both the years while minimum uptake of N (63.71  $kg ha^{-1}$ ) was obtained

in treatment  $V_3N_3$ . It was also observed that the minimum uptake of P, K and S were 7.44, 60.0 and 12.96 kg ha<sup>-1</sup>, respectively in treatment  $V_1N_3$  in both the years. Addition of chemical fertilizers and manure in soil increase availability of N, P, K and S contents in soil, resulting improved soil physical and chemical properties of soil. Maintenance of optimum levels of N, P, K and S in soil had led to favored in better plant growth and also higher transpiration rate, thus led to higher absorption of nutrients also. These results are in agreement with the research findings of Nasreen *et al.* (2007) and Kumara *et al.* (2018).



**Fig. 2. Effect of variety and nutrient management packages on nutrient uptake of onion.**

#### Post-harvest soil N, P, K and S status

The data presented in Figure 3a and 3b revealed that adoption of different nutrient management packages for two consecutive years in onion cultivation have remarkably influenced post-harvest soil N, P, K and S fertility status. The maximum value of residual N (1698 kg ha<sup>-1</sup>) was recorded in  $V_3N_2$  treatment, residual P (16.36 kg ha<sup>-1</sup>) in treatment  $V_3N_1$ , residual K (51.48 kg ha<sup>-1</sup>) in  $V_1N_2$  treatment and S (12.42 kg ha<sup>-1</sup>) in  $V_1N_3$  treatment. The minimum value of residual N and P were 1654 and 16.02 kg ha<sup>-1</sup>, respectively recorded in treatment  $V_2N_3$  followed by  $V_2N_1$  and also residual S (10.46 kg ha<sup>-1</sup>) was observed in treatment  $V_2N_2$ . It can be inferred from results that higher nutrient availability due to application of fertilizers and manures contributed to uptake by the crop and sustained the soil fertility to some extent as well as higher N, P, K and S reserves post-harvest soil. These findings were confirmed by Al-mansour *et al.* (2020); Kumar *et al.* (2018).

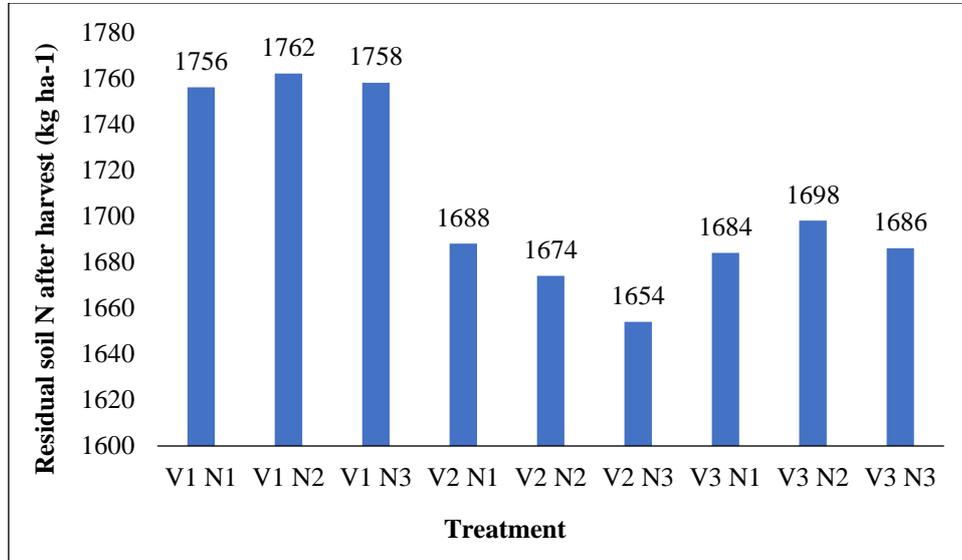


Fig. 3a. Effect of variety and nutrient management packages on residual soil N after harvest of onion.

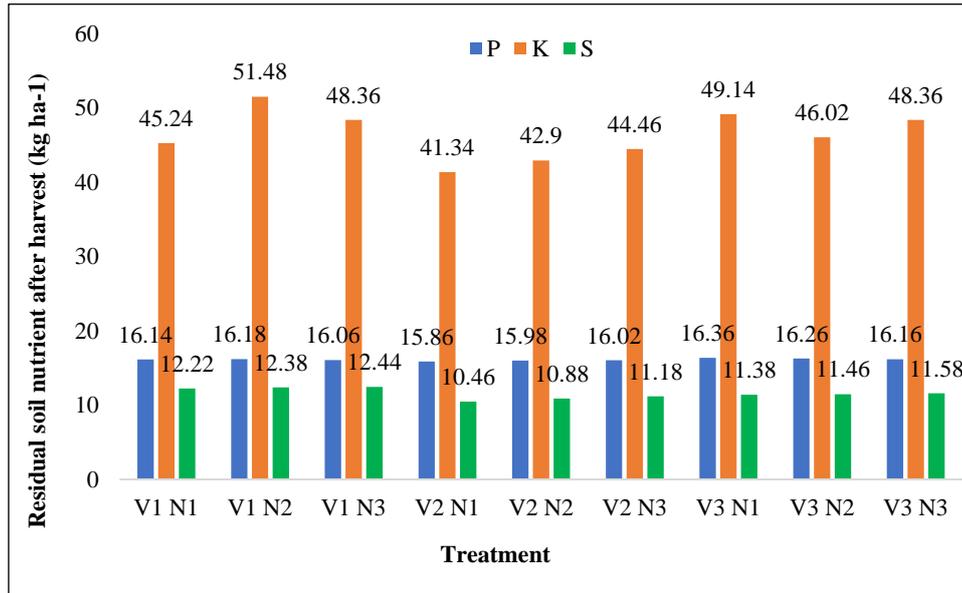
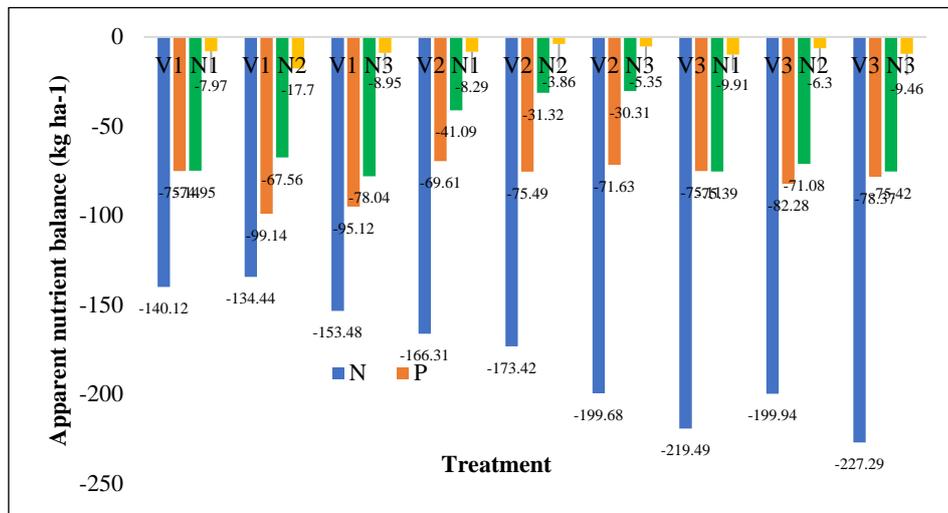


Fig. 3b. Effect of variety and nutrient management packages on residual soil P, K and S after harvest of onion.

#### Apparent N, P, K and S balance

Apparent N, P, K and S balance of onion were influenced by the application different nutrient management packages (Figure 4). The range of apparent N

balance (-227.29 to -134.44 kg ha<sup>-1</sup>), P balance (-99.17 to -69.61 kg ha<sup>-1</sup>), K balance (-78.04 to -30.31 kg ha<sup>-1</sup>) and S balance (-17.7 to -3.86 kg ha<sup>-1</sup>) were noted with the application of NPKS fertilizers in 2021-2022 and 2022-2023, respectively. The maximum apparent N balance (-134.44 kg ha<sup>-1</sup>) was recorded in treatment V<sub>2</sub>N<sub>2</sub> followed by V<sub>2</sub>N<sub>1</sub>, V<sub>2</sub>N<sub>3</sub> and V<sub>2</sub>N<sub>2</sub>. The minimum apparent N balance (-227.29 kg ha<sup>-1</sup>) was recorded in treatment V<sub>3</sub>N<sub>3</sub> followed by V<sub>1</sub>N<sub>2</sub> (-78.04 kg ha<sup>-1</sup>) in treatment V<sub>1</sub>N<sub>3</sub>. The apparent negative N, P, K and S balance of soil indicate that soil has unable to supply sufficient N, P, K and S for proper growth and development of crops. These results are in close conformity with the research findings of Shehata and Moubarak (2020) and Kucha *et al.* (2018).



**Fig. 4. Effect of variety and nutrient management packages on apparent nutrient balance of onion.**

#### Net N, P, K and S balance

. Positive balance indicated the nutrient accumulation and negative balance eventually cause soil degradation and adversely affect crop production. On the other hand, excess nutrient accumulation may lead to soil, water and air pollution. The N, P, K and S balance of onion due to application of different nutrient management packages were observed (Figure 5a and 5b). The range of net N balance (-146 to -38 kg ha<sup>-1</sup>), P balance (0.3 to 0.8 kg ha<sup>-1</sup>), K balance (-21.06 to -30.31 kg ha<sup>-1</sup>) and S balance (-2.68 to -0.70 kg ha<sup>-1</sup>) were observed with the application of different nutrient management packages in both the years. The results showed that net N, K and S balance in soil remained negative. The maximum net balance of N and K were -38.0 and 10.92 kg ha<sup>-1</sup>, respectively were recorded in treatment V<sub>1</sub>N<sub>2</sub> and net S balance (-0.70 kg ha<sup>-1</sup>) was noted in treatment V<sub>1</sub>N<sub>3</sub>. The minimum net N balance (-146.0 kg ha<sup>-1</sup>) was recorded in treatment V<sub>2</sub>N<sub>3</sub> while the minimum net K and S balance -21.06 and -2.68 kg ha<sup>-1</sup> were obtained in

treatment  $V_2N_1$ . The net P balance was positive both the years (Fig. 5b). The maximum net P balance ( $0.8 \text{ kg ha}^{-1}$ ) was recorded in treatment  $V_3N_1$  followed by  $V_1N_2$ . It may be due to higher availability of nutrients in root zone and enhanced bio-chemical activities of onion plants. These results of these investigation are in agreement of Al-mansour *et al.* (2020); Kucha *et al.* (2018).

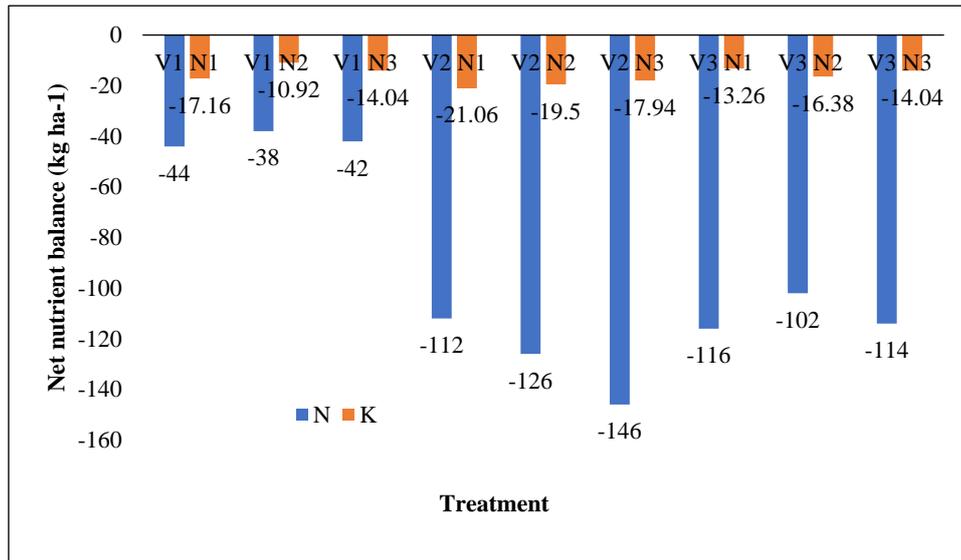


Fig. 5a. Effect of variety and nutrient management packages on net N and K balance of onion.

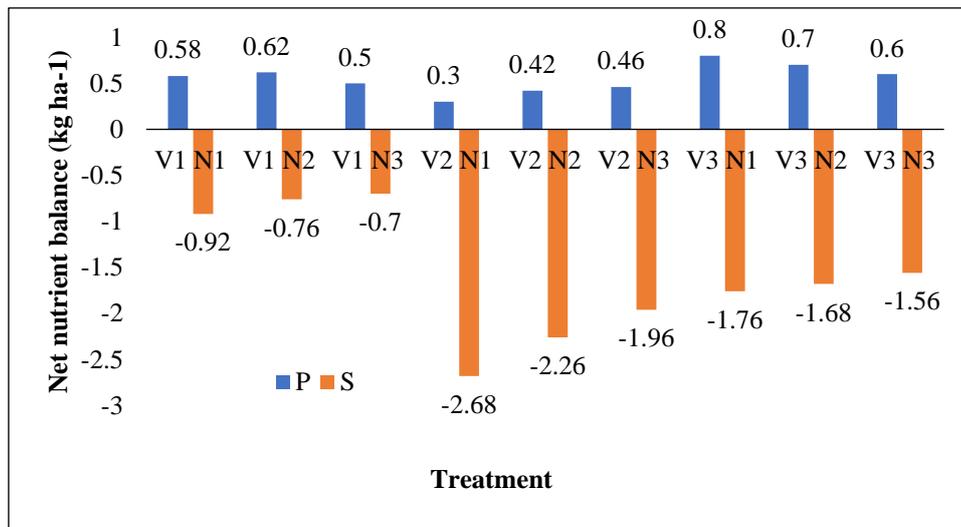


Fig. 5b. Effect of variety and nutrient management packages on net P and S balance of onion.

## Conclusion

It may thus be concluded from the results of the present study that bulb yield and storability of onion varieties was significantly influenced by application of organic manure in combinations chemical fertilizer. The highest total bulb yield (30.65 and 32.06 t ha<sup>-1</sup>) and marketable bulb yield (29.24 and 31.03 t ha<sup>-1</sup>) in 2021-2022 and 2022-2023, respectively was obtained from onion var. BARI Piaz-4 with application of 100% RDF (120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup>) + Vermicompost @ 3 t ha<sup>-1</sup>. The uptake of N, P, K and S by the crop was also highly favoured by the same treatment. Thus, BARI Piaz-4 appeared as high yield potential onion variety and a combination of 120-60-100-20-3-1.5 kg NPKSZnB ha<sup>-1</sup> + vermicompost @3 t ha<sup>-1</sup> to be the most suitable package in augmenting yield and sustaining soil health in the study location (AEZ-28) and similar other soils of the country.

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## RESPONSE OF POTATO VARIETIES TO DIFFERENT LEVELS OF IRRIGATION

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### Abstract

The field experiment was conducted at the Tuber Crops Research Sub-Centre, Munshiganj during the *rabi* seasons of 2019-20 and 2020-21, to investigate the effect of different levels of irrigation on the growth, yield and yield contributing characters of potato. The experiment comprised of two factors: Factor A-four irrigation levels, viz. I<sub>0</sub>= No irrigation, I<sub>1</sub>= One irrigation at 30 days after planting (DAP), I<sub>2</sub>= Two irrigations at 30 and 45 DAP and I<sub>3</sub>= Three irrigations at 30, 45 and 60 DAP (Control) and Factor B: five potato varieties, namely V<sub>1</sub>=BARI Alu-25, V<sub>2</sub>=BARI Alu-28, V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37 and V<sub>5</sub>=BARI Alu-40. Results revealed that BARI Alu-36 produced the highest tuber fresh yield under well-watered condition i.e. at three irrigations 30, 45 and 60 DAP (44.57 and 45.26 t/ha in 2019-20 and 2020-21, respectively) as well as under no irrigated condition (water stress) (25.54 t/ha and 28.92 t/ha in 2019-20 and 2020-21, respectively). On the contrary, though BARI Alu-37 was a good yielder (40.88 t/ha in 2019-20 and 44.86 t/ha in 2020-21) under well-watered condition i.e. at three times irrigated condition, this variety failed to give a reasonable yield under water stress condition. BARI Alu-36 showed the lowest yield reduction (42.70% and 36.10% in 2019-20 and 2020-21, respectively) in water shortage conditions. The more the water shortage the more the dry matter accumulation trend was found in both the seasons and the maximum tuber dry matter percentages of 23.66% and 23.46% were obtained from BARI Alu-28 and BARI Alu-25 varieties under no irrigation in 2019-20 and 2020-21, respectively. Therefore, considering the yield, percent yield reduction and dry matter percentages, BARI Alu-36, BARI Alu-28 and BARI Alu-25 may be cultivated under water shortage conditions in Bangladesh.

Keywords: Potato, water stress, dry matter, irrigation, variety.

### Introduction

Irrigation development is an important means for achieving food self-sufficiency in many countries of the world including Bangladesh. In order to address the challenges associated with food insecurity and water scarcity (Yohannes *et al.*, 2017), the knowledge of irrigation is very important. Many literatures also agree that development of irrigation can be taken as a strategy for reducing poverty and ensuring food security in the world's poorest regions (Magistro *et al.*, 2007). Potato is the fourth most important cultivated food crop and is believed to contribute significantly to sustain future global food security (Burlingame, 2009; FAOSTAT,

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2013). Potato cultivation holds significant potential in Bangladesh and plays a crucial role in Bangladesh's agricultural economy. Bangladesh with the annual potato production of over 10 million metric tons, stands 7<sup>th</sup> in terms of potato production in the world. Potato is the third most important food source in the country, following rice and wheat, and provide a rich supply of carbohydrates, vitamin C, potassium, and fiber, making a significant contribution to daily nutritional needs. Potato currently ranks second only to rice in terms of cultivated land area and yield in Bangladesh.

Among the vulnerable countries, the effects of climate change hold the top position by Bangladesh. The overall impacts of climate change may cause unstable agricultural productivity in the country to a large scale. It is often considered as a drought sensitive crop and its sustainable production is threatened due to frequent drought episodes. The shallow root system of potato makes the crop one of the most drought-sensitive species (Zarzyńska *et al.*, 2017). Drought, during the early growth stage, is considered to be the most harmful as it substantially reduces the total leaf area, photosynthetic rates, and assimilates partitioning to tubers leading to poor tuber initiation, bulking, and tuber yield (Evers *et al.*, 2010; Obidiegwu *et al.*, 2015). Drought limits the productivity of potato plants by affecting photosynthetic processes at the canopy, leaf or chloroplast level (Jones and Corlett, 1992). The sensitivity of potato to water stress is likely due to its shallow root system and complex physiological responses to moderate plant water deficits (Curwen, 1993). A total of 20 droughts already happened in Bangladesh since independence (Agarwala *et al.*, 2003). Every year, 3 to 4 million hectares of land are affected by droughts of different magnitudes (Rashid and Salam, 2007). Hijman (2003) predicted that the worldwide yield production of potato would reduce 18 - 32% in the next 30 years (e.i. until 2033) due to water deficiency. Every year Bangladesh experiences a dry period of five to seven months between November and May when rainfall is normally low. During this period, about 2.7 million hectares of land in Bangladesh become vulnerable to annual drought. There is about 10% of probability that 41-50% area of the country experiences drought in a year (Tanner *et al.*, 2007). English and Raja (1996) described three deficit irrigation case studies in which the reductions in irrigation costs were greater than the reductions in revenue due to reduced yields. Deficit irrigation can lead, in principle, to increased profits where water costs are high or where water supplies are limited. In these case studies, crop value was associated closely with yield, and crop grade and marketability were not germane. Under these circumstances, deficit irrigation can be a practical choice for growers. Tuber Crops Research Centre of BARI has released more than 104 varieties of potato but most of the varieties did not get popularity due to several reasons. Adaptability of the varieties in the changed climate was an important constraint. Therefore, physiological changes of BARI released potato varieties in the changed climate like water stress need to be studied to find out adaptable varieties. Information regarding this aspect is scarce

in Bangladesh. The present study was, therefore, undertaken to find the response of selected potato varieties to different levels of irrigation.

### Materials and methods

The experiment was conducted at the Tuber Crops Research Sub-Centre (TCRSC), Munshiganj during *rabi* season of 2019-20 and 2020-21. The 1st year Experiment was set on 27 November 2019 and the harvesting was done on 1 March 2020 and in the following year, the experiment was set on 30 November, 2020 and the harvesting was done on 5 March 2021. The soil of the experimental plot was sandy loam where sand, silt and clay are 35-50%, 45-60% and 20%, respectively. The soil pH was found 5.2-7.5. From November to March, there was no rainfall in both the years. The factorial experiment was executed with two factors, where Factor A: four levels of irrigation, namely  $I_0$  = No irrigation,  $I_1$  = One irrigation at 30 DAP,  $I_2$  = Two irrigation at 30 and 45 DAP and  $I_3$  = Three irrigation at 30, 45 and 60 DAP (Control) and Factor B: five potato varieties, viz.  $V_1$ =BARI Alu-25,  $V_2$ =BARI Alu-28,  $V_3$ =BARI Alu-36,  $V_4$ =BARI Alu-37 and  $V_5$ =BARI Alu-40. The experiment was laid out in a factorial Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 3.0 m X 3.0 m. Tubers were planted following 60 cm line to line and 25 cm plant to plant spacing. Cow dung was applied @ 10 t/ha during final land preparation. Fertilizers were applied in the form of urea, TSP, MoP, gypsum,  $ZnSO_4$  and boric acid @ 120-44-156-22-3-1 kg/ha of N-P-K-S-Zn-B. Half of urea and full dose of other fertilizers were applied immediately before planting the tubers in furrows and mixed properly with the soil. The rest amount of urea was side dressed at 35 days after planting (DAP). Weeding, earthing up and other intercultural operations were done as and when necessary for raising a good crop. Mancozeb (Active ingredient: Maneb and Metiram) and Secure (Active ingredient: Fluazinam) were sprayed 5 times to control diseases and Admire (Imidacloprid) was also sprayed 5 times at regular interval of 10 days to prevent insects like aphid and jassids. At the time of final land preparation, Carbofuran 5G was applied to the experimental soil to prevent the attack of cut worm and other soil pests. Data were taken on plant height, number of stems per hill, foliage coverage and plant vigor at 60 DAP, 60 DAP, 60 DAP, and 45 DAP, respectively (Kawochar and Uddin, 2015). Plant vigor was determined by the vigor codes (Kawochar and Uddin, 2015). Kawochar and Uddin (2015) reported that Code 1: Very weak - all the plants are small (< 20 cm), few leaves, weak plants, very thin stems and/or light green color. Code 3: weak plants, 75% of the plants are small (< 20 cm) or all the plants are between 20 and 30 cm, the plants have few leaves, thin stems and/or light green color. Code 5: medium, intermediate or normal plants. Code 7: vigorous plant growth, 75% of the plants are over 50 cm, robust with foliage of dark green color, thick stems and leaves very well developed. Code 9: very vigorous plants, all the plants are over 70 cm and ground coverage is complete, the plants are robust, with thick stems and abundant foliage of dark green color. Data on the number of tubers per plant at 95 DAP, weight of tubers (gm) per plant at 95 DAP, weight of individual tuber (gm) at 95

DAP, tuber fresh yield (t/ha) and tuber dry matter (%) at 95 DAP were recorded. Tuber fresh yield (t/ha) reduction percentage was calculated by the following formula:

$$\text{Tuber fresh yield reduction (\%)} = \frac{\text{Yield (t/ha) in (I}_3\text{)} - \text{Yield (t/ha) in (I}_0\text{)}}{\text{Yield (t/ha) in (I}_3\text{)}} \times 100$$

Quantity of approximate water supply: We used a siphon, record the time necessary for a siphon to fill a 100 liter container. Then water quantity was calculated from number of siphons and irrigation time.

Soil sample is collected in a moisture can and wet weight of the sample was recorded. The soil sample was dried in hot air oven at 105° C until constant weight was obtained and dry weight of the sample was recorded.

$$\text{Post-harvest soil moisture content (on weight basis)} = \frac{\text{Soil wet weight} - \text{Soil dry wet}}{\text{Soil dry weight}} \times 100$$

**Table 1. Approximate supplied water quantities assessment (litre) at 30, 45 and 60 DAP and post-harvest soil moisture (%) data at 95 DAP for each treatment**

Treatment	Amount of approximate supplied water (Litre)			Total (litre)	Soil moisture (%) at 95 DAP
	30 DAP	45 DAP	60 DAP		
V <sub>1</sub> I <sub>0</sub>	0	0	0	0	7.8
V <sub>1</sub> I <sub>1</sub>	150	-	-	150	10.5
V <sub>1</sub> I <sub>2</sub>	150	170	-	320	14.5
V <sub>1</sub> I <sub>3</sub>	150	170	190	510	16.5
V <sub>2</sub> I <sub>0</sub>	0	0	0	0	7.2
V <sub>2</sub> I <sub>1</sub>	150	-	-	150	11.5
V <sub>2</sub> I <sub>2</sub>	150	170	-	320	15.3
V <sub>2</sub> I <sub>3</sub>	150	170	190	510	16.8
V <sub>3</sub> I <sub>0</sub>	0	0	0	0	7.5
V <sub>3</sub> I <sub>1</sub>	150	-	-	150	11.75
V <sub>3</sub> I <sub>2</sub>	150	170	-	320	14.78
V <sub>3</sub> I <sub>3</sub>	150	170	190	510	17.5
V <sub>4</sub> I <sub>0</sub>	0	0	0	0	6.8
V <sub>4</sub> I <sub>1</sub>	150	-	-	150	10.55
V <sub>4</sub> I <sub>2</sub>	150	170	-	320	14.80
V <sub>4</sub> I <sub>3</sub>	150	170	190	510	17.30
V <sub>5</sub> I <sub>0</sub>	0	0	0	0	7.4
V <sub>5</sub> I <sub>1</sub>	150	-	-	150	10.85
V <sub>5</sub> I <sub>2</sub>	150	170	-	320	15.75
V <sub>5</sub> I <sub>3</sub>	150	170	190	510	16.75

Field data were analyzed statistically and means were separated by using Least Significant difference (LSD) test through Statistix10 statistical computer program.

## Results and Discussion

The results obtained from the experiment are presented and discussed character wise:

### Plant height

The interaction effects of varieties and irrigations were found significant on plant height of potato at 60 DAP in both 2019-20 and 2020-21 (Table 2). In 2019-20 and 2020-21 the tallest plant heights of 90.53 cm and 93.96 cm, respectively, were found in V<sub>3</sub>I<sub>3</sub>; while the shortest plant heights (51.20 cm) during 2019-20 were recorded in V<sub>2</sub>I<sub>0</sub>. The same was recorded as 50.67 cm in V<sub>1</sub>I<sub>0</sub> during 2020-21 at 60 DAP (Table 2). The result was supported by the findings of Deblonde and Ladent (2001) where they stated that potato stem height was sensitive to drought and the effect was stronger on later cultivars especially when water shortage started early. Schittenhelma *et al.* (2006) also reported to have decreased plant height in water deficit condition.

### Number of stems/hills

The interaction effect of variety and irrigation was non-significant on stem per hill at 60 DAP (Table 2). Similar results were reported by Lahlou *et al.* (2003) who stated that drought stress reduced the total stem number by 28%.

### Foliage coverage

The effect of interaction between varieties and irrigations on foliage coverage percentage was significant (Table 2). The maximum foliage coverage, 93.33% in 2019-20, was recorded from V<sub>3</sub>I<sub>3</sub> and 96.0% in 2020-21 from V<sub>3</sub>I<sub>2</sub> while the minimum foliage coverage, 61.67% in 2019-2020 and 63.33% in 2020-21 were found from V<sub>5</sub>I<sub>0</sub> at 60 DAP (Table 2). This result is in agreement with the findings of Schittenhelma *et al.* (2006) who found the decrease in ground coverage (i.e., foliage cover) with water deficit.

### Plant vigor

Interaction effect of variety and irrigation on plant vigor at 45 DAP during 2019-20 and 2020-21 was non-significant (Table 2). The highest plant vigor (10.00) in 2019-20 was recorded both from V<sub>3</sub>I<sub>2</sub> and V<sub>3</sub>I<sub>3</sub> and also, 10.00 in 2020-21 from V<sub>3</sub>I<sub>2</sub>. The lowest plant vigor of 6.67 in 2019-2020 was frond from V<sub>1</sub>I<sub>0</sub>, V<sub>2</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> and that of 6.33 in 2020-21 was found from V<sub>2</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> (Table 2). In 'no irrigation condition' the best performances in both the years in terms of plant vigor were found 8.67 and 8.83 from V<sub>3</sub>I<sub>0</sub> treatment (Table 3). Schittenhelma *et al.* (2006) also found similar effects from no irrigation treatments on plant vigor.

**Table 2. Interaction effect of varieties and irrigations on plant height, number of stems/hill, foliage coverage and plant vigor of potato**

Variety x Irrigation	Plant height (cm)		Number of stems/hill		Foliage coverage (%)		Plant vigor	
	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>
V <sub>1</sub> I <sub>0</sub>	51.68	50.67	5.50	5.00	71.67	69.17	6.67	6.67
V <sub>1</sub> I <sub>1</sub>	71.60	73.67	6.13	5.33	85.00	80.00	7.50	7.67
V <sub>1</sub> I <sub>2</sub>	77.07	79.11	6.57	5.97	88.33	85.00	7.67	8.33
V <sub>1</sub> I <sub>3</sub>	77.98	78.12	7.47	6.07	91.75	90.00	8.95	8.33
V <sub>2</sub> I <sub>0</sub>	51.20	53.33	5.63	5.03	71.67	65.00	6.67	6.33
V <sub>2</sub> I <sub>1</sub>	63.59	58.33	6.20	5.67	80.00	75.33	7.67	6.67
V <sub>2</sub> I <sub>2</sub>	69.33	69.00	7.00	6.00	83.67	84.00	8.00	8.33
V <sub>2</sub> I <sub>3</sub>	71.42	70.63	7.27	6.30	89.62	90.33	8.75	8.67
V <sub>3</sub> I <sub>0</sub>	64.33	72.17	6.07	6.00	73.33	74.00	8.67	8.83
V <sub>3</sub> I <sub>1</sub>	69.00	75.84	6.23	6.57	85.00	85.67	9.00	9.00
V <sub>3</sub> I <sub>2</sub>	85.06	89.30	6.67	7.67	90.00	96.00	10.00	10.00
V <sub>3</sub> I <sub>3</sub>	90.53	93.96	7.17	7.67	93.33	95.67	10.00	9.67
V <sub>4</sub> I <sub>0</sub>	54.15	57.33	4.97	5.33	66.67	65.00	6.67	6.33
V <sub>4</sub> I <sub>1</sub>	65.00	67.33	5.40	5.40	75.00	72.00	7.33	7.33
V <sub>4</sub> I <sub>2</sub>	72.87	72.33	5.67	5.83	83.33	80.00	8.33	8.00
V <sub>4</sub> I <sub>3</sub>	77.00	80.67	6.33	6.00	90.00	83.33	9.00	8.00
V <sub>5</sub> I <sub>0</sub>	56.07	59.00	4.40	4.70	61.67	63.33	7.00	6.43
V <sub>5</sub> I <sub>1</sub>	61.57	61.33	4.53	4.80	76.67	75.00	7.67	7.17
V <sub>5</sub> I <sub>2</sub>	68.73	73.00	5.13	5.17	86.67	88.33	8.67	8.07
V <sub>5</sub> I <sub>3</sub>	70.42	76.33	5.73	5.30	90.00	90.33	9.00	8.33
LS	*	*	NS	NS	*	*	NS	NS
CV (%)	6.22	6.93	4.42	6.01	4.45	4.16	5.17	4.59

Means bearing same letter (s) do not differ significantly by LSD

\*= Significant at 5% level of probability, NS= Non-significant, LS= Level of significance V<sub>1</sub>= BARI Alu-25, V<sub>2</sub>=BARI Alu-28 and V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37, V<sub>5</sub>=BARI Alu-40; I<sub>1</sub>= one irrigation at 30 DAP, I<sub>2</sub>=two irrigations at 30 & 45 DAP, I<sub>3</sub>=three irrigation 30, 45 & 60 DAP (Control); Y<sub>1</sub> = 2019-20, Y<sub>2</sub> = 2020-21

#### **Tuber grade (% by number) at 95 DAP**

The harvested potato tubers were separated into four grades, viz. <28 mm, 28-40 mm, 40-55 mm and >55 mm. In 2019-2020, the interaction effects of varieties and irrigations on tuber grades <28 mm, 28-40 mm and 40-55 mm showed that they

did not vary insignificantly among treatment combinations. But significant variations were found on tuber grade >55 mm (Table 3). In 2020-21, tuber grades, <28 mm, 28-40 mm and >55 mm varied significantly but the variation was found insignificant for tuber grade 40-55 mm (Table 3).

In case of small size tubers (<28 mm), the maximum tubers of 41.19% and 36.68% in 2019-20 were produced by the treatment combinations V<sub>4</sub>I<sub>0</sub> and V<sub>2</sub>I<sub>0</sub>, respectively, whereas the minimum values for small size tubers were found as 7.05% and 13.11% from the treatment combinations V<sub>3</sub>I<sub>2</sub> and V<sub>1</sub>I<sub>3</sub> in 2019-20 and 2020-21, respectively. In case of severe water shortage condition (no irrigation), the treatment combination V<sub>1</sub>I<sub>0</sub> produced the lowest percentages of 13.85% and 23.38% of small tubers in 2019-20 and 2020-21, respectively (Table 3). The maximum percentages (44.72% and 43.95%) of tubers under grade, 28-40 mm, were found from the treatment combinations V<sub>4</sub>I<sub>2</sub> and V<sub>3</sub>I<sub>2</sub> in 2019-20 and 2020-21, respectively, whereas the lowest percentages 19.43% and 30.58% tubers for 28-40 mm grade were found from the treatment combinations V<sub>2</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> in 2019-20 and 2020-21, respectively (Table 3). In case of the least water receiving combination (no irrigation) treatment combinations, V<sub>1</sub>I<sub>0</sub> and V<sub>5</sub>I<sub>0</sub> performed well producing the highest percentages of 35.81% and 43.69% under the tuber grade, 28-40 mm, in 2019-20 and 2020-21, respectively (Table 4). Treatment combinations V<sub>2</sub>I<sub>3</sub> and V<sub>1</sub>I<sub>3</sub> produced the maximum of 47.14% and 36.24% tubers under grade 40-55 mm, whereas the lowest percentages (23.04% and 22.17%) of tubers for 40-55 mm grade were found from the same treatment combination V<sub>5</sub>I<sub>0</sub> in 2019-20 and 2020-21, respectively (Table 3). Under no irrigation, treatment combinations, V<sub>3</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> performed well producing the highest percentages (36.53% and 30.25%) of tubers under grade 40-55 mm in 2019-20 and 2020-21, respectively (Table 3).

The maximum of 18.95% and 15.80% of large sized tubers (>55mm), were produced by the treatment combinations V<sub>1</sub>I<sub>3</sub> and V<sub>5</sub>I<sub>0</sub>, whereas the minimum of 4.56 and 5.55 were obtained from the treatment combinations V<sub>3</sub>I<sub>2</sub> and V<sub>5</sub>I<sub>0</sub> in 2019-20 and 2020-21, respectively (Table 3).

Under zero irrigation condition, V<sub>1</sub>I<sub>0</sub> performed well yielding 44.11% and 43.69% of tubers to produce seed sized tubers (28-40 mm) in 2019-20 and 2020-21, respectively, whereas V<sub>2</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> showed very poor performance in producing only 19.43% and 30.58% seed sized tubers (Table 3). Similar results were reported by Deblonde and Ladent (2001).

#### **Tuber grade (% by weight) at 95 DAP**

In 2019-20, the interaction effects of variety and irrigation on the tuber grades, 28-40mm and >55m varied significantly but the effect was insignificant for tuber grades, <28mm and 40-55mm, whereas all the tuber grades (<28mm, 28-40mm,

40-55mm and >55mm) varied significantly in 2020-21 (Table 4). For small sized tubers (<28mm), the maximum of 8.53% and 7.82% tubers were produced by treatment combinations V<sub>4</sub>I<sub>0</sub> in 2019-20 and V<sub>5</sub>I<sub>0</sub> in 2020-21, respectively. The minimum of 0.98% and 1.21% tubers were produced for the same grade potato tubers respectively, in 2019-20 and 2020-21 from the same treatment combination V<sub>3</sub>I<sub>3</sub>. Treatment combination V<sub>4</sub>I<sub>0</sub> performed well producing 2.87% and 3.26% small tubers (<28mm) in 2019-20 and 2020-21, respectively under no irrigation condition (Table 4). The maximum percentages of tubers, 27.50% and 27.94%, under grade 28-40 mm were obtained from treatment combinations V<sub>4</sub>I<sub>3</sub> and V<sub>1</sub>I<sub>0</sub> in 2019-20 and 2020-21, respectively. On the other hand, the lowest, 10.43% and 18.07% tubers for 28-40 mm grade were found from the treatment combinations V<sub>2</sub>I<sub>1</sub> and V<sub>3</sub>I<sub>3</sub> in 2019-20 and 2020-21, respectively (Table 4). Under no irrigation condition (least water receiving combination), the treatment combinations, V<sub>1</sub>I<sub>0</sub> and V<sub>5</sub>I<sub>0</sub> performed well producing the highest 27.94% and 21.90% tubers under grade 28-40mm in 2020-21 and 2019-20, respectively, as revealed from the same table. Treatment combinations V<sub>3</sub>I<sub>2</sub> and V<sub>4</sub>I<sub>1</sub> produced the maximum (60.68% and 51.06%) tubers for the grade 40-55 mm, whereas the lowest (41.85% and 34.69%) tuber percentages were found from the treatment combinations, V<sub>4</sub>I<sub>2</sub> and V<sub>4</sub>I<sub>3</sub> in 2019-20 and 2020-21, respectively for this grade. Under zero irrigation condition, the treatment combinations V<sub>3</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub> performed well producing the highest percentages (58.28% and 50.74%) of tubers under grade 40-55mm in 2019-20 and 2020-21, respectively (Table 4). The treatment combinations V<sub>1</sub>I<sub>3</sub> and V<sub>3</sub>I<sub>3</sub> produced the highest percentages (40.51% and 40.82%) of large sized tubers under the grade, >55mm, in 2019-20 and 2020-21, respectively, whereas the lowest percentages (21.72% and 21.23%) were obtained from the combinations V<sub>4</sub>I<sub>1</sub> and V<sub>4</sub>I<sub>2</sub> in 2019-20 and 2020-21, respectively for this grade. In case of severe water stress (no irrigation), the highest (31.12% and 28.26%) tubers under grade >55mm were produced by V<sub>1</sub>I<sub>0</sub> and V<sub>5</sub>I<sub>0</sub> in 2019-20 and 2020-21, respectively (Table 4). From the above results it was found that water stress during tuber formation stage reduced the tuber size. Larger sized tuber formation was favored by well-watered condition. Similar findings were reported by Mackerel and Jefferies (1998), Struik and Voorst (1986) and Onder *et al.* (2005).

#### **Number of tubers per hill**

In both 2019-2020 and 2020-21, non-significant variation was found on number of tubers per hill at 95 DAP from the interaction effects of variety and irrigation (Table 5). In least water receiving combination, the highest (10.97 in 2019-2020 and 10.38 in 2020-21) number of tubers were produced by the treatment combination, V<sub>3</sub>I<sub>0</sub>, whereas the lowest (8.07 in 2019-2020 and 8.49 in 2020-21) number of tubers were produced by the treatment combination, V<sub>5</sub>I<sub>0</sub>. Eiasu *et al.* (2007) also found similar findings. They found that fewer stolons per stem

reflected lower number of tubers and yields. Schittenhelma *et al.* (2006) also found that water deficit decreased tuber number.

### Fresh weight of tubers per hill

The effect of interaction between varieties and irrigations on fresh weight of tubers/hill was significant (Table 5). The maximum fresh weight of tuber per hill in severe water stressed conditions were found 541 gm in 2019-20 and 541 gm in 2020-21 recorded from V<sub>3</sub>I<sub>0</sub> while the minimum fresh weights of tubers/hill (299 gm in 2019-2020 and 304 gm in 2020-21) were found from V<sub>5</sub>I<sub>0</sub> at 95 DAP.

**Table 3. Interaction effect of varieties and irrigations of potato on tuber grade**

Variety x Irrigation	(% by number)							
	<28 mm		28-40 mm		40-55 mm		>55 mm	
	Y <sub>1</sub>	Y <sub>2</sub>						
V <sub>1</sub> I <sub>0</sub>	13.85	23.38	44.11	43.69	31.85	26.06	10.20	6.87
V <sub>1</sub> I <sub>1</sub>	28.04	19.31	20.44	41.14	41.51	30.51	10.01	9.05
V <sub>1</sub> I <sub>2</sub>	19.98	16.98	28.33	35.50	36.37	34.47	15.32	13.06
V <sub>1</sub> I <sub>3</sub>	23.35	13.11	20.38	35.89	37.32	36.24	18.95	14.76
V <sub>2</sub> I <sub>0</sub>	38.97	27.63	19.43	37.56	35.57	28.98	6.03	5.84
V <sub>2</sub> I <sub>1</sub>	31.66	21.95	20.57	38.31	40.11	31.96	7.65	7.78
V <sub>2</sub> I <sub>2</sub>	27.18	18.44	24.34	40.41	38.64	32.41	9.84	8.73
V <sub>2</sub> I <sub>3</sub>	20.54	15.15	21.07	38.65	47.14	30.90	11.26	15.30
V <sub>3</sub> I <sub>0</sub>	26.58	26.47	31.07	39.87	36.53	27.72	5.82	5.93
V <sub>3</sub> I <sub>1</sub>	22.04	20.95	32.73	40.99	38.22	30.24	7.01	7.82
V <sub>3</sub> I <sub>2</sub>	7.05	15.62	41.51	43.95	46.87	31.12	4.56	9.30
V <sub>3</sub> I <sub>3</sub>	9.25	14.84	39.93	40.83	40.44	30.12	10.39	14.20
V <sub>4</sub> I <sub>0</sub>	41.19	33.34	24.19	30.58	28.54	30.25	6.08	5.83
V <sub>4</sub> I <sub>1</sub>	25.74	24.85	34.03	33.02	31.23	33.01	9.00	9.13
V <sub>4</sub> I <sub>2</sub>	22.36	19.05	44.72	43.60	25.38	28.75	7.54	8.60
V <sub>4</sub> I <sub>3</sub>	16.95	16.57	42.85	42.27	30.53	29.97	9.68	11.20
V <sub>5</sub> I <sub>0</sub>	36.18	36.68	35.81	35.60	23.04	22.17	5.02	5.55
V <sub>5</sub> I <sub>1</sub>	27.03	26.18	23.03	35.99	39.68	28.19	10.26	9.64
V <sub>5</sub> I <sub>2</sub>	17.67	17.97	29.02	37.41	40.82	32.54	12.48	12.07
V <sub>5</sub> I <sub>3</sub>	12.41	13.76	33.56	38.81	39.43	31.64	14.60	15.80
LS	NS	*	NS	**	NS	NS	**	**
CV (%)	11.73	12.75	10.85	8.05	6.58	10.45	14.90	11.15

Means bearing same letter (s) do not differ significantly by LSD

\*= Significant at 5% level of probability, \*\*=Significant at 1% level of probability, NS= Non-significant, LS= Level of significance V<sub>1</sub>= BARI Alu-25, V<sub>2</sub>=BARI Alu-28 and V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37, V<sub>5</sub>=BARI Alu-40; I<sub>1</sub>= one irrigation at 30 DAP, I<sub>2</sub>=two irrigations at 30 & 45 DAP, I<sub>3</sub>=three irrigation 30, 45 & 60 DAP (Control); Y<sub>1</sub> = 2019-20, Y<sub>2</sub> = 2020-21

**Table 4. Interaction effect of varieties and irrigations of potato on tuber grade**

Variety x Irrigation	(% by weight)							
	<28mm		28-40mm		40-55mm		>55mm	
	Y <sub>1</sub>	Y <sub>2</sub>						
V <sub>1</sub> I <sub>0</sub>	6.72	3.94	11.42e-h	27.94	50.74	43.01	31.12cd	25.12ij
V <sub>1</sub> I <sub>1</sub>	5.64	2.89	11.51e-h	27.77	52.36	40.51	30.49cd	28.83f-i
V <sub>1</sub> I <sub>2</sub>	3.83	2.17	12.72e-h	21.36	44.58	40.26	38.87a	36.20bcd
V <sub>1</sub> I <sub>3</sub>	2.24	1.57	11.46e-h	20.56	45.79	37.23	40.51a	40.63ab
V <sub>2</sub> I <sub>0</sub>	7.22	5.08	10.63fgh	23.33	54.97	46.68	27.18c-g	24.90ij
V <sub>2</sub> I <sub>1</sub>	5.63	3.97	10.43gh	21.46	58.00	47.55	25.94d-h	27.02g-j
V <sub>2</sub> I <sub>2</sub>	4.30	2.80	11.01fgh	20.29	56.70	46.04	27.99c-f	30.87e-h
V <sub>2</sub> I <sub>3</sub>	2.61	2.01	13.16e-h	21.30	59.95	38.47	24.28f-i	38.23abc
V <sub>3</sub> I <sub>0</sub>	2.87	3.26	12.43e-h	22.46	58.28	47.82	26.41d-h	26.46g-j
V <sub>3</sub> I <sub>1</sub>	2.04	2.28	13.47e-h	23.58	57.74	46.12	26.76c-h	28.02f-i
V <sub>3</sub> I <sub>2</sub>	1.36	1.76	13.12e-h	19.25	60.68	41.57	24.84e-i	37.42abc
V <sub>3</sub> I <sub>3</sub>	0.98	1.21	14.94d-g	18.07	56.67	39.90	27.40c-g	40.82ab
V <sub>4</sub> I <sub>0</sub>	8.53	4.60	16.12de	23.07	51.71	50.74	23.63f-i	21.59j
V <sub>4</sub> I <sub>1</sub>	5.06	3.05	23.80abc	21.97	49.41	51.06	21.72hi	23.92ij
V <sub>4</sub> I <sub>2</sub>	3.81	2.56	26.30ab	25.34	41.85	40.87	28.05c-f	21.23d-g
V <sub>4</sub> I <sub>3</sub>	2.63	1.79	27.50a	26.03	41.86	34.69	28.02c-f	37.50abc
V <sub>5</sub> I <sub>0</sub>	6.66	7.82	21.90bc	22.83	46.30	41.10	25.13e-i	28.26f-i
V <sub>5</sub> I <sub>1</sub>	4.39	4.81	13.10e-h	23.49	52.52	35.68	29.98cde	36.02b-e
V <sub>5</sub> I <sub>2</sub>	2.62	2.82	16.36de	22.66	49.23	41.17	31.79bc	33.35c-f
V <sub>5</sub> I <sub>3</sub>	1.47	1.86	19.49cd	23.51	47.95	37.07	31.09cd	37.57abc
LS	NS	**	**	**	NS	**	**	*
CV (%)	11.66	12.13	14.63	9.06	5.18	6.02	10.45	9.07

Means bearing same letter (s) do not differ significantly by LSD

\*= Significant at 5% level of probability, \*\*=Significant at 1% level of probability, NS= Non-significant, LS= Level of significance V<sub>1</sub>= BARI Alu-25, V<sub>2</sub>=BARI Alu-28 and V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37, V<sub>5</sub>=BARI Alu-40; I<sub>1</sub>= one irrigation at 30 DAP, I<sub>2</sub>=two irrigations at 30 & 45 DAP, I<sub>3</sub>=three irrigation 30, 45 & 60 DAP (Control); Y<sub>1</sub> = 2019-20, Y<sub>2</sub> = 2020-21

### Mean tuber weight

The effect of interaction between varieties and irrigations on mean individual tuber weight was non-significant in 2019-2020 but significant in 2020-21 (Table 5). The maximum mean tuber weight in severe water stressed conditions were 49 gm in

2019-2020 and also 49 gm in 2020-21) recorded from V<sub>3</sub>I<sub>0</sub> while the minimum mean tuber weights of 37 gm in 2019-2020 from V<sub>5</sub>I<sub>0</sub> and 35 gm in 2020-21 from V<sub>4</sub>I<sub>0</sub> were recorded at 95 DAPS. From the same treatment combination, V<sub>4</sub>I<sub>3</sub>, the individual tuber weights in 2019-2020 and 2020-2021 were found 61 gm and 59 gm, respectively.

### **Fresh tuber yield**

In 2019-2020, the fresh tuber yield (t/ha) at 95 DAP due to the interaction effect of variety and irrigation was found non-significant but significant variations were recorded in 2020-21 (Table 5). In severe water stressed condition, the treatment combination, V<sub>3</sub>I<sub>0</sub> produced the highest fresh tuber yields of 25.54 t/ha in 2019-2020 and 28.92 t/ha in 2020-21. The lowest values of the same parameter were, 12.99 t/ha in 2019-2020 and 16.50 t/ha in 2020-21 produced by the treatment combination, V<sub>5</sub>I<sub>0</sub>. The results are in agreement with the findings of Lahlou *et al.* (2003). They reported that the yields were frequently constrained by drought in most environments. The drought stress affected the development and growth of shoots, roots and tubers. Water stress before tuber initiation reduced tuber set for certain varieties which was reported by van Loon (1981). Cavagnaro *et al.* (1971) also reported that drought stress at the beginning of the tuberization stage induced a longer period of tuber formation but decreased tuber number, growth and yield.

### **Tuber dry matter**

In 2019-2020, due to interaction effect of variety and irrigation, the tuber dry matter percentage at 95 DAP was found significant but in 2020-21, it was non-significant variation (Table 5). In severe water stressed condition, the tuber dry matter (%) was found the highest (23.66% in 2019-2020) as recorded from V<sub>2</sub>I<sub>0</sub> and in 2020-2021, it was recorded as 23.46% produced by the treatment combination, V<sub>1</sub>I<sub>0</sub>. The lowest tuber dry matter percentages in 2019-2020 was 19.86.86% and in 2020-21 was 20.09% obtained from the same treatment combination, V<sub>3</sub>I<sub>0</sub>. From the findings it was clear that gradual increase in dry matter was observed in all the genotypes with the shortage of irrigation water. Deficit water caused lowering the rate of photosynthesis and reduced other physiological activities. The main reason of dry matter increase was the shortage of water. Under stressed condition, the plant might have used the water from the tuber. These findings are in agreement with Levy (1983) who reported that tubers from water stressed plants had higher contents of total sugars and dry matter than well-watered plants. Steckel and Gray (1979) found similar findings that the dry matter content of potato tubers grown under low soil moisture was much higher than in tubers from well-watered plants

**Table 5. Interaction effect of varieties and irrigations on number of tubers per plant, weight of tuber, individual tuber weight, fresh tuber yield and dry matter of potato at 95 DAP**

Variety x Irrigation	No. of tubers/ hill		Fresh weight of tuber per hill (g)		Individual tuber weight (g)		Fresh tuber yield (t/ha)		Dry matter (%)	
	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>1</sub>	Y <sub>2</sub>
V <sub>1</sub> I <sub>0</sub>	9.59	8.78	363	314	38	36	17.16	17.55	23.40	23.46
V <sub>1</sub> I <sub>1</sub>	10.08	9.75	444	411	44	42	22.03	23.64	22.15	22.26
V <sub>1</sub> I <sub>2</sub>	11.11	10.20	542	496	49	49	28.03	29.32	21.01	21.50
V <sub>1</sub> I <sub>3</sub>	11.83	11.05	617	583	53	53	33.74	35.56	20.29	20.04
V <sub>2</sub> I <sub>0</sub>	8.90	8.70	392	333	44	38	16.07	18.28	23.66	22.74
V <sub>2</sub> I <sub>1</sub>	10.09	9.26	498	441	49	48	23.29	25.29	22.29	21.70
V <sub>2</sub> I <sub>2</sub>	10.52	9.89	528	507	50	52	26.44	30.82	21.16	19.94
V <sub>2</sub> I <sub>3</sub>	11.40	10.82	598	571	52	53	32.28	35.74	20.47	19.19
V <sub>3</sub> I <sub>0</sub>	10.97	10.38	541	510	49	49	25.54	28.92	19.86	20.09
V <sub>3</sub> I <sub>1</sub>	12.00	11.11	620	565	52	51	31.38	33.11	18.77	19.10
V <sub>3</sub> I <sub>2</sub>	13.10	12.07	708	628	54	52	37.17	38.21	17.84	17.88
V <sub>3</sub> I <sub>3</sub>	14.13	12.98	816	721	58	55	44.57	45.26	17.41	16.98
V <sub>4</sub> I <sub>0</sub>	8.68	9.20	357	320	41	35	15.02	17.42	19.92	20.43
V <sub>4</sub> I <sub>1</sub>	10.11	9.22	506	407	50	44	22.75	23.37	18.54	19.41
V <sub>4</sub> I <sub>2</sub>	11.33	11.36	595	571	52	50	30.38	33.78	17.74	18.32
V <sub>4</sub> I <sub>3</sub>	12.32	12.19	748	721	61	59	40.88	44.86	17.38	17.15
V <sub>5</sub> I <sub>0</sub>	8.07	8.49	299	304	37	36	12.99	16.50	20.54	20.78
V <sub>5</sub> I <sub>1</sub>	10.60	8.78	445	431	42	49	19.88	24.48	19.37	19.08
V <sub>5</sub> I <sub>2</sub>	12.25	9.99	575	532	47	53	28.96	31.54	18.75	18.07
V <sub>5</sub> I <sub>3</sub>	14.46	11.01	775	639	54	58	44.17	40.43	18.25	16.99
LS	NS	NS	**	NS	NS	*	**	*	*	NS
CV (%)	5.70	6.82	5.67	11.58	6.79	8.29	4.96	9.24	2.12	1.95

Means bearing same letter (s) do not differ significantly by LSD

\*= Significant at 5% level of probability, \*\*=Significant at 1% level of probability, NS= Non-significant, LS= Level of significance V<sub>1</sub>= BARI Alu-25, V<sub>2</sub>=BARI Alu-28 and V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37, V<sub>5</sub>=BARI Alu-40; I<sub>1</sub>= one irrigation at 30 DAP, I<sub>2</sub>=two irrigations at 30 & 45 DAP, I<sub>3</sub>=three irrigation 30, 45 & 60 DAP (Control); Y<sub>1</sub> = 2019-20, Y<sub>2</sub> = 2020-21

#### Varieties and no irrigation interactions on yield reduction (%)

Under no irrigation condition, the highest yield reductions of 70.59% in 2019-20 and 61.17% in 2020-21 at final harvest (95 DAP) were found from the treatment combination V<sub>5</sub>I<sub>0</sub> and V<sub>4</sub>I<sub>0</sub>, respectively. The combination V<sub>3</sub>I<sub>0</sub> showed the best performance producing 42.70% yield reduction in 2019-20 and 36.10% in 2020-21 at final harvest followed by treatment combinations V<sub>1</sub>I<sub>0</sub> (49.14%) and V<sub>2</sub>I<sub>0</sub> (48.85%) in 2019-20 and 2020-21, respectively (Table 6). The results are in agreement with the findings of Costa *et al.* (1997) and Stark and McCann (1992),

where Costa *et al.* (1997) found that withholding water during tuberization severely penalized tuber yield. Stark and McCann (1992) observed the highest tuber yield reduction from water deficit during the mid-bulking period. Baghani (2009) investigated the effect of deficit irrigation on potato and concluded that under deficit irrigation conditions tuber yield of all potato cultivars studied reduced yields significantly compared to that of normal irrigation condition.

**Table 6. Interaction effects of variety and no irrigation on tuber fresh yield reduction (%)**

Variety x Irrigation	Tuber fresh yield (t/ha) reduction (%) at 95 DAP	
	2019-20	2020-21
V <sub>1</sub> I <sub>0</sub>	49.14	56.27
V <sub>2</sub> I <sub>0</sub>	50.22	48.85
V <sub>3</sub> I <sub>0</sub>	42.70	36.10
V <sub>4</sub> I <sub>0</sub>	63.26	61.17
V <sub>5</sub> I <sub>0</sub>	70.59	59.19
Mean	55.18	52.32

V<sub>1</sub>= BARI Alu-25, V<sub>2</sub>=BARI Alu-28 and V<sub>3</sub>=BARI Alu-36, V<sub>4</sub>=BARI Alu-37, V<sub>5</sub>=BARI Alu-40. I<sub>1</sub>= one irrigation at 30 DAP, I<sub>2</sub>=two irrigations at 30 & 45 DAP, I<sub>3</sub>=three irrigation 30, 45 & 60 DAP (Control).

### Pests and disease reaction

In case of no irrigation, some whitefly and aphids infestation were observed but not destructive. Regular spraying of insecticides minimized the damage due to whitefly and aphids infestation. This might cause as potato plants are water stressed, they produce fewer defensive compounds. Nutrients might be more concentrated in water deficient potato plants, providing a substantial food source for these pests. Some late blight disease symptoms caused by *Phytophthora infestans* were observed in case least water receiving combination which was under control with regular fungicide spraying. This fungal attack might be occurred due to fungal diseases that usually live on dead wood can invade living tissues when potato plants are moisture stressed. There were also some common scab infections occurred in case least water receiving combination. These might be caused because of water stressed soil condition was more favorable for potato common scab infection than well watered condition. Moreover, drought stress and pathogen infection simultaneously occur in the field.

### Conclusion

The experimental results revealed that potato varieties differed significantly in their response to different levels of irrigation. In general, some varieties were considerably more tolerant to water stress treatments than others. Plant growth, dry matter and tuber yield were all reduced by water stress, and the reduction was much greater at

the highest water stress level (no irrigation) of soil moisture content. BARI Alu-25, BARI Alu-28 and BARI Alu-36 varieties can be the good candidates for inclusion in breeding programs as they showed water stress tolerance.

### Acknowledgement

The authors would like to acknowledge Bangladesh Agricultural Research Institute (BARI) for providing fund for accomplishment of the research work.

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## **EFFECT OF CLIMATE CHANGE ON TEA PRODUCTION IN BANGLADESH: ECONOMIC IMPLICATIONS FOR DOMESTIC CONSUMPTION, EXPORT EARNINGS AND TRADE DEFICIT**

SUDIP DEY<sup>1</sup>

### **Abstract**

This paper explores climate change's effects on Bangladesh's tea production, focusing on the economic consequences for domestic consumption, export earnings, and trade deficits. This study utilizes annual time series data from 1971 to 2022 to analyze the influence of climate variables on tea production. The findings indicate that while both maximum and minimum humidity negatively affect tea production, only maximum humidity has a significant impact, suggesting optimal production at moderate humidity levels. Rainfall plays a crucial role by enhancing root growth, soil moisture, nutrient supply, and pest prevention, significantly boosting tea production. Temperature effects are mixed; minimum temperature supports production, whereas maximum temperature has harmful effects, such as heatwaves, pest outbreaks, and reduced photosynthesis. Additionally, carbon dioxide (CO<sub>2</sub>) emissions enhance both tea production and leaf quality by improving photosynthesis and respiration. From 2002 to 2021, domestic tea consumption surged significantly due to population growth, rising incomes, urbanization, changing preferences, and perceived health benefits. Conversely, export earnings declined significantly, driven by high domestic consumption, falling global prices, limited tea varieties, and increased international competition. The study identifies a persistent trade deficit over the past 12 years, linked to high production costs, low productivity, poor quality, and insufficient innovation. To mitigate these challenges, the study recommends strategies including import tariffs, export incentives, infrastructure improvements, higher labor wages, the creation of new tea varieties, improving quality, adopting modern technologies, and fiscal and monetary policy adjustments to boost export earnings and achieve trade balance.

**Keywords:** Climate change; Tea production; Domestic consumption; Export earnings; Trade deficit.

### **Introduction**

Tea is the most extensively consumed beverage in the world, behind water, and in Bangladeshi culture, it's a popular drink for entertaining guests. The quantity and

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quality of tea are primarily influenced by climate factors, including temperature, precipitation, humidity, greenhouse gases, etc. Bangladesh depends greatly on tea production to meet its domestic consumption demands, generate substantial export revenue, and maintain its trade balance. Climate change has become the biggest threat to the tea industry. Most tea-exporting countries have decided to tackle this challenge with profound attention. Under the current climate conditions, both the quantity and quality of tea are being adversely affected (Biswas, 2018). At one time, tea was Bangladesh's second-most important export commodity, coming after jute. Bangladesh ranks 8<sup>th</sup> in production area, 10<sup>th</sup> in production volume, and 12<sup>th</sup> in tea exports (ITC, 2015). The tea farming sector is recognized for enhancing living standards, generating employment opportunities, ensuring food security, and alleviating poverty in rural areas of producing regions. In Bangladesh, a significant portion of the population relies heavily on the tea industry. Currently, Bangladesh has 167 commercial tea production estates and gardens covering 279,507.88 acres, employing approximately 150,000 workers. Additionally, Bangladesh produces 3 percent of the world's tea. In 2021, the market size of tea industry in Bangladesh was around taka 3,500 crore. It is the country's second-largest cash crop after jute, contributing roughly 1 percent to Bangladesh's gross domestic product (GDP) (Hossain, 2022).

Numerous studies have examined how tea output responds to climate change. Raza (2019) explored the prospects of the tea industry in Bangladesh, while Nasir and Shamsuddoha (2012) focused on tea production, consumption, and exports from both global and Bangladeshi viewpoints. Arefin and Hossain (2022) provided insights into the current status and future potential of tea production in Bangladesh. Han et al. (2018) analyzed how climate change impacts tea cultivation in China. Islam et al. (2021) examined the climate and environmental challenges affecting tea cultivation in the Sylhet region of Bangladesh. Rahman (2022) discussed how rainfall influences tea production and its socio-economic implications in Bangladesh. While numerous studies have explored climate change and tea production, none, to our knowledge, have thoroughly examined the economic implications related to domestic consumption, foreign export earnings, and trade deficits from a Bangladeshi perspective. Additionally, our research stands out by including both minimum and maximum humidity in the model and employing advanced econometric and statistical methods, setting it apart from previous studies.

This study utilizes statistical and econometric approaches to assess climate-related effects on tea production in Bangladesh, as well as economic data on tea consumption, export earnings, and trade surplus. This analysis provides valuable information to stakeholder policymakers, allowing them to build reactive policies against climate change impacts that will keep tea as a vital economic sector in Bangladesh. This study provides knowledge that is essential for Bangladesh's financial growth because agriculture remains the backbone of the country's economic structure. In order to come up with adaptation strategies, people need to

know a lot about how changes in climate affect growing tea, as well as how domestic tea consumption, export volumes, and trade imbalances affect the economy. These measures are vital for protecting the livelihoods of individuals reliant on tea cultivation and the nation's economic stability.

## Materials and Methods

### Data Collection

This study utilizes annual time series data from 1971 to 2022, gathered from various secondary sources. The average precipitation (in millimeters) and temperature (in degrees Celsius), including both minimum and maximum values, are sourced from the Climate Change Knowledge Portal (2021). Data on carbon dioxide (CO<sub>2</sub>) emissions (in million tons) is obtained from the CO<sub>2</sub> country profile for Bangladesh by Hannah Ritchie and Max Roser (Ritchie et al., 2020). Humidity data (both minimum and maximum in percentages) is retrieved from the Climate Information Management System (2024). Data on domestic tea consumption (in million kilograms), production (in million kilograms), export (in million kilograms and million US dollars), and import (in million kilograms) is collected from the Bangladesh Tea Board (2024).

### Model Specification

The analysis examines six climate change variables in Bangladesh, including both minimum and maximum humidity and average precipitation levels alongside minimum and maximum temperatures and carbon dioxide emissions. The log-log model analysis requires the application of logarithms to existing variables for both dependent and independent measurements. Logarithmic transformation enhances regression analysis by addressing nonlinearity while controlling heteroscedasticity and simplifying data relationships and data handling as well as stabilizing data variations to enable more interpretable results and percentage change analysis in diverse fields. The study considers the following model:

$$\text{LNTEA}_t = \alpha_0 + \alpha_1 \text{LNHUMDYMIN}_t + \alpha_2 \text{LNHUMDYMAX}_t + \alpha_3 \text{LNPCIPT}_t + \alpha_4 \text{LNTEMPRMIN}_t + \alpha_5 \text{LNTEMPRMAX}_t + \alpha_6 \text{LNCARBDO} + U_t \dots \dots \dots (i)$$

Where, LNTEA = Log of tea production, LNHUMDYMIN = Log of minimum humidity, LNHUMDYMAX = Log of maximum humidity, LNPCIPT = Log of average precipitation, LNTEMPRMIN = Log of minimum temperature, LNTEMPRMAX = Log of maximum temperature, and LNCARBDO = Log of carbon dioxide (CO<sub>2</sub>) emissions.

### Econometric and Statistical Methods

The stationarity of variables was verified through augmented Dickey-Fuller (1979) and Phillips-Perron (1988) tests with Eviews software. The Fully Modified OLS

(FMOLS) model is employed to demonstrate the impact of climate change on tea productivity.

The fully modified ordinary least squares (FMOLS) technique, introduced by Phillips and Hansen (1990), assumes the presence of a single co-integration vector. According to their study, the FMOLS estimator exhibits super consistency and asymptotic deviations. The FMOLS technique provides several key advantages. It is particularly effective in generating reliable parameter estimates, even with small sample sizes. It also tackles intricate issues, including measurement errors, endogeneity, serial correlation, and omitted variable bias. This method also allows for variations in long-term parameters, as highlighted by the studies of Kalim and Shahbaz (2009) and Fereidouni et al. (2017). Before employing FMOLS, the variables must exhibit co-integration at the first difference. In our analysis, all variables were confirmed to be co-integrated.

Using SPSS software, the planned comparison method is employed to assess significant differences in domestic tea consumption and export earnings over the past 20 years (both variables are normally distributed). The years from 2002 to 2021 are divided into four different groups (Group 1: 2002–2006, Group 2: 2007–2011, Group 3: 2012–2016, and Group 4: 2017–2021), each spanning five years. The one-way ANOVA (analysis of variance) is then applied to determine whether there are significant differences in domestic consumption, export earnings, and periods across these four groups. Additionally, the trade deficit (based on export and import volumes) over the last 12 years (2010–2021) is analyzed using graphical representations.

## Results and Discussion

### Descriptive Statistics

Table 1 illustrates the descriptive statistics for the variables from 1971 to 2022, including the mean, median, maximum, and minimum values for each variable.

**Table 1. Descriptive statistics**

	Lntea	Lnhumdy min	Lnhumdy max	Lnpcipt	Lntempr min	Lntempr max	Lncarb do
Mean	3.9020	4.0069	4.5222	7.6962	3.0382	3.4136	3.0567
Median	3.9405	4.0149	4.5214	7.6975	3.0359	3.4136	3.1043
Max	4.5696	4.2246	4.5408	7.9531	3.0763	3.4528	4.6259
Min	2.5217	1.2556	4.4930	7.4260	2.9997	3.3891	1.2556
Obs.	52	52	52	52	52	52	52

*Source:* Eviews software based on annual time series data (1971–2022).

**Table 2. Augmented Dickey-Fuller (ADF) unit root test**

Variables	Level			First Difference		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
LNTEA	0.33	0.00***	0.99	0.00***	0.00***	0.00***
LNHUMDYMIN	0.42	0.00***	0.73	0.00***	0.00***	0.00***
LNHUMDYMAX	0.56	0.45	0.54	0.00***	0.00***	0.00***
LNPCIPT	0.63	0.21	0.64	0.00***	0.00***	0.00***
LNTEMPRMIN	0.94	0.45	0.79	0.00***	0.00***	0.00***
LNTEMPRMAX	0.20	0.00***	0.74	0.00***	0.00***	0.00***
LNCARBDO	0.30	0.67	1.00	0.00***	0.00***	0.00***

Source: Eviews software based on annual time series data (1971-2022). Notes: \*\*\* P<0.01, \*\*P<0.05, \*P<0.10.

**Table 3. Phillips-Perron (PP) unit root test**

Variables	Level			First Difference		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
LNTEA	0.10	0.00***	0.99	0.00***	0.00***	0.00***
LNHUMDYMIN	0.32	0.00***	0.67	0.00***	0.00***	0.00***
LNHUMDYMAX	0.45	0.50	0.45	0.00***	0.00***	0.00***
LNPCIPT	0.72	0.85	0.57	0.00***	0.00***	0.00***
LNTEMPRMIN	0.80	0.90	0.89	0.00***	0.00***	0.00***
LNTEMPRMAX	0.43	0.32	0.81	0.00***	0.00***	0.00***
LNCARBDO	0.12	0.56	1.00	0.00***	0.00***	0.00***

Source: Eviews software based on annual time series data (1971-2022). Notes: \*\*\* P<0.01, \*\*P<0.05, \*P<0.10.

### Unit Root Test

To assess the stationarity of the variables, we applied the augmented Dickey-Fuller (1979) and Phillips-Perron (1988) unit root tests. The results, shown in Tables 2 and 3, indicate that the tests were conducted twice: first on the variables in their original form and then on their first differences. The findings from both tests confirm that all variables are stationary at the first difference, indicating that their order of integration is I (1).

### Co-integration test

Selecting the appropriate lag length is essential before conducting co-integration tests, as it dramatically influences the test results. The optimal lag length is determined using the Akaike (1973) Information Criterion (AIC), which recommends using three lags. Consequently, a co-integration test is performed with a lag length of three. The results of the Johansen (1988) co-integration analysis are presented in Table 4, where both the trace and Max-Eigen statistics indicate the presence of two co-integrating equations at the 1 percent and 5 percent significance levels. This reflects the long-term association between tea production and the explanatory variables.

**Table 4. Results of co-integration test**

No. of CE(S)	Trace statistic value	Prob.	Max-Eigen statistic value	Prob.
None	237.71***	0.00	102.80***	0.00
At most 1	134.91***	0.00	49.71***	0.01
At most 2	85.19	0.08	37.08	0.06
At most 3	48.11	0.50	21.54	0.52
At most 4	26.57	0.70	14.23	0.70
At most 5	12.34	0.79	8.83	0.74
At most 6	3.51	0.81	3.51	0.81

Source: Eviews software based on annual time series data (1971-2022). Notes: \*\*\* P<0.01, \*\*P<0.05.

### Estimated Results of FMOLS and Discussion

The estimated equation is:

$$LNTEA = 30.27 - 0.27LNHUMDYMIN - 2.89LNHUMDYMAX + 0.03LNPCIPT + 5.71LNTEMPRMIN - 9.03LNTEMPRMAX + 0.33LNCARBDO$$

The study applied an advanced regression method, fully modified OLS (FMOLS), to derive its findings. First of all, the results indicate that lower humidity levels (LNHUMDYMIN) are associated with a decrease in domestic tea production (LNTEA), though this relationship is insignificant (Mallik and Ghosh, 2022). The

coefficient for minimum humidity is -0.27, suggesting that a 1 percent rise in minimum humidity corresponds to a 0.27 percent decline in tea production (Table 5). Similarly, maximum humidity (LNHUMDYMAX) negatively affects domestic tea production (LNTEA) in Bangladesh, which is significant at the 10 percent level of significance (Mallik and Ghosh, 2022). A 1 percent increase in maximum humidity leads to a 2.89 percent reduction in tea production. Consequently, both minimum and maximum humidity levels appear to be unfavorable for tea production. Moderate humidity is crucial for tea production. Humidity plays a role in the quality of tea leaves, affecting the aroma and taste. A moderate level of humidity, between 60 percent and 70 percent, is considered ideal for optimal tea cultivation (Barman, 2024). Tea plantations thrive in climates with moderate humidity, where it's crucial to maintain the proper humidity levels for processing freshly harvested leaves into tea. During the oxidation process, often referred to as fermentation in the tea industry, it's essential to carefully manage both temperature and humidity. This ensures that the polyphenols in the withered leaves develop into the theaflavins, thearubigins, and other compounds that give black teas, pouchong, and oolongs their distinctive flavors and colors. If the leaves dry out, oxidation slows because water is needed for the process. To sustain fermentation, a relative humidity of 95 percent to 98 percent RH (relative humidity) at 20°C to 26°C is required, and even a slight drop in humidity can negatively impact the process, leading to lower yields (Barman, 2024).

This study shows that precipitation (LNPCIPT) has a positive and significant impact on tea (LNTEA) production (Farukh et al., 2020; Mallik & Ghosh, 2022; Ali et al., 2014; Rahman, 2022). Table 5 shows that a 1 percent rise in precipitation results in a 0.03 percent increase in tea production. Moderate rainfall is significant for tea production. Tea cultivation requires 1750 to 2500 millimeters of rainfall, which is why tea production is more abundant in countries with monsoons and tropical regions. It helps the tea plants develop new roots and creates moisture in the soil for tea plants, and the rainwater contains nitrogen, which is very beneficial for tea plants and enhances the quality of tea. Furthermore, sufficient rainfall facilitates the dissolution and movement of nutrients in the soil. During the rainy season, crucial nutrients such as nitrogen, phosphorus, and potassium become more accessible to tea plants. When there is insufficient rainfall, nutrient absorption can be restricted, resulting in diminished plant health and lower yields. Rainfall distribution and quantity have a direct effect on the chemical makeup of tea leaves, which in turn influences the tea's flavor, aroma, and general quality. Consistent rainfall can help manage the presence of certain pests and diseases in tea plantations. For example, it can remove pests or fungi that flourish in dry conditions, thereby decreasing the reliance on chemical treatments. The present analysis reveals that minimum temperature (LNTEMPMIN) has a positive and highly significant effect on tea (LNTEA) production (Mallik and Ghosh, 2022). A 1 percent rise in the minimum temperature results in a 5.71 percent increase in tea production. It depicts that minimum temperatures are favorable for tea

production in Bangladesh. Conversely, the analysis shows a negative and highly significant impact of maximum temperature (LNTEMPMAX) on tea production (LNTEA), with a high coefficient of 9.03 (Gunathilaka et al., 2017; Verma et al., 2016; Mila et al., 2024), which means that maximum temperatures are very detrimental for tea plantations. This indicates that a 1 percent increase in maximum temperature results in a 9.03 percent decrease in tea production. As rising temperatures impact other agricultural products in the country, tea cultivation is also being affected. Several studies suggest that this impact may become even more pronounced in the future. Sudden changes in temperature or abnormal temperature increases can have an immediate negative effect on tea production, leading to a decrease in yield. Moreover, tea produced at higher temperatures is generally bitter. The rises in global temperatures and climate change have become the biggest threats to the tea industry. Intense heat and a lack of heavy rainfall have led to an infestation of red spider mites. According to Brodowicz (2024), as temperatures rise and rainfall decreases, tea plants' ability to photosynthesize will slowly diminish. This reduction in photosynthesis will, in turn, impact the growth and development of the tea plants. According to Saha (2024), the number of heatwaves in the Sylhet region from April to October has increased compared to previous years. Sylhet is known for its cooler climate, but recently, the number of cold days has decreased. Data indicates that since 2005, rainfall during the pre-monsoon season in Sylhet has also declined. The ideal temperature for tea cultivation is between 18°C to 30°C. If the temperature goes above or below this range, tea production starts to fall. Due to global warming, temperatures of 34°C to 35°C are now common in April, May, and other months. When the temperature exceeds the optimal range by 4°C, tea production can decrease by up to 20 percent. The impact of temperature has significantly reduced tea production in Bangladesh. The color, brightness, and liquor production of black tea depend on two key components: theaflavins and thearubigins. As temperatures rise, not only does tea production decrease, but the levels of these essential components in tea also decline. Consequently, the quality of the tea is believed to diminish, according to experts.

Finally, we found that carbon dioxide (CO<sub>2</sub>) emissions (LNCARBDO) have a positive and significant impact on tea (LNTEA) production (Pokharel et al., 2021) in Bangladesh. A 1 percent increase in carbon dioxide emissions leads to a 0.33 percent increase in tea production. Carbon dioxide (CO<sub>2</sub>) is crucial for the vascular plants' growth and development. A rise in atmospheric CO<sub>2</sub> levels is expected to significantly impact photosynthesis, metabolism in plants, and overall growth (Ainsworth and Rogers, 2007; Nowak et al., 2004). When tea plants are exposed to higher levels of CO<sub>2</sub>, it notably enhances both photosynthesis and respiration in the leaves (Li et al., 2017). The effects of increased CO<sub>2</sub>'s impacts on tea plants' respiration and photosynthesis ultimately influenced the biosynthesis of essential secondary metabolites, resulting in the production of a higher quality and greater quantity of green tea. Numerous bioactive substances, such as caffeine, amino

acids, and polyphenols, are crucial in determining the functional quality of tea. Higher CO<sub>2</sub> levels significantly affect these compounds in tea leaves, which are vital for maintaining tea quality (Pokharel et al., 2021).

**Table 5: Results of Fully Modified Least Squares (FMOLS)**

**Dependent variable: LNTEA**

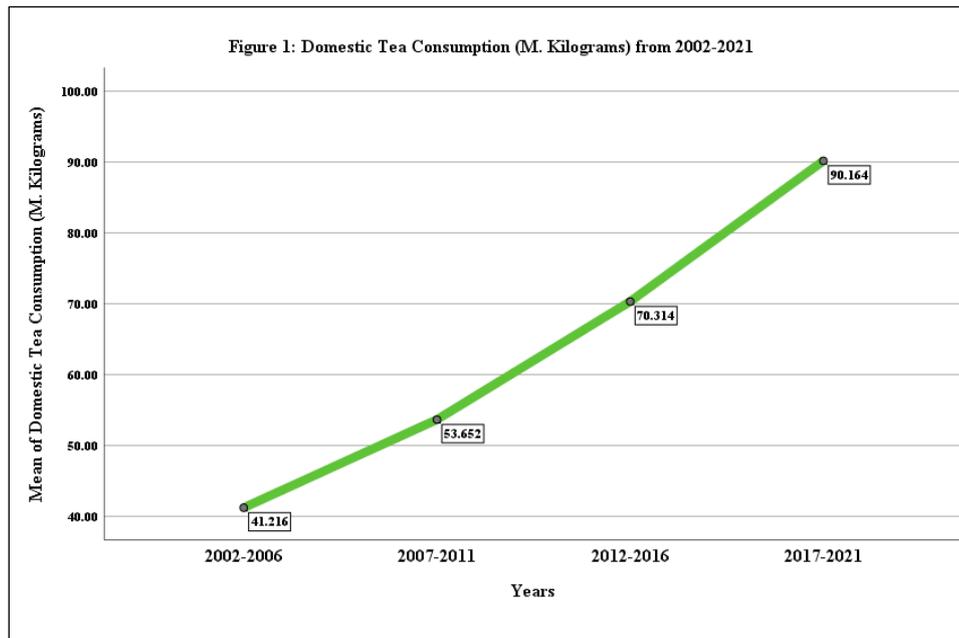
Variables	FMOLS			
	Coefficient	Std. error	t-statistics	Prob.
C	30.27	8.1434	3.72	0.00***
LNHUMDYMIN	-0.27	0.2221	-1.20	0.23
LNHUMDYMAX	-2.89	1.5629	-1.85	0.07*
LNPCIPT	0.03	0.1586	2.04	0.05**
LNTEMPRMIN	5.71	2.0510	2.78	0.00***
LNTEMPRMAX	-9.03	2.6136	-3.45	0.00***
LNCARBDO	0.33	0.0224	14.76	0.00***
R <sup>2</sup>			0.92	

*Source:* Eviews software based on annual time series data (1971-2022). Notes: \*\*\* P<0.01, \*\*P<0.05, \*P<0.10.

### Domestic Consumption

The ANOVA (Analysis of Variance) analysis shows an F-value of 66.58 with a p-value of 0.00 (Appendix A: Table 6), indicating significant differences among the four groups since the p-value is below the 5 percent significance level. The contrast values for the null hypothesis (H<sub>0</sub>: Assume equal variances) and the alternative hypothesis (H<sub>a</sub>: Does not assume equal variances) are 105.31, with corresponding t-statistics of 11.69 and 12.60 (Appendix B: Table 7). Both p-values are 0.00, below the 5 percent significance level. This suggests significant differences in mean domestic tea consumption between group four (2017-2021) and the other three groups (2002-2006, 2007-2011, and 2012-2016). Therefore, domestic tea consumption increased significantly from 2002 to 2021 (Arefin and Hossain, 2022). The outcomes are shown in Figure 1. For the past 7-8 years, domestic consumption has increased by 6-7 percent. As noted by Shyamol (2023), Bangladesh's economy has seen substantial growth over the past decade, leading to a rise in tea consumption across the country. The average tea consumption per person in Bangladesh has increased to over 580 grams, up from just 100 grams (Hossan, 2022). The sharp increase in domestic tea consumption suggests a growing demand for tea within the country. This could be due to factors like population growth, increasing per capita income, continuous urbanization, the purchasing power of people, better prices in the domestic market compared to the global market, changing consumer preferences, health benefit issues, and effective local marketing strategies (Boonerjee et al., 2024). If tea production hasn't

expanded enough to meet both domestic and international demand, the rise in local consumption could be taking up a large portion of the tea supply, leaving less for export. Focusing more on the domestic market might boost the local economy by retaining more value within the country, benefiting local producers and related industries. However, if domestic consumption keeps rising at the expense of exports, there could be long-term risks to Bangladesh's competitiveness in global tea markets. Losing market share can be challenging to recover.

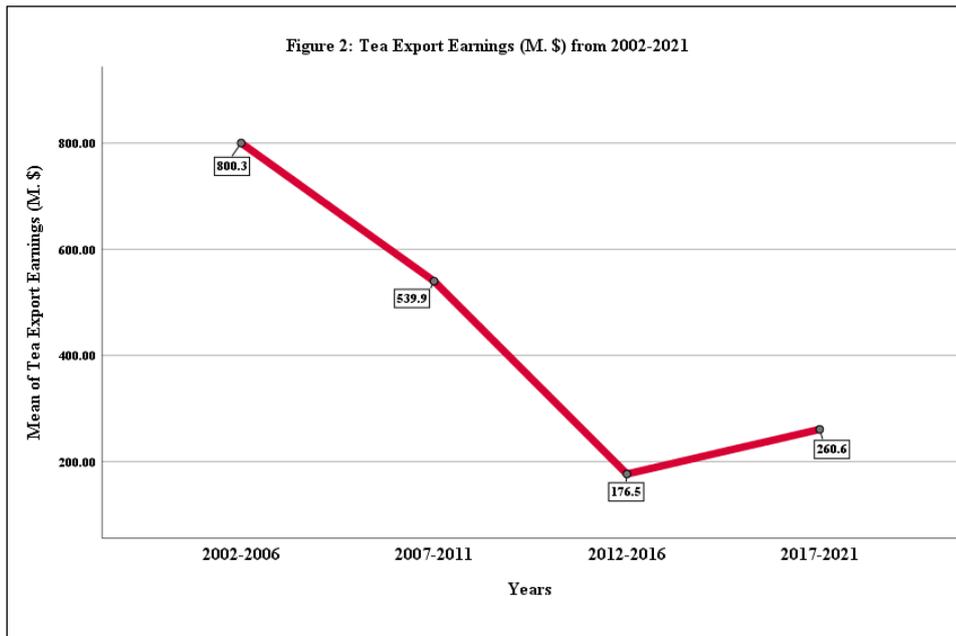


### Export Earnings

The ANOVA analysis resulted in an F-value of 8.15 with a p-value of 0.00 (Appendix C: Table 8), indicating significant differences among the four groups since the p-value is less than the 5 percent significance level. The contrast values for the null hypothesis ( $H_0$ : Assume equal variances) and the alternative hypothesis ( $H_a$ : Does not assume equal variances) are -734.81, with t-statistics of -2.13 and -3.18, respectively (Appendix D: Table 9). Both p-values, 0.04 and 0.01, fall below the 5 percent significance level, indicating significant differences in mean tea export earnings between group four (2017–2021) and the other three groups (2002–2006, 2007–2011, and 2012–2016). As a result, export earnings declined significantly from 2002 to 2021 (Arefin and Hossain, 2022). Figure 2 presents these findings. In today's interconnected world, export earnings are essential for developing countries like Bangladesh to stimulate economic growth and bring prosperity to countries around the world. Exporting allows nations to utilize their

unique resources, skills, and knowledge to gain access to global markets and promote development.

Researchers have identified three key factors contributing to the decline in tea exports: increased domestic demand, limited production capacity, and a reduction in the output of premium-quality tea. Although overall production has grown, it has not kept pace with rising demand. A producing country is expected to meet domestic demand while maintaining export capacity, but this has not been fully realized. The tea consumed in the domestic market has seen lower demand internationally (Islam, 2023). The drop in export earnings indicates that the country's tea is facing stronger competition in global markets. Competitors are likely offer better prices, higher quality, or more appealing varieties, affecting the country's market share (Boonerjee et al., 2024). Additionally, global tea prices may have fallen, reducing earnings despite steady or increased export volumes. The domestic market appears more profitable, prompting producers to prioritize local sales over exports. This decline in export earnings highlights the need to rethink the country's export strategy, including improving the quality of its tea, seeking new markets, and enhancing international marketing efforts.



### Trade Deficit

Over the past twelve years, tea imports consistently exceeded exports, leading to a trade deficit (in volume) from 2010 to 2021 (Figure 3). In 2010, tea imports totaled

4.13 million kilograms, while exports were only 0.91 million kilograms, resulting in a trade deficit of 3.22 million kilograms. By 2015, imports had surged to 10 million kilograms, while exports dropped to 0.54 million kilograms, increasing the trade deficit to 9.46 million kilograms. However, in 2020 and 2021, the trade deficit turned positive, with very small surpluses of 1.50 and 0.06 million kilograms, respectively. As seen in Figure 3, the export trend of tea shows fluctuations. Industry experts point out that the steady increase in domestic consumption, along with variations in production, has contributed to this uneven export pattern. Additionally, the quality of locally produced tea leaves has also played a role (Faruque, 2022).

A negative trade balance could indicate that the country's industries are struggling to compete internationally. This could be due to high production costs, low productivity, or insufficient innovation. Additionally, the economy may be more focused on consumption than production, resulting in a higher level of imports compared to exports. In a developing country like Bangladesh, export earnings hold greater significance than import revenues. Rising imports can deflate the economy, worsen the fiscal deficit, and weaken the local currency as domestic industries shrink and jobs are outsourced. It is possible that the nation would sell its resources and assets to foreign companies in an attempt to attract foreign investment to close the trade imbalance. Over the past 12 years, we have seen a rise in imports, which challenges our economy and affects exchange rates. A persistent trade deficit can weaken the national currency because increased demand for foreign currency is needed to cover the cost of imports. To mitigate this, we should consider implementing import tariffs on tea imports. Additionally, the government could offer incentives to boost export activities, motivating exporters to increase their exports. The government may need to introduce policies to boost exports, such as enhancing infrastructure, increasing labor wages, applying modern technology, and investing in technology for export-focused industries (Razzaque et al., 2024). Additionally, adjustments to fiscal and monetary policies might be required to tackle the root causes of the trade deficit. Since in most cases we import high-quality tea that is not produced locally, we should work on enhancing our tea production and introducing more varieties. Currently, tea quality is high only in Sylhet and Chattogram, while in other regions, tea quality is not so good. Faruque (2022) observes that renowned tea companies continue to import tea leaves from countries like Kenya to uphold the quality of their premium brands. Most of the 167 tea gardens in the country have struggled to produce high-quality leaves as garden owners focus on boosting yields and maximizing profits. Despite the Bangladesh Tea Board's push to increase overall tea production, it has not been very responsible for maintaining quality standards.

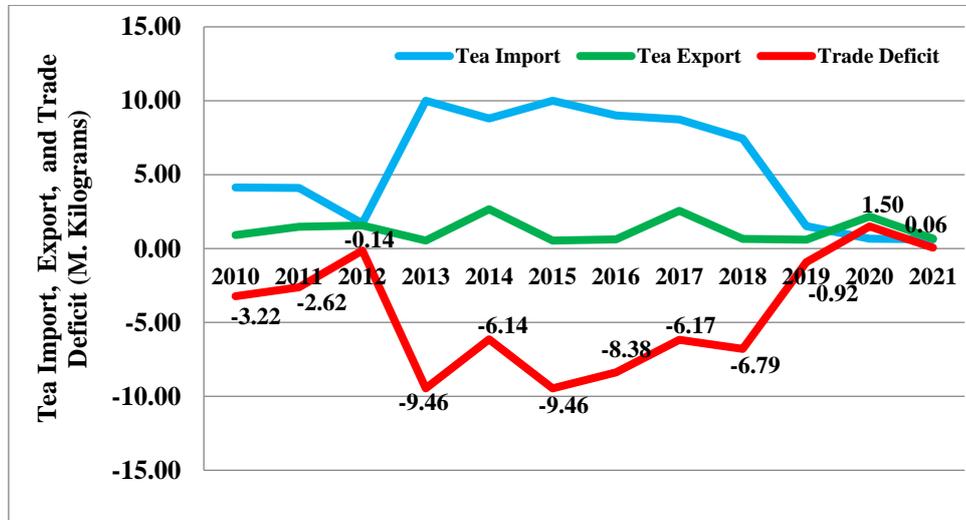


Fig. 3. Tea Import, Export, and Trade Deficit (M. Kilograms) from 2010-2021.

### Conclusion

This study provided a comprehensive analysis of the effects of climate change on tea production in Bangladesh, as well as the economic implications related to domestic consumption, export earnings, and the trade deficit. One important contribution of this research is its examination of these economic factors using advanced econometric and statistical methods. The study revealed two opposing climate effects on tea production because maximum humidity with minimum humidity along with maximum temperature creates negative impacts, but rainfall with minimum temperature and carbon dioxide emissions supports its growth. Over the past twenty years the study revealed substantial growth in domestic tea consumption which resulted from population expansion together with increased earning capacity, shifts in consumer taste preferences and surging urbanization rates etc. The market has shown export earnings reduction because domestic demand remains high while prices have fallen globally and competition increased. Over the past 12 years, the trade deficit has continued despite high production costs accompanied by low productivity and insufficient quality innovations. The study demonstrated that strategic measures, including strong import tariffs with enhanced export incentives together with infrastructure improvements, should be used to address these problems. The research advocated for wages that benefit workers as well as a double effort to create new tea plant varieties and better quality while synchronizing national policies with monetary instruments and embracing progressive farming methods. The research acknowledged its limitations and suggested that future studies could benefit from including additional variables like soil fertility, solar radiation, and wind speed to explore new dimensions.

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**Appendices****Appendix A: Table 6. ANOVA**

Tea Consumption	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6752.53	3	2250.84	66.58	0.00
Within Groups	540.88	16	33.80		
Total	7293.41	19			

Source: SPSS software based on secondary data (2002-2021).

**Appendix B: Table 7. Contrast tests**

Variable	Hypotheses	Contrast	Value of Contrast	t	Sig. (2-tailed)
Tea Consumption	Assume equal variances	1	105.31	11.69	0.00
	Does not assume equal variances	1	105.1	12.60	0.00

Source: SPSS software based on secondary data (2002-2021).

**Appendix C: Table 8. ANOVA**

Export Earning	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1206347.14	3	402115.71	8.15	0.00
Within Groups	789568.19	16	49348.01		
Total	1995915.32	19			

Source: SPSS software based on secondary data (2002-2021).

**Appendix D: Table 9. Contrast tests**

Variable	Hypotheses	Contrast	Value of Contrast	t	Sig. (2-tailed)
Export Earnings	Assume equal variances	1	-734.81	-2.13	0.04
	Does not assume equal variances	1	-734.81	-3.18	0.01

Source: SPSS software based on secondary data (2002-2021).



## EVALUATION OF DIFFERENT NEWER INSECTICIDES AGAINST MANGO HOPPER

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### Abstract

The experiment was conducted during 2022-23 mango cropping season at Lac Research Station, Bangladesh Agricultural Research Institute (BARI), Chapainawabganj to evaluate some newer insecticides against mango hopper, *Idioscopus spp.* (Hemiptera: Cicadellidae). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments comprised 12 treatments, viz. Chlorpyrifos+Cypermethrin 55 EC @ 1 ml/L of water, Cypermethrin 10 EC @ 1 ml/L of water, Diafenthiuron 50 EC @ 1.2 ml/L of water, Chlorpyrifos+Beta-cypermethrin 60 EC @ 1 ml/L of water, Lambda-Cyhalothrin 2.5 EC @ 1 ml/L of water, Monomihypo+Imidacloprid 80 WG @ 0.5 g/L of water, Nitenpyram+Pymetrozine 80 WDG @ 0.5 g/L of water, Imidacloprid+Lambda-Cyhalothrin 20 SC @ 0.5 ml/L of water, Indoxacarb+Emamectin Benzoate 25 WDG @ 0.1 g/L of water, Cartap+Acetamiprid 95 SP @ 1.5 g/L of water, imidacloprid 20 SL @ 0.5 ml/L of water and an untreated control. Each insecticide was sprayed twice, the 1<sup>st</sup> spray at 10 days of flowering and the second in 30 days after the 1st spray. All insecticidal treatments were found superior over untreated control for the management of mango hopper. Spraying Imidacloprid 20 SL @ 0.5 ml/L of water was found the most effective for the management of mango hopper, which offered the highest reduction (83.12% and 69.89%, after the first and second spray, respectively) of mango hopper population over control. This treatment also offered the highest fruit retention (100.22%, 56.2% and 101.09% at pea, marble and mature stages of fruit development, respectively) over control. Spraying Imidacloprid+Lambda-Cyhalothrin @ 0.5 ml/L of water offered the second highest efficacy both in terms of pest population reduction and fruit retention over control.

Keywords: *Mangifera indica*, fruit, mango hopper, insecticide

### Introduction

Mango (*Mangifera indica* L.) is an important fruit crop in Bangladesh and occupies important place in horticultural wealth and economy of the country. Of the many aspects responsible for low mango yields, pests and diseases are considered the

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major factors. More than 300 insect pests have been recorded to attack mango crops in different regions of the world (Patel *et al.*, 2004). Fruits are utilized at all stages of development, i.e., from immature stage to mature stage and during this period fruits are attacked by several insect-pests (Kumar *et al.*, 2005). The pests include leaf hopper, mealy bug, inflorescence midge, fruit fly, scale insects, shoot borer, leaf webber and stone weevil, causing considerable crop damage (Hati *et al.*, 2005). Among the mango pests, mango hoppers are the most serious and extensive pests across the country (Verghese, 2000) and become a serious pest at flowering and fruiting stages (Kumari *et al.*, 2014) which can cause yield loss up to 80-100 percent (Rahman and Kuldeep, 2007). Mango hopper is a great menace nowadays for mango cultivation. The hoppers cause a loss of 20-100% of inflorescence (Haseeb, 2006) and the severely infested plants bear only a few fruits or no fruit at all. Mango hoppers (nymphs and adults) puncture and suck the sap from different growing parts of shoots, inflorescences and mango leaves which cause dropping of immature fruits (Adnan *et al.*, 2014). This pest is causing irreparable loss to mango trees by making the plants sick, yellow, weak and fruitless. Hoppers also secrete honeydew which favours the growth of sooty mould on leaves, shoots and inflorescences of mango trees. This black coating interferes with photosynthetic activity of affected plant parts resulting in no flowers and dropping of immature fruits. On heavily infested trees, crop losses of 50% or more have been recorded (Patel *et al.*, 2004). For the management of hopper incidence on mango, farmers mainly rely on insecticides. Many synthetic insecticides having different mode of actions have been recommended so far by different scientists for the management of mango hopper (Ghosh, 2013; Munj *et al.*, 2018; Ramesh and Virendra, 2014). This research work on mango hopper would provide significant information to protect mango flowers and leaves from the attack of this insect and increase the yield which will boost the farmer's economy as well as the country. There is very little scientific information on control of mango hopper and the use of insecticides in controlling it in Bangladesh. Some field studies were also conducted by the previous reporter (Hasan, 2003). Under this circumstance, the present research work was carried out to evaluate some new insecticides against mango hopper.

### **Materials and Methods**

The study was conducted at the mango orchard of Lac Research Station, Chapainawabganj, BARI, Bangladesh during the mango fruiting season of 2022-23. The experiment was laid out in a randomized complete block (RCB) design with 3 replications. One mango tree constituted one replication. Around 15 years old mango trees of var. BARI Aam-3 were used for the study. The experiment consisted of 12 treatments which are given in Table 1.

**Table 1. Details of treatments used in insecticidal trial**

Treatment	Chemical name	Trade name	Doses/L of water
T <sub>1</sub>	Chlorpyrifos + Cypermethrin	Promix 55 EC	1 ml
T <sub>2</sub>	Cypermethrin	Biddut 10 EC	1 ml
T <sub>3</sub>	Diafenthiuron	Tens Care 50 EC	1.2 ml
T <sub>4</sub>	Chlorpyrifos+ Beta- Cypermethrin	Lirifos Plus 60 EC	1 ml
T <sub>5</sub>	Lambda-Cyhalothrin	Hector 2.5 EC	1 ml
T <sub>6</sub>	Monomihypo + Imidacloprid	Killer 80 WG	0.5 g
T <sub>7</sub>	Nitenpyram + Pymetrozine	Pulsor 80 WDG	0.5 g
T <sub>8</sub>	Imidacloprid + Lambda-Cyhalothrin	Chaser 20 SC	0.5 ml
T <sub>9</sub>	Indoxacarb + Emamectin Benzoate	Erdogan Super 25 WDG	0.1 g
T <sub>10</sub>	Cartap + Acetamiprid	Safa 95 SP	1.5 g
T <sub>11</sub>	Imidacloprid	Locker 20 SL	0.5 ml
T <sub>12</sub>	-	-	-
(untreated control)			

Different new insecticides were applied as a full cover spray on mango trees from the ground using a power sprayer. Mancozeb (Indofil M-45) @ 2.0 g/L of water was sprayed after each spray of assigned spray schedule. Each treatment of this trial was sprayed twice as a full cover spray such as the first application was made within 10 days of flowering while the second in one month after the first application. Each insecticide was used at a pre-determined single dose. The efficacy of different insecticides was observed separately on the tree inflorescences. Adult mango hoppers were collected from the inflorescences. Pre-treatment observation was recorded one day before and post-treatment observations on survival population were recorded 7, 14 and 21 days after spray application with the help of a one meter long nylon sweeping net. First spray was done on 13 February and second spray (14 March) after 1 month of the first spray. Each mango trees were visually divided into 4 quadrant and mango hoppers were collected from each quadrant of the trunk and leaves by up-down and down-up (for trunk) and left-right and right-left (for leaves) movements of a single continuous sweep of the net. Collected mango hoppers were kept in properly labeled polythene bags and were counted later in the laboratory. Ten inflorescences were randomly selected in each tree and tagged before fruit setting. Fruits of the tagged inflorescences were counted at different stages (pea stage, marble stage and mature stage) in each tree to count fruit retention up to mature stage. The collected data were statistically analyzed through the analysis of variance using Web Agri Stat Package (WASP 1.0) (Jangam and Thali, 2004). Means were separated by Least Significant Difference (LSD) test at 5% level of significance. The insect population data were transformed to  $\sqrt{(x + 0.5)}$  values.

## Results and Discussion

The efficacy of different insecticides against mango leaf hopper in mango crop is presented in (Tables 2 and 3). The results revealed that all the treatments were found effective in controlling mango leaf hopper as compared to control. The data regarding the effectiveness of different treatments are described below in details:

The overall results after the first spray showed that the lowest average population of mango hopper/inflorescence was observed from T<sub>11</sub> (2.28) which was statistically similar to T<sub>8</sub> (2.43) and T<sub>5</sub> (2.75) and the maximum average population of mango hopper/inflorescence was recorded in in T<sub>2</sub> (4.13) (Table 2). Among the insecticidal treatments, the treatment T<sub>11</sub> was found the most effective with the highest reduction (83.12%) over untreated control followed by T<sub>8</sub> (82.01%), T<sub>5</sub> (79.94%) T<sub>6</sub> (77.94%) and T<sub>7</sub> (76.83%), respectively (Table 2). The insecticidal treatments followed the order of reduction over untreated control was T<sub>3</sub> (76.46%) > T<sub>1</sub> (76.16%) > T<sub>9</sub> (75.35%) > T<sub>10</sub> (75.20%) > T<sub>4</sub> (72.53%) > T<sub>2</sub> (69.43%).

Similar trend was recorded on second spray of application (Table 3). The overall result after the 2nd spray showed that the lowest average population of mango hopper/inflorescence was noted in T<sub>11</sub> (3.60) which was statistically similar to T<sub>8</sub> (3.74) and T<sub>5</sub> (4.05) and the maximum average population of mango hopper/inflorescence was recorded in in T<sub>2</sub> (5.44) (Table 3). The treatment T<sub>11</sub> was found the most effective with the highest reduction (69.89%) over untreated control followed by T<sub>8</sub> (68.72%), T<sub>5</sub> (66.13%), T<sub>6</sub> (64.13%) and T<sub>7</sub> (62.70%), respectively. The insecticidal treatments followed the order of reduction over untreated control was T<sub>3</sub> (62.45%) > T<sub>1</sub> (62.04%) > T<sub>9</sub> (61.12%) > T<sub>10</sub> (60.95%) > T<sub>4</sub> (58.61%) > T<sub>1</sub> (54.51%).

These results corroborate the results of Adnan *et al.* (2014), Chaudhari *et al.* (2017) and Shawan *et al.* (2018) who found imidacloprid as the most superior to all the insecticide treatments against mango hopper, whereas Kumar and Giraddi (2001) reported that imidacloprid and lambda-cyhalothrin were highly effective recording least population of mango hoppers up to 21 days after the spray, totally two sprays were required to manage the mango hoppers. Efficacy of new insecticides on fruit retention at the pea stage, marble stage and mature stage is presented in Table 4. The highest number of fruit retention was recorded in T<sub>11</sub> (8.93/10 inflorescences) treatment which was followed by T<sub>8</sub> (8.70/10 inflorescences) and T<sub>5</sub> (8.43/10 inflorescences) and the lowest was in treatment T<sub>12</sub> (4.46/10 inflorescences). Accordingly, the highest percent fruit retention over untreated control was recorded in T<sub>11</sub> (100.22% in pea stage, 56.20% in marble stage and 101.09% in mature stage) which was followed by T<sub>8</sub> (95.06% in pea stage, 18.27% in marble stage and 75.82% in mature stage) and T<sub>5</sub> (89.01% in pea stage, 56.20% in marble stage and 101.09% in mature stage). This finding is in agreement with Kumar *et al.* (2020) who reported that the highest number of fruits retained and percent fruit retention was found in imidacloprid sprayed treatment over untreated control. Insecticides can encourage population growth of harmful insects by eradicating

natural enemies that previously held them in control. The nonspecific nature of broad-spectrum chemicals makes them more likely to have such unintentionally effect on the abundance of both harmful and beneficial insects.

**Table 2. Efficacy of some newer insecticides on the abundance of mango hopper after first spray**

Treatments	Mean population of mango hopper/inflorescences/tree				Average	(%) reduction over untreated control
	First spray					
	Pre count	7 DAS	14 DAS	21 DAS		
T <sub>1</sub> = Promix 55 EC	10.89 (3.37)	2.63 (1.76)	3.04 (1.88)	4.01 (2.12)	3.22 (1.92)	76.16%
T <sub>2</sub> = Biddut 10 EC	10.82 (3.36)	3.25 (1.93)	3.92 (2.10)	5.21 (2.38)	4.13 (2.15)	69.43%
T <sub>3</sub> = Tens Care 50 EC	11.10 (3.40)	2.57 (1.75)	3.00 (1.87)	3.97 (2.11)	3.18 (1.91)	76.46%
T <sub>4</sub> = Lirifos Plus 60 EC	11.02 (3.39)	3.00 (1.87)	3.35 (1.96)	4.58 (5.08)	3.71 (2.05)	72.53%
T <sub>5</sub> = Hector 2.5 EC	10.79 (3.36)	2.22 (1.64)	2.30 (1.67)	3.67 (2.04)	2.71 (1.79)	79.94%
T <sub>6</sub> = Killer 80 WG	11.06 (3.40)	2.47 (1.72)	2.62 (1.76)	3.85 (2.08)	2.98 (1.86)	77.94%
T <sub>7</sub> = Pulsor 80 WDG	10.89 (3.37)	2.48 (1.72)	2.99 (1.86)	3.97 (2.11)	3.13 (1.90)	76.83%
T <sub>8</sub> = Chaser 20 SC	10.82 (3.36)	2.12 (1.61)	2.17 (1.63)	2.99 (1.86)	2.43 (1.71)	82.01%
T <sub>9</sub> = Erdogan Super 25 WDG	10.79 (3.36)	2.83 (1.82)	3.21 (1.92)	3.97 (2.11)	3.33 (1.95)	75.35%
T <sub>10</sub> = Safa 95 SP	11.03 (3.39)	2.65 (1.77)	3.18 (1.91)	4.23 (2.17)	3.35 (1.96)	75.20%
T <sub>11</sub> = Locker 20 SL	10.79 (3.36)	1.97 (1.57)	2.03 (1.59)	2.86 (1.83)	2.28 (1.66)	83.12%
T <sub>12</sub> = Untreated control	11.06 (3.40)	12.45 (3.59)	13.61 (3.75)	14.50 (3.87)	13.51 (3.74)	-
CV (%)	10.42	15.41	14.79	6.72	10.05	-
LSD (0.05)	NS	0.03	0.003	0.03	0.04	-

DAS- Days after spraying, Figures in parenthesis are  $\sqrt{(x + 0.5)}$  transformed values, CV = Coefficient of Variation, LSD = Least Significant Difference.

**Table 3. Efficacy of some newer insecticides on the abundance of mango hopper after second spray**

Treatments	Mean population of mango hopper/inflorescences/tree				Average	(% reduction over untreated control
	Second spray					
	Pre count	7 DAS	14 DAS	21 DAS		
T <sub>1</sub> = Promix 55 EC	9.43 (3.15)	3.73 (2.05)	4.64 (2.26)	5.26 (2.40)	4.54 (2.24)	62.04%
T <sub>2</sub> = Biddut 10 EC	9.26 (3.12)	4.35 (2.20)	5.52 (2.45)	6.46 (2.63)	5.44 (2.43)	54.51%
T <sub>3</sub> = Tens Care 50 EC	9.39 (3.14)	3.67 (2.04)	4.60 (2.25)	5.22 (2.39)	4.49 (2.23)	62.45%
T <sub>4</sub> = Lirifos Plus 60 EC	9.69 (3.19)	4.10 (2.14)	4.95 (2.33)	5.83 (2.51)	4.95 (2.33)	58.61%
T <sub>5</sub> = Hector 2.5 EC	8.70 (3.03)	3.32 (1.95)	3.90 (2.09)	4.92 (2.32)	4.05 (2.13)	66.13%
T <sub>6</sub> = Killer 80 WG	9.21 (3.11)	3.57 (2.01)	4.22 (2.17)	5.10 (2.36)	4.29 (2.18)	64.13%
T <sub>7</sub> = Pulsor 80 WDG	9.41 (3.14)	3.58 (2.01)	4.59 (2.25)	5.22 (2.39)	4.46 (2.22)	62.70%
T <sub>8</sub> = Chaser 20 SC	8.74 (3.03)	3.22 (1.92)	3.77 (2.06)	4.24 (2.17)	3.74 (2.05)	68.72%
T <sub>9</sub> = Erdogan Super 25 WDG	9.11 (3.10)	3.93 (2.10)	4.81 (2.30)	5.22 (2.39)	4.65 (2.26)	61.12%
T <sub>10</sub> = Safa 95 SP	9.67 (3.18)	3.75 (2.06)	4.78 (2.29)	5.48 (2.44)	4.67 (2.27)	60.95%
T <sub>11</sub> = Locker 20 SL	9.39 (3.14)	3.07 (1.88)	3.63 (2.03)	4.11 (2.14)	3.60 (2.02)	69.89%
T <sub>12</sub> = Untreated control	9.51 (3.16)	11.35 (3.44)	12.01 (3.53)	12.55 (3.61)	11.96 (3.52)	-
CV (%)	10.08	12.13	10.94	13.88	7.98	-
LSD (0.05)	NS	0.13	0.03	0.02	0.02	-

DAS- Days after spraying, Figures in parenthesis are  $\sqrt{(x + 0.5)}$  transformed values, CV = Coefficient of Variation, LSD = Least Significant Difference

**Table 4. Efficacy of some newer insecticides on fruit retention**

Treatments	Mean number of fruits/10 tagged inflorescences/tree			(% ) Fruit retention over untreated control		
	Pea stage	Marble stage	Mature stage	Pea stage	Marble stage	Mature stage
T <sub>1</sub> = Promix 55 EC	6.13	3.13	1.30	37.44	7.93	42.85
T <sub>2</sub> = Biddut 10 EC	5.76	3.33	1.36	29.14	14.82	49.45
T <sub>3</sub> = Tens Care 50 EC	6.19	3.16	1.43	38.78	8.96	57.14
T <sub>4</sub> = Lirifos Plus 60 EC	6.04	3.33	1.36	35.42	14.82	49.45
T <sub>5</sub> = Hector 2.5 EC	8.43	3.43	1.60	89.01	18.27	75.82
T <sub>6</sub> = Killer 80 WG	8.30	3.30	1.46	86.09	13.79	60.43
T <sub>7</sub> = Pulsor 80 WDG	6.56	3.23	1.46	47.08	10.21	60.43
T <sub>8</sub> = Chaser 20 SC	8.70	4.03	1.63	95.06	38.96	79.12
T <sub>9</sub> = Erdogan Super 25 WDG	6.33	3.13	1.26	41.92	7.93	38.46
T <sub>10</sub> = Safa 95 SP	6.33	3.40	1.06	41.92	17.24	16.48
T <sub>11</sub> = Locker 20 SL	8.93	4.53	1.83	100.22	56.20	101.09
T <sub>12</sub> = Untreated control	4.46	2.90	0.91	-	-	-
CV (%)	3.63	7.44	6.74	-	-	-
LSD (0.05)	0.42	0.42	0.15	-	-	-

CV = Coefficient of Variation, LSD = Least Significant Difference

### Conclusion

On the basis of the trial results, the two sprays, 1st spray at 10 days of flowering and the second in one month after the first application, of imidacloprid 20 SL (Locker) @ 0.5 ml/L of water were found to be the most effective against mango hopper followed by imidacloprid + lambda-cyhalothrin 20 SC (Chaser 20 Sc) @ 0.5 ml/L of water. The highest percent fruit retention was recorded from the two sprays of imidacloprid 20 SL (Locker) @ 0.5 ml/L of water over untreated control.

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**INFESTATION AND POPULATION FLUCTUATION OF SOME INSECT  
PESTS AT ROOF TOP GARDEN IN GAZIPUR, BANGLADESH**

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Keywords: Fruitfly, Infestation, Mealybug, Population fluctuation, Spiraling Whitefly.

Rooftop gardens guide the social life as well as provide experience of self-identification and independence, the place one can in particular acquire self-satisfaction (Rashid and Ahmed, 2010). It can play an important role in supplying fruit and vegetable at urban markets and meeting the food demand of growing urban community (FAO,2012; Orsini *et al.*, 2014).

With fast and unplanned urbanization, poverty and food insecurity has been growing alarmingly in Dhaka city (Choguill, 1995). Rooftop gardening can be a positive approach in ensuring meals furnish and enjoyable dietary desires of the city dwellers.

Many people are involved in rooftop gardening, especially in city areas at Bangladesh. Their efforts are helping to make the cities greener, despite lack of cultivable lands. People expecting chemical-free vegetables and fruits but insect pest attack occurs in rooftop garden where people apply chemical insecticide without knowing the insect pest. Total 24 families and 46 species of insect attack were reported at rooftop garden (Han *et al.*, 2017). Insect pest attack and its severity may be different in roof garden compare to field agriculture but in Bangladesh research work is very scanty related to insect pest incident at rooftop garden. Insect pest status and their population fluctuation will help to develop sustainable pest management strategy at rooftop garden. So, the present study was designed to know the insect pest status and population fluctuation at rooftop garden.

The experiment was conducted at rooftop garden of Horticulture Research Centre (HRC) and rooftop garden of Soil Science Division (SSD), Bangladesh Agricultural Research Institute (BARI), Gazipur during 2021-2022. The rooftop garden of HRC was based on fruit crop where guava, mango, papaya, lemon available and in SSD rooftop garden, bottle gourd, guava, mango etc were present. Data were collected by visual observation at HRC and in SSD rooftop garden, pheromone traps were used in both sites. For visual observation every plant was observe closely at 15 days interval to identify insect pest and their infestation.

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Magnifying glass and microscope were also used to identify insect pest complex. Percent plant infestation by an insect pest was calculated by counting total number of plants and number of infested plants by the pest. In case of more than 40% plant infestation by an insect pest, percent leaf infestation was calculated. For percent leaf infestation calculation, 10 leaves of 5 infested plants were randomly selected and infested leaf was counted.

Three pheromone traps of *B. cucurbitae* and three pheromone traps of *B. dorsalis* were set in the rooftop garden of SSD. Population of *B. cucurbitae* and *B. dorsalis* were counted from pheromone trap catches. The mean number of *B. cucurbitae* and *B. dorsalis* were determined from total trap catches at the same dates.

The insects namely spiraling whitefly and mealybug were found at guava plant of the HRC rooftop garden (Table 1). It was observed that less than 34% (17 to 33.67%) guava plants of the HRC rooftop garden were infested by spiraling whitefly but more than 80% (83.33 to 100%) guava plants were infested by mealybug. In some cases, both insects were present at the same leaf of a plant with a complex situation although spiraling whitefly, mealybug complex infested guava plant did not exceed 20% (0 to 16.67%) (table1). Table 1 also indicates that 30 to 80% guava leaves were infested at rooftop garden by mealybug during the study period. The highest mealybug infested guava plants and leaves were found in the month of April and infestation rate was lower in the month of December-January.

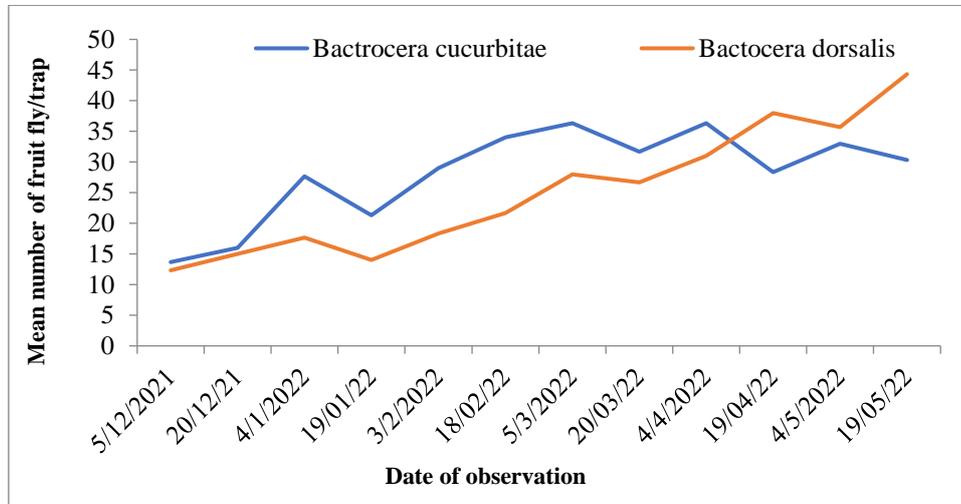
In case of mango, papaya and lemon only mealybug was found. During the study period 12.5 to 35% mango plants and 16.67 to 39.33% Papaya plants were infested by mealybug. In both cases, the highest mealybug population was found in the month of April and lower in the month of December to January (Table 1).

There were two lemon plants in HRC rooftop garden and both of them were infested by mealybug. It was observed that 30 to 80% leaves of lemon were infested by mealybug at rooftop garden of HRC building. The highest leaf infestation was found in the month of April and the lowest in the month of January (Table 1).

Fruitfly population was observed at rooftop garden of SSD by using pheromone trap. Average number of fruitfly per pheromone trap is shown in figure 1. It was found that *B. cucurbitae* and *B. dorsalis* population were found throughout the observation period ranged from 13.67 to 36.33 per trap and 12.33 to 44.33 per trap respectively. *B. cucurbitae* population was found the highest in the month of March- April and *B. dorsalis* population was found the highest in the month of May. Both insects population were found the lowest in the month of December (Figure 1).

**Table 1. Percent plant and leaves infestation at rooftop garden by different insect pest during 5 December, 2021 to 19 May, 2022**

Observed plants or leaves	Insects	Infestation rates (%) at different observation dates												
		05/12/21	20/12/21	04/01/22	19/01/22	03/02/22	18/02/22	05/03/22	20/03/22	04/04/22	19/04/22	04/05/22	19/05/22	
Guava plants	Mealybug	83.33	83.33	100	100	100	100	91.67	83.33	100	83.33	100	83.33	83.33
	Spiraling whitefly	17	18.22	18.33	21.33	26.67	33.67	28.67	25	26.67	28.67	22	19.33	
	Mealybug and spiraling whitefly complex	0	0	0	8.33	8.33	16.67	8.33	8.33	16.67	8.33	0	0	
Guava leaves	Spiraling whitefly	40	30	60	70	60	80	70	60	80	70	50	60	
Mango plants	Mealybug	14.5	12.5	15	13.33	25	25	22.5	27.5	32.5	35	32.5	28.5	
Papaya plants	Mealybug	16.67	18.33	16.66	23.33	21.67	31.33	33.67	31.33	37.67	39.33	33.33	27.67	
Lemon leaves	Mealybug	40	50	30	50	60	60	70	60	80	70	50	40	



**Fig.1. Mean number of fruitfly per pheromone trap during 5 December, 2021 to 19 May, 2022.**

Insect pest status and population study were studied by different researcher at field condition but scanty at rooftop condition. According to rooftop gardener response, Sheel *et al.*, 2019 was found ant, mealybug, whitefly and green leafhopper as most occurring insect at rooftop garden which confirm the result of the present study. Khan (2022) was found the highest incidence of spiraling whitefly population in September followed by October, November and May while the lowest in July followed by June, January and February, respectively. In study, mealybug and spiraling whitefly infested plants and leaves were observed high at February to April but low at December to January. Less green vegetation, low temperature and relative humidity may be the reason of lower mealybug and spiraling whitefly infestation at December to January. On the other hand, high temperature and green vegetation may be the reason of higher insect population at April.

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