Volume 51 Number 1 BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH March 2026

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

BJAR

Volume 51 Number 1
March 2026

Bangladesh Journal of Agricultural Research

Please visit our website : www.bari.gov.bd

Bangladesh Journal of AGRICULTURAL RESEARCH

Volume 51 Number 1

March 2026

BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

Editorial Board

Bangladesh Agricultural Research Institute (BARI)
Joydebpur, Gazipur 1701
Bangladesh

BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

Vol. 51 March 2026 No. 1

C O N T E N T S

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 453-460, March 2026

EVALUATION OF DIFFERENT MANAGEMENT OPTIONS AGAINST WHITEFLY, *BEMISIA TABACI* FOR SUPPRESSING TOMATO LEAF CURL VIRUS

N. K. DUTTA[1], K. BEGUM[2], M. A. SARKAR[3]
A. K. M. R. H. FERDOUS[4] AND M. H. RASHID[5]

Abstract

Whitefly, *Bemisia tabaci*, is a seirous insect pest of tomato and a vector of tomato leaf curl virus (ToLCV). Five management approaches were evaluated against whitefly to suppress ToLCV during Rabi 2021-22 in the research field of BARI, Gazipur. Two management packages i.e., T_3 (Seed treatment with Fortenza 60 FS @ 2.5 ml kg^{-1} seed + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and 2 sprays with Tundra 20 SP at 10 days interval) and T_4 (Seedbed netting with 60 mesh nylon net + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and 2 sprays with Tundra 20 SP at 10 days interval) offered satisfactory effectiveness considering reduced infestation of whitefly and ToLCV infection, higher yield and marginal benefit cost ratio (MBCR).

Keywords: Whitefly, tomato, leaf curl virus, management.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular and widely grown vegetables crop of both tropics and subtropics of the world, belonging to the family Solanaceae. Tomato fruit is considered to be fairly high in vitamins A and C, having high cash value with potential for value-added processing. Tomato is infested by several insect pests, viz., whitefly, fruit borer and leaf miner. Whitefly is one of the most devastating sucking pests of tomato. This pest not only sucks the plant sap but it also transmits the tomato leaf curl virus (ToLCV) disease in tomato. The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is one of the most serious pests found in protected horticulture because of its broad host range, high reproductive rate, and short life cycle (Oliveira *et al*., 2001).

The management of whitefly and ToLCV in tomato should focus on several areas. These encompass the exploration of eco-friendly alternatives like biorational

[1,2,3&4]Entomology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, and [5]Regional Agricultural Research Station, BARI, Burirhat, Rangpur-5400, Bangladesh.

insecticides, the development of effective strategies for managing resistance, the incorporation of precision agriculture technologies to reduce insecticide usage and the investigation of biocontrol agents and cultural practices that can contribute to whitefly control. Protection of the crop from ToLCV during the first 5 or 6 weeks after transplanting is crucial to reduce yield losses (Sakia and Muniyappan, 1989). Seed treatment or seed bed netting can be helpful in protecting whitefly for first week leading to reduction in ToLCV infection at initial stages of the crop. The development of insecticide resistance has contributed to the need for alternatives to insecticides to manage *B. tabaci* and ToLCV in tomato growing regions. Intensive use of neonicotinoid insecticides to manage *B. tabaci* has led to the development of tolerance to certain neonicotinoids among some populations of whitefly in Florida (Schuster *et al*., 2008).

Presently, the farmers are totally dependent on the use of traditional insecticides to control whitefly but they are not getting desired result. So, developing alternatives to traditional toxic chemical pesticides is of paramount importance. Therefore, this study has been designed to develop sustainable management package for tomato whitefly as well as whitefly transmitted tomato leaf curl virus disease.

Materials and Methods

The experiment was conducted in the research field of BARI, Gazipur during Rabi 2021-22. The experiment was laid out in RCBD having 3 replications. Seeds of 'BARI Hybrid tomato-5' variety was sown in a plot of 4.8m x 2.5m. Weeding and other intercultural operations were done as and when necessary to raise a good crop. Treatment applications were started as soon as the infestation were noticed. Non target pests were controlled with spraying emamectin benzoate (Proclaim 5SG) @ 1 g/litre of water. The treatments were assigned as follows:

T_1 = Seed treatment with cyantraniliprole (Fortenza 60 FS) @ 2.5 ml/kg seed + Spraying Sodium lauryl ether sulphate (Fizimite 10%) @ 1ml/L of water. Altogether 5 sprays were done at 10 days interval

T_2 = Seedbed netting with 60 mesh nylon net + Spraying Sodium lauryl ether sulphate (Fizimite 10%) @ 1ml/L of water. Altogether 5 sprays were done at 10 days interval

T_3 = Seed treatment with cyantraniliprole (Fortenza 60 FS) @ 2.5 ml/Kg seed + Alternate spraying of Sodium lauryl ether sulphate (Fizimite 10%) @1 ml/L of water and Acetamiprid (Tundra 20 SP) @ 1 g/L of water. Altogether 5 sprays were done, 3 sprays with Fizimite 10% and 2 sprays with Tundra 20 SP at 10 days interval.

T_4 = Seedbed netting with 60 mesh nylon net + Alternate spraying of Sodium lauryl ether sulphate (Fizimite 10%) @1ml/L of water and Acetamiprid (Tundra 20 SP) @ 1g/L of water. Altogether 5 sprays were done, 3 sprays with Fizimite 10% and 2 sprays with Tundra 20 SP at 10 days interval.

T_5= Farmers' practice: Spraying with Imidacloprid (Imitaf 20 SL) @ 0.5 ml/litre of water (altogether 10 sprays were done at 7 days interval); and

T_6= Untreated control.

Whitefly population and virus infected plants were recorded at weekly interval. The fruit yield was obtained from each plot was converted into per hectare. The data collected was subjected to statistical analysis after necessary transformation using R software and treatment means were separated using Duncan's Multiple Range test DMRT ($P \leq 0.05$).

Results and Discusion

Effectiveness of different management packages against whitefly population, ToLCV infection and yield of tomato

Results of field studies on effectiveness of different management packages against whitefly population, ToLCV infection and yield of tomato are presented in Table 1. The results indicated that T_4 (Seedbed netting with 60 mesh nylon net + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval) recorded the lowest whitefly population (2.98/5 leaves) which was followed by T_3 (Seed treatment with Fortenza 60 FS @ 2.5 ml kg^{-1} seed + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval). Similarly, highest reduction (85.62%) of whitefly population over control was recorded from T_4. The control plots recorded the highest whitefly population (20.72/5 leaves). Table 1 also indicated that T_4 recorded the lowest ToLCV infected plants (6.02%) which is statistically at par with T_3. The control plots recorded the highest ToLCV infected plants (38.04%). Similarly, the highest reduction (84.21%) of ToLCV infected plants over control was recorded from T_4. Significantly the highest yield was also obtained from T_4 (51.15 t/ha) which was statistically at par with T_3 (51.02 t/ha).

Table 1. Effectiveness of different treatments in reducing whitefly population and ToLCV infection and yield of tomato at Gazipur during Rabi 2021-22

Treatments	Mean whitefly population /5 leaves	Reduction of whitefly population over control (%)	Mean ToLCV infected plants (%)	Reduction of ToLCV infected plants over control (%)	Marketable yield (t ha^{-1})
T_1= Seed treatment with Fortenza 60 FS @ 2.5 ml^{-1} kg seed + Spraying Fizimite 10% @ 1 ml l^{-1} of water. Total 5 sprays at 10 days interval	9.25b	64.20	15.34b	59.67	47.82ab
T_2= Seedbed netting, 60 mesh nylon net + Spraying Fizimite 10% @ 1 ml l^{-1} of water. 5 sprays at 10 days interval	9.62b	65.01	15.25b	59.91	47.06b
T_3= Seed treatment with Fortenza 60 FS @ 2.5 ml kg^{-1} seed + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval = T_3	3.23d	84.41	6.24c	83.60	51.02a
T_4= Seedbed netting with 60 mesh nylon net + Alternate spraying of Fizimite 10% @ 1 ml^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval =T_4	2.98d	85.62	6.02c	84.21	51.15a
T_5= Farmers' practice: Spraying of Imitaf 20 SL @ 0.5 ml l^{-1} of water. Total 5 sprays at 7 days interval =T_5	5.42c	69.01	9.05d	76.21	49.05ab
T_6= Untreated Control	20.72a	-	38.04a	-	43.06c
CV (%)	12.61	-	9.14	-	3.69

Means having same letter(s) in a column are not significantly different at P> 0.05.

Correlation between key parameters

The correlation between whitefly population and ToLCV infection in tomato is represented in Fig. 1. The relationship is significant and it was observed that ToLCV infection in tomato increased with the increase of whitefly population. Whereas, the correlation between ToLCV infection and yield of tomato is represented in Fig. 2. The relationship is significant and it was observed that around 94% yield would be affected by ToLCV infection in tomato plants.

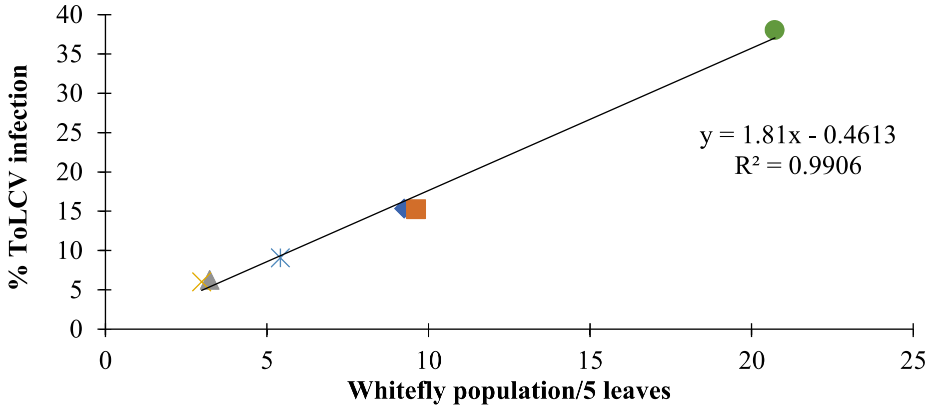


Fig. 1. Relationship between whitefly population and ToLCV infection in Tomato

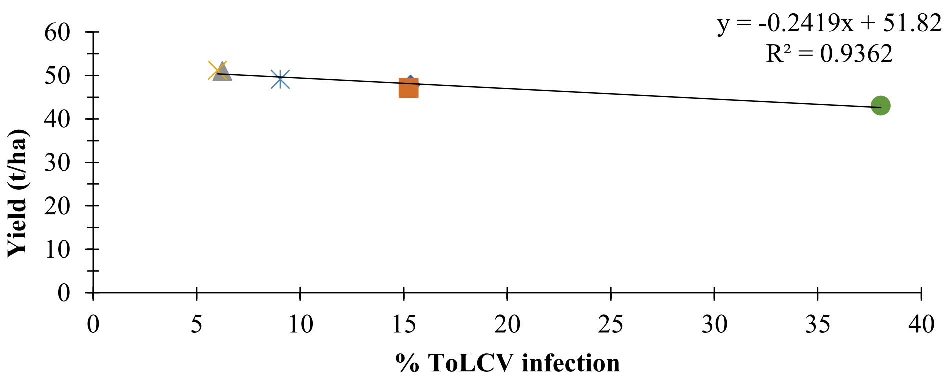


Fig. 2. Relationship between ToLCV infection and yield of Tomato

Marginal benefit-cost ratio of different management packages

The marginal benefit-cost ratio (MBCR) as worked out based on the expenses incurred and value of tomato obtained from the treated plots for the control of whitefly population and ToLCV infection in tomato is given in Table 2. It was noted here that expenses incurred referred to those only on pest control. It was revealed that the highest marginal benefit-cost ratio (MBCR) (8.85) was calculated from T_3 (Seed treatment with Fortenza 60 FS @ 2.5 ml kg^{-1} seed + Alternate spraying of Fizimite 10% @ 1 ml^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval). Management approach T_4 (Seedbed netting with 60 mesh nylon net + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval) also offered statifactory MBCR (8.00). So, considering MBCR, seed treatment or seedbed netting along with alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water could be recommended against whitefly for suppressing tomato leaf curl virus.

Table 2. Benefit cost analysis of different management packages for the management whitefly population and ToLCV infection in tomato at Gazipur during Rabi 2021-22

Treatments	Marketable yield (t ha^{-1})	[1]Gross return (Tk ha^{-1})	[2]Cost of treatment (Tk ha^{-1})	Net return (Tk ha^{-1})	Adjusted net return (Tk ha^{-1})	Marginal benefit cost ratio (MBCR)
T_1= Seed treatment with Fortenza 60 FS @ 2.5 ml^{-1} kg seed + Spraying Fizimite 10% @ 1 ml l^{-1} of water. Total 5 sprays at 10 days interval	47.82	956400	16990	939410	78210	4.60
T_2= Seedbed netting, 60 mesh nylon net + Spraying Fizimite 10% @ 1 ml l^{-1} of water. 5 sprays at 10 days interval	47.06	941200	18275	922925	61725	3.38
T_3= Seed treatment with Fortenza 60 FS @ 2.5 ml kg^{-1} seed + Alternate spraying of Fizimite 10% @ 1 ml l^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with Tundra 20 SP at 10 days interval = T_3	51.02	1020400	16390	1004010	145050	8.85
T_4= Seedbed netting with 60 mesh nylon net + Alternate spraying of Fizimite 10% @ 1 ml^{-1} of water and Tundra 20 SP @ 1 g l^{-1} of water. Total 5 sprays; 3 sprays with Fizimite 10% and Two sprays with	51.15	1020300	17675	1002675	141475	8.00

Treatments	Marketable yield (t ha^{-1})	[1]Gross return (Tk ha^{-1})	[2]Cost of treatment (Tk ha^{-1})	Net return (Tk ha^{-1})	Adjusted net return (Tk ha^{-1})	Marginal benefit cost ratio (MBCR)
Tundra 20 SP at 10 days interval =T_4						
T_5= Farmers' practice: Spraying of Imitaf 20 SL @ 0.5 ml l^{-1} of water. Total 5 sprays at 7 days interval =T_5	49.05	981000	15625	965375	104175	6.67
T_6= Untreated Control	43.06	861200	0.00	861200	-	-

[1]Farmgate price of tomato @ Tk. 20.00 kg^{-1};

[2][Seed rate of tomato: 250 g/ha; Cost of seed treating chemical Fortenza 60 FS: Tk. 24000/ litre; One laborer for seed treating of 2 ha crop @ Tk 550.00 labour^{-1} day^{-1}; Cost of seed bed netting/ha crop: 1525/-; Cost of Fizimite 10%: Tk. 4500/ litre; Cost of Tundra 20SP: Tk. 3900/ litre; Cost of Imitaf 20SL: Tk. 1850/ litre; Cost of spray: Two laborers for spraying ha $^{-1}$ crop @ Tk 550.00 labour^{-1} day^{-1}]

Limited works have been done to develop management approach against whitefly transmiiting ToLCV comprising of seed treatment or seed bed netting in tomato. Kumar (2018) reported that the root treatment done with Imidacloprid 70 WS solution @ 3 g/L of water for 30 minutes followed by one spray with Imidacloprid 17.8 SL@ 0.3 ml/L and second spray with Dimethoate 30 EC @1.5ml/L water was more effective in reduction of whitefly population of tomato and offered the highest benefit cost ratio (BCR) (6.67) which was followed by seed treatment done with Imidaclorprid 70 WS @ 3g/kg of seed and 2 sprays done with Dimethoate 30 EC @1.5ml/L water having BCR 5.97. Sharma et *al*., (2017) reported that combination of carbofuran (soil application) + Imidacloprid (seed treatment) + Imidacloprid (foliar application) proved significantly superior and caused maximum reduction in whitefly population. However, Muqit and Akanda (2007) reported that tomato yellow leaf curl disease incidence was reduced by 12 to 37% and yield was increased by 5 to 21% due to netting (40 meshes) and pesticidal spray.

Many studies on whitefly management in tomato have been done on efficacy of insecticides. Jha and Kumar (2018) reported that imidacloprid provided the highest reduction of whitefly population in tomato, followed by mixture of profenophos and cypermethrin. Meena and Ranju (2014) reported that control of whitefly by prophenophos was most effective insecticides followed by indoxacarb > neem seed kernel extract (NSKE 5%). Balakrishnan *et al.*, (2009) also reported that indoxacarb 14.5 SC (500 ml ha^{-1}) against whitefly reduced population by

(79.01%). Although insecticidal control is one of the common means against whitefly, tomato being a vegetable crop, use of broad-spectrum insecticides will leave considerable toxic residues on the fruits and may cause considerable health hazards. Chemical control of whitefly is quite challenging because it also causes mortality of its natural enemies.The integration of pest management tactics was cheaper than synthetic insecticides even though the chemical insecticides offered good control of pests (Kumar. 2018). Therefore, Integrated Pest Management of tomato whitefly could be adopted for successfully managing leaf curl virus as alternative to chemical insecticides.

Conclusion

The present study clearly indicated that seed treatment or seedbed netting in combination with altrnatenate spraying of bio and chemical insecticide effectively controlled whitefly population resulting in reduced ToLCV infection in tomato with higher marginal benefit cost ratio. These integrated management practices can be recommended to farmers for sustainable whitefly and ToLCV management.

References

Balakrishnan, N., B. V. Kumar and P. Sivasubramanian. 2009. Bioefficacy of biofenthrin 10 EC against sucking insects, bollworm and natural enemies in cotton. *Madras Agric. J.* **96**(1-6): 225-229.

Jha, S. K. and M. Kumar. 2018. Evaluation and Economics of Various Insecticide against Whitefly *Bemisia tabaci* on Tomato. *Int. J. Curr. Microbiol. App. Sci*. **7**: 382-387.

Kumar, R. 2018. Evaluation of insecticides against whitefly on tomato and their effect on natural enemies. *J. Pharmacogn. Phytochem*. **7** (1S): 789-792.

Meena, L. K. and S. V. S. Ranju. 2014. Bioefficacy of insecticides against whitefly and leafhopper of tomato under field condition. *Annals of Plant Protection Science*. **22**(1): 14-17.

Muqit, A. and A. M. Akanda. 2007. Management of tomato yellow leaf curl virus through netting. *The Agriculturists.* **5**: 1-5.

Oliveira, M. R. V., Henneberry, T. J. and P. Anderson. 2001. History, current status, and collaborative research projects for *Bemisia tabaci*. *Crop Prot.* **20**: 709-723. doi: 10.1016/S0261-2194(01)00108-9.

Sakia, A. K. and V. Muniyappa. 1989. Epidemiology and control of tomato leaf curl virus in southern India. *Trop. Agric.* **66**: 350 – 354.

Schuster, D. J., P. A. Stansly, P. R. Gilreath, and J. E. Polston. 2008. Management of *Bemisia*, TYLCV and insecticide resistance in Florida vegetables. *J. Insect Sci*. **8**: 43-44.

Sharma, D., A. Maqbool, V V S. Jamwal, K. Srivastava, and A. Sharma. 2017. Seasonal dynamics and management of whitefly (*Bemesia tabaci* Genn.) in tomato (*Solanum esculentum* Mill.). *Braz. Arch. Boil. Technol*. **60**: e17160456.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 461-471, March 2026

DETERMINANTS OF ONION YIELD VARIATION AMONG FARMERS IN PABNA DISTRICT, BANGLADESH: EVIDENCE FROM AN ORDERED LOGISTIC REGRESSION MODEL

S. ISLAM[1], M. RASEL[2] AND N. MOHAMMAD[3]

Abstract

Many socioeconomic, institutional, and biophysical factors contribute to substantial variation in onion yields among growers in Bangladesh in general and in Sujanagar upazila of Pabna district in particular. The main objective of the present study was to identify factors affecting the probability of onion yield falling into low, medium, or high categories, given a set of yield-determining inputs. Primary data collected from 40 randomly selected onion growers in Sujanagar upazila were analysed using a proportional odds (ordered logistic) model. The study finds that several socioeconomic and agro-ecological variables-, such as farmer age, plot size, onion variety (Kings and Taherpuri), farming experience, and fertilizer use- significantly influence onion yield categories. Therefore, it is imperative to provide greater support to small farmers and arrange training programs and extension services to enhance farmers' skill and experience. Moreover, agricultural advisory services should emphasize the appropriate use of fertilizers, pesticides, and weedicides to enhance onion yields in the study area.

Keywords: Ordered logistic regression, Proportional odds, Onion, and Yield categories

Introduction

Flavouring food by adding different plant parts during cooking or in the preparation of pastes or salads is a common practice worldwide (Islan *et al*., 2011). In this case, spices play a vital role. Onion is one of the most important spice crops and is widely used in daily diets on a large scale. In preparing soup, meat dishes, salads, sandwiches; it is extensively used as a condiment and sometimes is cooked alone as a vegetable (Vohra *et al*., 1974). The diversified use of onions has increased their importance among all the spices. Onion is widely consumed across the world, with an estimated demand of about 25g/capita/day (Akter *et al*., 2023). Onion ranks second globally in terms of area under cultivation (Bapari *et al*., 2016). Among other competing spices, onion production is considered more lucrative (Mila and Parvin, 2019).

Onion is the most important spice crop for Bangladesh's people, as it is considered indispensable in daily cooking (Anjum and Barmon, 2017). Almost all food dishes

[1]Department of Agricultural Economics, Gazipur Agricultural University (GAU), Gazipur, and [2&3]Agricultural Statistics and ICT Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

are prepared using it. Among all the spices, onion takes the first place in Bangladesh based on the daily intake (35-40 g/day/person) (Khan *et al*., 2024). In total, about 2.04 lakh hectare area is used for onion production in our country, which produces about 25.47 lakh MT/year, but the average yield (13.78 t/ha) is very low compared to the world's onion yield (BBS, 2023). Consequently, the Government has prioritized the agriculture sector by providing subsidies and input support to increase onion production (Fatima, 2021). Being a widely used spice, Bangladesh has a vast demand for onion, but the country faces difficulty in meeting even 15% of the annual requirements of onion through domestic production (Hossain *et al*., 2017). Therefore, every year the country needed to import between 0.9 to 1.1 million tons of onion from the neighbouring countries. This results in an annual expenditure of approximately Tk. 4 lakh crore in foreign currency (Jubayer *et al*., 2024).

Onion is grown in all districts of Bangladesh, but among them, Pabna has the largest onion production rate. About 800,000 tones onion is produced in Pabna district alone, which is one-third of the total production (BBS, 2023). Despite being a leading onion-producing district, productivity in Pabna remain low and insufficient (Haque *et al*., 2011). For increasing onion yield, the agricultural extension department is trying to promote improved technologies, but the national average onion yield could not go up from 13.78 t/ha with higher yield variations among farmers (Khan *et al*., 2024). Again, farmers follow different management practices depending on their infrastructure and socioeconomic conditions, which ultimately leads to variability in yields (Zegeye *et al.,* 2024). Past research identifies that various onion growers in the country are getting much below or above the average national onion production. Therefore, it is essential to identify the socio-economic and biophysical factors that determine farmers' placement into low, medium, and high onion yield groups. Several studies have been conducted at global, national, and regional levels on onion production, productivity, technical efficiency, and so on. To the best of the authors' knowledge, limited empirical evidence exists on yield-category variation of onion in Bangladesh. The study was, therefore, was conducted to explore the scenario of onion yield in Pabna district and determine the factors affecting the onion yield variation among the farmers of Pabna district.

Materials and Methods

Study area

The study area was carefully selected to ensure the representative results. So, we selected the Pabna district purposively. Subsequently, Sujanagar upazila was purposively selected, and farmers were chosen randomly. The rationale behind this selection is that Pabna district is predominantly agro-based and onion is the second most dominant crop (first is jute). Farming is the principal occupation of the majority of the population, and livelihoods largely depend on agricultural activities.

Data sources

The present study primarily relies on farm-level primary data; therefore, a survey was conducted in the Pabna district. A well-designed and pre-tested questionnaire was used to collect both quantitative and qualitative information. Data comprised household's socioeconomic characteristics (household education level, farming experience), land holding (agricultural land, plot size, land ownership, area under onion), farm input utilization (fertilizers, pesticides, weedicides), farm output (onion yield). Secondary information was collected from published and unpublished documents to support research findings.

Exploratory data analysis

Initially, descriptive (Table 1) and inferential analyses were conducted to understand the characteristics of the data. Then, to meet the objectives, ordered logistic regression also known as proportional odds model was applied to identify the factors impacting onion yields at different yield groups of low, medium, or high. This category is made inspiring the national minimum yield 13.78 t/ha and maximum yield 19.7 t/ha (Khan et al., 2022), because, instead of arbitrarily defining "low" or "high" yield categories, the national minimum-maximum yield provides a data-driven and scientifically defensible threshold for classification. Previous research suggests that variation in yields of crops of the study area is a common feature on grounds of varying agro-ecological and socio-economic conditions of the households. Present study also proves this, for example, some farmers achieved onion yield much below the mean yield level of the sample farmers and others crossed yield beyond the mean yield. In practice, ordered logistic or ordered probit regression models are suitable for analysing yield variation when the dependent variable is categorical. Here, onion yield are categorised using nationa categories of low, medium or high were regressed on some explanatory variables through ordered logistic regression. We know that soil parameters are considered important explanatory variables that may have influence on the variation of production. But in this study, the data collection was confined to 2-3 nearby unions within the same upazila and generally, no difference is found in the soil parameters between the nearby unions. Therefore, soil parameters were not included as explanatory variables in this study. In current study, yield categories are taken as 1, 2, and 3 to represent low, medium or high yield groups. By comparing average yield of sample farmers with the world's average onion yield, we have developed categories of dependent variable.

Table 1. Descriptions and measurements of variables

Variable	Measurement	Description
Yield group	Low, medium, and high	Group 1 = low, yield less than 13.78 ton/ha, 2 = medium, yield within ≥ 13.78 and ≤ 19.7, and 3 = high if more than 19.7 ton/ha
Education	Below SSC, above SSC	Respondent's education, 1= below SSC, and 2= above SSC
Age group	Young, middle-aged, and old-aged)	Group 1= young, age up to 35 years, 2= middle aged, 36 to 50 years, and 3= old aged, above 50 years
Plot size	Marginal, small, and medium	Group 1= marginal farm, up to 0.2 ha, 2=s mall farm, 0.21 to 1.0 ha, and 3= medium farm, 1.01 to 3.0 ha
Variety	Hybrids, Kings, Rani-1, Sukhsagor, Taherpuri	Farmer's used o nion variety, 1= Hybrids, 2= Kings, 3= Rani-1, 4= Sukhsagor, 5=Taherpuri
Fertilizer	kg	Quantity of fertilizers used in total kg per hectare
Pesticides	Sprays	Number of pesticide sprays on the onion vegetable
Weedicide	Sprays	Number of weedicide sprays for weed management
Prior harvest	Yes/No	Farmers harvest some onions before harvesting time, yes, or no
Land owner	Self/Lease	Land ownership of the respondents, 1= self, and 0 otherwise
Experience	Low, medium, High	Onion cultivation experience, low = 1, up to 5 years of, medium = 2, 6 to 11 years, and high=3, above 11 years

An ordered logistic model estimates the probability of falling into a specific category based on the independent variables, assuming that the effect of these variables is consistent across all categories of the dependent variable.

$$P_{ij} = P_r(y_j = i)P_r(k_{i-j} < x_j\beta + u_j \leq k_i) = \frac{1}{1+\exp(-k+x_j\beta)} - \frac{1}{1+\exp\,(-k-1+x_j\beta)}$$

Here, y_j is supposed to be logistically distributed in ordered logit and the coefficients of β (β_1, β_2, β_3,.., β_k) along with the cut-points k_1, k_2,...,k_{k-1}, where k means the number of possible outcomes.

Statistical software

Data input, organization, manipulation, editing, report, recoding etc. were conducted using Excel. Statistical measures as a number, range, mean, variance, standard deviation etc. were used in describing the variables whenever applicable. Exploratory data analysis and ordinal logistic regression were conducted using R Studio, version 2024.12.1+563. In this study, R software was used for our analysis, and extreme events. And the rest of the works were done in an Excel File.

Results and Discussion

Descriptive results

According to preliminary results, the average yield is estimated as 17.87 t/ha, ranging from 10.18 to 26.14 t/ha (Table 2). Two key observations emerge from these results. First, a wide output difference among farmers is evident from the values of variance and standard deviation. Second, the average yield seems to follow normality due to the median yield of 17.61 and the coefficient of skewness of -0.03 (fairly symmetric). Therefore, greater efforts are required to reduce the wide yield gap between low- and high- onion growers. Moreover, the current onion yield of 17.87 t/ha in Pabna district is well above the national average onion yield of 13.78 t/ha in the country.

Table 2. Descriptive statistics of yield

Parameters	Yield (t/ha)
Average	17.87
Standard deviation (SD)	4.10
Minimum	10.18
Maximum	26.14
Median	17.61
Variance	16.81
Skewness	-0.03
No. of observations	40

Table 3 below reveals frequency, percent of farmers, and average yields coming under three onion yield levels. A large number of respondents (47.5%) obtained a yield of the middle category, covering yield from 13.78 to 19.7 t/ha. So, it appears that the medium level category would have a higher probability of entering into a higher onion yield category. Around 37.5% farmers could obtain a high yield level, while about 15% achieved a low yield level. All this implies that the combined probability of both low and medium farmers might be higher of entering into the higher yield category than large farmers, as evident from the joint percentage (62.5%) of farmers subject to providing appropriate farm input packages and given their prevailing socio-economic and agro-ecological characteristics.

Table 3. Statistics on average yield by category

Statistics	Frequency	Percent	Cumulative percent	Mean yield	SD
Low	6	15	15	11.46	1.17
Medium	19	47.5	62.5	16.54	1.66
High	15	37.5	100	22.12	1.86
Total	40	100		17.87	

SD = Standard Deviation

Econometric Results

Table 4 presents ordered logistic regression estimates using R Studio. Total 40 observations used in the analysis are displayed at the start of the output table. The model was compared with a saturated model (Likelihood ratio value and associated p-value are shown in the table) and no significant difference was observed, hence the model can explain the variability of onion yield reliably. We can see that the predictor variables significantly affect the onion yield categories of onion growers. The effect of individual variables is elaborated with reference to respective coefficients and associated t-values with two-tailed *p*-values. Positive coefficients indicate that higher levels of these variables increase the likelihood of farmers attaining higher onion yield categories. Conversely, farmers with more units of the variables may have less probability of entering into a higher yield group.

Overall, 5 variables are found statistically significant but with different significance levels and signs. Positive and significant coefficient holder variables inform that, remaining variables included in the model being the same, farmers of old age, having a small plot, having medium or higher level of experience of onion cultivation, and using fertilizer tend to have higher onion yield levels per hectare. On the contrary, the Kings and Taherpuri varieties are negatively but significantly affecting onion production.

Holding other variables constant, for old farmers, the log odds of being in a higher yield category versus the combined low and medium yield categories are higher than those of young farmers. This may be because old farmers tend to be more experienced and bear greater responsibility for the household livelihoods. Generally, they are more devoted to farming activities than the young farmers. This ultimately contributes to higher onion yields.

Keeping other variables constant, for the farmers who have cultivated onion in a small plot, the log odds of obtaining higher onion yield versus the combined low and medium yield categories are higher than the farmers who use marginal plot size. This confirms that farmers with small plot sizes allow them to produce a greater quantity of onions which enable them to derive greater benefits from onion production than farmers having marginal plot.

Furthermore, some of the varieties of onion also significantly affect the onion yield. Holding other variables constant, for the farmers using Kings variety, the log odds of being in a higher yield category versus the combined low and medium yield categories are less as compared to the farmers using Hybrid variety. Similarly, for the farmers using Taherpuri variety, the log odds of being in a higher yield category versus the combined low and medium yield categories are less as compared to the farmers using Hybrid variety if other factors remain constant.

Farming experience in onion production has a positive and significant effect on onion yield. Assuming other factors remain unchanged, for the farmers who have medium experience in farming, the log odds of being in a higher yield category versus the combined low and medium yield categories are higher than the farmers who have low farming experience. Again, for the farmers who have higher experience in farming, the log odds of being in a higher yield category versus the combined low and medium yield categories are higher than the farmers who have low farming experience if other factors remain constant. This indicates that experience in years that the farmer would have engaged in onion production improves the farmer's abilities in production as farmers becoming more familiar with the production environment and gaining greater expertise in onion cultivation. This helps to the greater onion yield in fact.

Keeping other variables constant, the farmers may have more probability of obtaining higher onion yield versus the combined low and medium yield categories if they apply more fertilizers. For example, one unit (kg in this case) increase in fertilizer, we expect a 0.14 increase in the log odds of being in a higher yield level versus the joint effect of low and medium categories. This indicates that the use of fertilizer enhances onion production by improving soil fertility and providing essential nutrients to the onion crop.

Some variables such as pesticides, prior harvest, land ownership, weedicides and education are not significantly affecting the yield categories but still these bear theoretically expected signs. For example, pesticides and weedicides have positive signs while prior harvest, land ownership and education variables have negative signs. Applying pesticides and weedicides have more probability of going to a higher onion yield group as evident in results of ordered logistic regression. The farmers who have done prior harvest may have less probability of shifting to a higher yield category than farmers who haven't done prior harvest. Again, the farmers who have own land, may have less probability of being in a higher yield category than the farmers who have leased land. Moreover, farmers above SSC education may have less probability of shifting to a higher yield category than the farmers below SSC level of education.

Table 4. Parameter estimates for three yield groups

Ordered logistic regression		Observations		40
Variables	Coefficient	SE	t-value	p-value
Young (ref. category)				
Middle-age	9.53	6.23	1.52	0.126
Old age	12.61	6.61	1.90	0.056*
Marginal plot (ref)				
Small plot	34.18	6.54	5.23	0.000***
Hybrid (ref)				
Kings	-33.10	9.27	-3.57	0.000***
Rani-1	-9.45	7.93	-1.19	0.233
Sukhsagor	-2.58	14.61	-0.18	0.859
Taherpuri	-100.99	6.54	-15.44	0.000***
Pesticides	5.73	8.13	0.74	0.481
No prior harvest (ref)				
Prior harvest	-6.42	9.12	-0.70	0.481
Land ownership lease (ref)				
Land ownership self	-4.37	3.52	-1.24	0.214
Low experience (ref)				
Medium experience	16.63	3.00	5.54	0.000***
High experience	17.48	3.03	5.77	0.000***
Fertilizer	0.14	0.08	1.66	0.096*
Weedicides	8.93	5.60	1.59	0.111
Education below SSC (ref)				
Education above SSC	-6.34	12.39	-0.51	0.609
1|2	17.62	4.62	3.81	0.000
2|3	73.18	16.45	4.44	0.000
Likelihood Ratio and P-values				9.13 and 1.0

Note: *P≤0.1; **P≤0.05; ***P≤0.01; SE = Standard Error

Zegeye *et al*., (2024) explained the factors which have a great impact on onion production in Raya Kobo district, Ethiopia. They found that factors such as gender, age, education level, experience, labor force, land size, access to extension services, irrigation water, land plough frequency, and fertilizer availability have positive and significant influence on onion production among farm households in the study area. However, excessive fertilizer use was found to have a negative effect. On the other hand, our study has found out that farmer's age, plot size, experience, variety of onion, and fertilizer use can significantly affect the onion yield categories. Among them, old farmers, small plot size, medium or higher experienced farmers and fertilizer use have positive effect which can enhance the onion yield of higher levels. Education level is not significant in this study but it was found from the paper of Zegeye *et al*. (2024) education as a positive and significant variable. Again, they didn't include variety of onion which is one of the most important explanatory variables that has significant effect on onion yield variation among farmers.

Limitations

This study has several limitations that should be considered when interpreting the results. First, the relatively small sample size may limit the statistical power and increase the variability of the estimated effects. Second, some extremely large coefficient estimates observed in the model could indicate potential overfitting or the influence of outliers, which may distort the true relationships between variables. Third, the choice of model may not fully capture the underlying data structure, and alternative model specifications might provide different insights. Finally, given these constraints, caution should be exercised in generalizing the findings to other contexts or for future projections, as the results are specific to the study conditions and dataset used.

Conclusion

The main aim of this study was to identify socio-economic and farm-input factors that influence farmers' placement into low, medium, and high onion yield categories. Using data collected from randomly selected farmers in Pabna, an ordered logistic regression analysis was conducted to understand the factors behind onion yield variation. The results highlighted several important variables, including older farmers, small plot size, medium or high farming experience, and fertilizer use, which positively contribute to achieving higher onion yields. These findings show that demographic, socio-economic, institutional, and farm-specific factors all play a key role in explaining yield differences among farmers, emphasizing the need to consider a wide range of influences when aiming to improve onion production in the study area.

Recommendations

Based on these findings, it is recommended to strengthen agricultural extension services so that farmers receive practical farm management advice and can enhance their farming experience. Providing additional support and facilities to smallholder farmers can help them achieve higher onion yields. Efforts should also focus on the proper and balanced use of fertilizers, pesticides, and weedicides to increase production efficiency and improve yield quality. Finally, implementing training programs for medium and highly experienced farmers can further boost productivity by promoting best agronomic practices. Together, these measures can help reduce yield variation and support higher onion production in the study area.

References

Akter, S., K. T. Rahman, A. R. Anik, and M. R. Amin. 2023. Growth and trend analysis of onion production in Bangladesh. *Annals of Bangladesh Agriculture* **27**(2): 201-210.

Anjum, A., And B. K. Barmon. 2017. Profitability and comparative advantage of onion (Allium cepa) production in Bangladesh: An economic study in some selected areas. *The Agriculturists* **15**(2): 66-78.

Bapari, M. Y., M. K. I. Chowdhury, M, M. E. Haque, and A. Al-Mamun. 2016. Economic analysis of onion production in Sujanagar and Santhia areas of Pabna, Bangladesh. *International Journal of Humanities and Social Science Invention* **5**(10): 5-12.

BBS. 2023. Yearbook of Agricultural Statistics of Bangladesh-2023. 35th Series, Published: June 2024. Bangladesh Bureau of Statistics, Statistics & Informatics Division, Ministry of planning, Government of the People’s Republic of Bangladesh, p. 144, 162.

Fatima, M. K. 2021. Use of modern onion cultivation practices by the farmers of Pabna district (Doctoral dissertation, department of agricultural extension and information system, Sher-E-Bangla Agricultural University, Dhaka-1207).

Haque, M. A., M. M. Miah, S. Hossain, M. S. Rahman, andM. Moniruzzaman. 2011. Profitability of onion cultivation in some selected areas of Bangladesh. *Bangladesh Journal of Agricultural Research* **36**(3): 427-435.

Hossain, M. M., F. A. R. U. Q. Abdulla, and I. Parvez. 2017. Time series analysis of onion production in Bangladesh. *Innovare Journal of Agricultural Science* **5**(1): 1-4.

Islan, M. S., K. M. Rahman, M. K. Hasan, and K. M. Adnan. 2011. Present Status and Potentiality of Onion Production in Bangladesh. *Bangladesh journal of political economy* **27**(1-2): 253-264.

Jubayer, M. A., M. A. Alam, M. F. Imam and M. F. Hasan. 2024. Growth, Instability in Production and Price Forecasting of Onion in Bangladesh. *Journal of the Bangladesh Agricultural University* **22**(3): 377-385.

Khan, M., M. Rahman, and R. Sarker, R. 2022. Effect of variety and seed rate on yield and quality of onion (*Allium cepa* L.) SETS. *Program Leader*, 244.

Khan, M. A., M. M. Haque, M. A. Islam, R. Sarker, and M. M. Rahman. 2024. Effect of technological interventions on yield gap analysis and profitability of winter onion (*Allium cepa* L.) varieties. *Archives of Agriculture and Environmental Science* **9**(4): 722-727.

Mila, F. A., and M. T. Parvin. 2019. Forecasting area, production and yield of onion in Bangladesh by using ARIMA model. *Asian Journal of Agricultural Extension, Economics & Sociology* **37**(4): 1-12.

Vohra, S. B., M. Rizman. And J. A. Khan. 1974. Medicinal use of common Indian vegetables. *Planta Medica* **23**(4): 381-393.

Zegeye, M. B., T. A. Alemu, M. A. Sisay, S. G. Mulaw, S. G., and T. W. Abate. 2024. Factors affecting onion production: An empirical study in the Raya Kobo district, Amhara regional state, Ethiopia. *Plos one***19**(6):134-305.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 473-487, March 2026

IMPROVEMENT OF CROPPING PATTERN BY INCORPORATING SESAME IN THE FALLOW LAND BEFORE MUSTARD– B. AMAN RICE IN CUMILLA DISTRICT

M. J. UDDIN[1]

Abstract

An on-farm study at Kesobpur, Titas, Cumilla (AEZ-19) during 2022–23 and 2023–24 evaluated an improved cropping pattern—Mustard (BARI Sarisha-18)–Sesame (BARI Til-4)–B. *Aman* rice (BRRI dhan91)—against the farmers' existing Mustard (Tori-7)–Fallow–B. Aman rice (Furchun). The improved system, tested in an RCBD with five replications, significantly ($P < 0.05$) increased yields of all component crops. Mean rice equivalent yield (REY) was 15.32 ± 0.33 t ha^{-1}, 151% higher than the existing pattern. Production efficiency, land-use efficiency, harvest index, gross return (Tk. 329,757 ± 7,000 ha^{-1}), and gross margin (Tk. 209,860 ± 6,250 ha^{-1}) were also significantly higher. The marginal benefit–cost ratio (4.39) confirmed economic superiority. The Mustard–Sesame–B. *Aman* rice pattern is statistically and agronomically superior and recommended for wider adoption in AEZ-19 and similar agro-ecological zones of Bangladesh.

Keywords: Mustard–Sesame–B.*Aman* rice, Cropping pattern, Rice equivalent yield, Production Efficiency, Land-use efficiency and Profitability.

Introduction

Bangladesh agriculture faces the pressing challenge of ensuring food and income security for a rapidly growing population amid severe constraints on the horizontal expansion of arable land. Consequently, future increases in agricultural production must rely largely on vertical intensification including enhanced yield per unit area, increased cropping intensity, and efficient utilization of fallow periods by improving crop sequencing and varietal replacement (FAO, 2021; BBS, 2022). In this context, optimization of existing cropping patterns is a key strategy for improving land-use efficiency and farm profitability. A cropping pattern represents the annual sequence and temporal arrangement of crops within a given land area, shaped by climatic conditions, soil properties, rainfall, irrigation facilities, crop varieties, input availability, market access, and technological advancement (Hossain *et al*., 2018). Previous studies have shown that rational modification of cropping patterns, particularly by including short-duration crops in fallow periods,

[1]Principal Scientific Officer, On-Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Shasongacha, Cumilla-3500, Bangladesh.

can substantially enhance system productivity and farmers' income without exerting additional pressure on limited land resources (Islam *et a*l., 2020). Cropping system intensification and diversification are recognized globally as key strategies for enhancing productivity and sustainability in smallholder agriculture (Cassman, 1999; Tilman *et al*., 2002.

Rice-based cropping systems dominate Bangladeshi agriculture. For irrigated ecosystems, the Bangladesh Rice Research Institute (BRRI) recommended the transplanted *Aman*–mustard–Boro cropping pattern using short-duration mustard varieties such as Tori-7 (70-75 days) during the transition between T. *Aman* and Boro rice (Khan *et al*., 2004). However, traditional local mustard variety produce low yield and return limited economic value due to poor genetic potential and susceptibility to pests and diseases, thereby constraining overall system productivity (Ali *et al*., 2019).

To overcome these limitations, the Bangladesh Agricultural Research Institute (BARI) has developed high-yielding yellow-seeded mustard varieties, including BARI Sarisha-18, which possess higher yield potential and improved oil quality compared to Tori-7 (BARI, 2021). These varieties, with a growth duration of about 92-94 days, offer opportunities for diversifying rice-based cropping systems. In addition, sesame (*Sesamum indicum* L.), a short-duration and drought-tolerant oilseed crop, has proven suitable for cultivation during fallow periods, contributing to increased cropping intensity, income diversification, and reduced production risk (Rahman *et al*., 2020).

In Cumilla district, particularly in the Kasobpur area of Titas Upazila, the mustard–fallow–B. *Aman* rice cropping pattern is widely practiced, covering about 10.76% of the cultivated land (DAE, 2020). Despite its dominance, this system remains characterized by inefficient use of the fallow period and low land productivity. Studies elsewhere in Bangladesh have demonstrated that replacing fallow periods with oilseed crops such as sesame can significantly enhance system productivity and profitability, while mustard residues contribute to improved soil fertility and performance of succeeding rice crops (Singh and Ghosh, 1999; Islam *et al*., 2017. However, location-specific on-farm evidence on the agronomic and economic feasibility of replacing the existing mustard–fallow–B. *Aman* system with an intensified mustard–sesame–B. *Aman* rice cropping pattern using high-yielding varieties remains limited in the Cumilla district. Therefore, the present study was conducted to evaluate the productivity and profitability of an improved mustard–sesame–B. *Aman* rice cropping pattern through varietal replacement and crop inclusion under farmers' field conditions to provide practical insights for the sustainable intensification of rice-based cropping systems in AEZ-19 and similar agro-ecological regions of Bangladesh.

Materials and Methods

Experimental site and agro-ecological conditions

The on-farm trial was conducted during two consecutive cropping cycles (2022–23 and 2023–24) to increase crop productivity through varietal replacement of mustard and transplanted *Aman* (B. *Aman*) rice in the existing cropping system Mustard (Tori-7)–Fallow–B. *Aman* (*Furchun*). The experiment was carried out at farmers' fields in Cumilla district, which falls under the Old Meghna Floodplain Agro-Ecological Zone (AEZ-19). The experimental area is located between 24°16′ N latitude and 90°89′ E longitude. The land was classified as lowland with good drainage. The soil was sandy loam in texture, belonging predominantly to Dark Grey Floodplain soils. Soil reaction ranged from slightly acidic to nearly neutral (pH 5.3–5.4). Organic matter content was low, and the overall fertility status of the soil was poor, with low levels of nitrogen (N), phosphorus (P), potassium (K), and Boron (B). Topsoil was acidic to neutral, while subsoil was neutral in reaction.

The climate of the study area is subtropical monsoon. The majority of annual rainfall occurred from April to September, while the crops grown during the *Rabi* and pre-*kharif* seasons received about 140.5 mm of rainfall from October to March. During the study period, the monthly mean maximum and minimum temperatures were 31.9°C and 19.3°C, respectively, with an annual rainfall of approximately 2024 mm and a mean relative humidity of 82.7%. The highest temperature (33.9°C) was recorded in August, whereas the lowest (10.1°C) occurred in December. Relative humidity ranged from 75.2% in March to 84.5% in August (Bangladesh Meteorological Department, 2024).

Experimental design and treatments

The experiment was laid out in a randomized complete block design (RCBD) with five dispersed replications. Two cropping patterns were evaluated as treatment variables: (i) Improved cropping pattern: Mustard (BARI Sarisha-18) – Sesame – B. *Aman* rice (BRRI Dhan91), and (ii) Farmers' existing pattern: Mustard (Tori-7) – Fallow – B. *Aman* rice (*Furchun*). Each unit plot measured 400 m^2.

Crop management practices

Mustard: Mustard was grown during the *rabi* season as the first crop in the sequence. In the improved pattern, BARI Sarisha-18 was sown using the broadcast method at a seed rate of 7 kg ha^{-1}. Sowing was done during 4-5 November 2022 and 10-12 November 2023, while harvesting took place during 6–8 March 2023 and 11–25 February 2024, respectively. Fertilizers were applied following the Fertilizer Recommendation Guide (FRG, 2018). Intercultural operations, including weeding and pest management, were performed as required.

Sesame: Sesame was cultivated as the second crop in the improved cropping sequence. Seeds were broadcast at a rate of 7-8 kg ha^{-1}**.** The crop was sown during 15-18 March 2023 and 10-25 March 2024**,** and harvested during 15-18 June 2023 and 5-10 June 2024, respectively. Recommended fertilizer doses and intercultural operations were followed to ensure optimum crop growth.

B. Aman rice: B. Aman rice was the third crop in both cropping patterns. In the improved pattern, BRRI Dhan91 was used, while farmers' local variety *Furchun* was maintained in the existing pattern. Seeds were broadcast at a rate of 30 kg ha^{-1} during 20–25 June in both years. Fertilizer application and crop management practices were followed according to BRRI (2013) guidelines. Rice was harvested on 20 November 2023 and 8 November 2024 in the respective seasons. Plants were harvested, leaving approximately 15 cm stubble height, and the remaining residues were incorporated into the soil.

Crop establishment and calendar: Mustard was sown during late October to early November (Rabi season) and harvested in January. Sesame was sown immediately after mustard harvest in late January to early February and harvested in April. B. Aman rice was established in July under rainfed conditions using broadcast seeding and harvested in November. These planting windows correspond to the prevailing cropping calendar of AEZ-19 in Cumilla.

Data collection and analysis: Agronomic performance of the cropping patterns was evaluated using parameters such as field duration, rice equivalent yield (REY), production efficiency, and land utilization index (LUI). Standard procedures were followed for calculating these indices to compare the productivity and efficiency of the improved and existing cropping systems.

Rice Equivalent Yield (REY): For comparison between crop sequences, the yield of every crop was converted into rice equivalent yield on the basis of the prevailing market price of the individual crop (Verma and Modgal, 1983). REY was calculated to compare productivity of different crops on a common basis using prevailing market prices:

REY (t ha^{-1}) = Σ (Yield of crop × Price of crop) / Price of rice

Production Efficiency: Production efficiency value in terms of kgha^{-1}day^{-1} was calculated the total main product in a cropping pattern divided by the total duration of crops in that pattern (Tomar and Tiwari, 1990). Production efficiency was computed as:

PE (kg ha^{-1} day^{-1}) = REY / Twhere T is the total duration of the cropping system (days).

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

UE (%) = $(\Sigma d_i / 365) \times 100$

where d_i is the duration (days) of the i-th crop

Harvest Index (HI) is a measure of a crop's efficiency in converting total biological yield

(biomass) into economic yield (the usable harvested portion such as grain, seed, or tuber). It indicates how effectively a plant partitions dry matter to the harvested product. It was calculated by the following formula:

HI = Economic yield / Biological yield or expressed as percentage:

HI (%) = (Economic yield / Biological yield) × 100

Profitability Analysis

Economic performance was assessed using gross return, gross margin, and marginal benefit–cost ratio (MBCR). Marginal Benefit–Cost Ratio (MBCR) is an economic indicator used to evaluate the additional return obtained from an improved technology or treatment compared with an existing practice, relative to the additional cost incurred. It shows how much extra benefit is gained for each additional unit of cost invested. The Marginal of prevalent pattern (F) and any potential replacement (E), which was computed as (CIMMYT, 1988).

MBCR = (Gross return_1 − Gross return_0) / (Cost_1 − Cost_0) Where, Gross return_1 = Gross return from improved technology/patter, Gross return_0 = Gross return from existing (control) practic, Cost_1 = Cost of improved technology/patter and Cost_0 = Cost of existing practice

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) appropriate for RCBD. Year effects were tested, and data were pooled over years after confirming homogeneity of variance. Treatment means were compared using the least significant difference (LSD) test at the 5% level of probability. Standard errors were calculated to indicate variability among replications. The experiment was laid out in a randomized complete block design (RCBD) with five replications and two cropping patterns over two years. The data were subjected to analysis of variance (ANOVA) using the following model:

$Yijk=\mu+Ti+Yj+(TY)ij+Rk(Yj)+\varepsilon ijk$

Where, Yijk = observed response, μ = overall mean, Ti = treatment effect, Yj = year effect, (TY)ij = treatment × year interaction, Rk(Yj) = replication effect within year, εijk = error term.

Homogeneity of variance across years was tested; non-significant treatment × year interactions allowed pooling of data over years. Mean comparisons were performed using least significant difference (LSD, 0.05) and standard errors (SE) were reported. Significant differences are denoted by different letters in tables ($P \leq 0.05$).

Results and Discussion

Crop management and field duration

Crop management practices, including sowing/transplanting dates, harvesting time, fertilizer application, intercultural operations, and plant protection measures for both the improved and farmers' existing cropping patterns, are presented in **Table 1**. Variation in crop duration among the component crops was primarily influenced by varietal characteristics and cropping sequence.

Under the improved cropping pattern**-** Mustard (*BARI Sarisha-18*)–Sesame (*BARI Til-4*)–B. Aman rice (*BRRI dhan91*)- the mean field duration of mustard ranged from 90 to 95 days, while sesame occupied the field for 85 to 90 days. The field duration of B. Aman rice varied from 139 to 141 days. In contrast, under the farmers' existing cropping pattern-Mustard (*Tori-7*)-Fallow–B. Aman rice (local variety *Furchun*)- the field duration of mustard was considerably shorter **(**60–68 days), whereas B. Aman rice required a longer duration (144–147 days).

As a result, the **total field duration** of the improved cropping pattern was markedly higher (**319–328 days**) compared with the existing pattern (**210-215 days**), reflecting the successful utilization of the fallow period through inclusion of sesame. Similar increases in total cropping duration and cropping intensity through the incorporation of short-duration oilseed crops have been reported by Sultana *et al*. (2021).

The longer duration of B. *Aman* rice in the existing cropping pattern was attributed to the use of a long-duration local variety (*Furchun*), whereas the improved pattern employed BRRI dhan91, which, despite being a high-yielding variety, matured slightly earlier **(**139–141 days). Early harvesting of BRRI Dhan91 during 8–20 November in both study years facilitated the timely sowing of mustard within the optimum planting window. Timely establishment of *Rabi* crops following *Aman* rice harvest is critical for achieving higher yields and better system productivity (Mondal *et al*., 2014; Rahman *et al*., 2020).

The turnaround time, the interval between harvest of one crop and sowing of the next, was substantially reduced in the improved cropping pattern **(**37-47 days**)** compared with the existing pattern **(**150–155 days). Reduction in turnaround time is a key indicator of improved land-use efficiency and has been identified as a major contributor to enhanced cropping intensity and profitability in rice-based systems (Hossain *et al*., 2018;

Grain/seed and by-product yield

Grain/seed and by-product yield of the component crops under the improved and farmers' existing cropping patterns are presented in Table 2. Yield performance varied markedly between cropping patterns and years, largely due to varietal replacement and improved crop management practices.

Under the improved cropping pattern**,** seed yield of mustard (*BARI Sarisha-18*) was 1.62 and 1.88 t ha^{-1} during the first and second years, respectively, with corresponding stover yields of 1.50 and 1.32 t ha^{-1}. The mean seed yield of *BARI Sarisha-18* **(**1.75 t ha^{-1}**) was** more than 84% higher than that of the local variety *Tori-7* grown in the farmers' existing pattern. The higher yield of *BARI Sarisha-18* may be attributed to its superior genetic potential and better response to recommended management practices, as also reported by Nazrul *et al*. (2013)

Sesame grown in the improved cropping pattern produced grain yields of 1.34 t ha^{-1} in the first year and 1.27 t ha^{-1} in the second year, with a mean yield of 1.31 t ha^{-1}. The corresponding mean stover yield was 2.31 t ha^{-1}. These yields are comparable with earlier findings for *BARI Til-4*, a short-duration and high-yielding sesame variety well suited for inclusion between mustard and B. *Aman* rice (Mondal *et al*., 2015).

Grain yield of B. *Aman* rice (*BRRI dhan91*) under the improved pattern was 3.25 and 3.55 t ha^{-1} in the first and second years, respectively. The mean grain yield (3.40 t ha^{-1}) and straw yield (3.44 t ha^{-1}) were 30% and 57% higher, respectively, than those obtained from the farmers' existing pattern, where the local variety *Furchun* was used. The yield advantage of *BRRI Dhan91* can be attributed to varietal superiority and the application of improved production technologies, which have been shown to significantly enhance rice yield in the *Aman* season (Nazrul *et al*., 2013).

In contrast, lower yields of both grain and by-products under the farmers' existing pattern were mainly due to the use of low-yielding local varieties, imbalanced fertilizer application, and suboptimal crop management practices. Overall, all component crops under the Mustard–Sesame–B. *Aman* rice sequence produced consistently higher grain/seed and by-product yields in both years compared with the farmers' existing cropping pattern. Similar yield improvements through varietal replacement and improved management in diversified rice-based systems have also been reported by Nazrul *et al*. (2013).

Field duration

The field duration of a cropping pattern is primarily governed by the growth duration of its component crops. In the farmers' existing cropping pattern (Mustard–Fallow–B. *Aman*), mustard variety *Tori-7* and local B. *Aman* variety *Furchun* were used. In contrast, the improved cropping pattern consisted of mustard (*BARI Sarisha-18*), sesame (*BARI Til-4*), and B. *Aman* rice (*BRRI Dhan91*).

BARI Sarisha-18 required approximately 26–27 days longer to reach maturity than *Tori-7*, whereas *BRRI Dhan91* matured in nearly the same duration as *Furchun*. The additional time required for mustard in the improved pattern was effectively compensated by the inclusion of sesame and better synchronization of crop sequences. As a result, production efficiency was higher in the improved cropping pattern than in the farmers' existing pattern (Table 1). Similar observations on improved production efficiency through crop diversification and varietal substitution in rice-based systems have been reported by Mondal *et al*. (2014).

Crop Yields and Field Duration

Grain/seed yields of mustard, sesame, and B. Aman rice were significantly higher ($P \leq 0.05$**)** in the improved cropping pattern than the farmers' existing system (Table 2). Mustard yield increased by 84% and B. Aman rice by 30%, while sesame yielded 1.31 t ha^{-1}. The improved system utilized the previously fallow period, increasing total cropping duration and reducing turnaround time.

Rice equivalent yield (REY): The overall productivity of the cropping systems was assessed using rice equivalent yield (REY), which integrates the yield performance of all component crops into a single comparable unit based on prevailing market prices. Table 3 showed that the improved cropping pattern recorded a substantially higher mean REY (15.32 tha^{-1}) than the farmers' existing cropping pattern. The improved pattern produced approximately 151% higher REY than the existing system, mainly due to the inclusion of sesame as an additional crop, adoption of high-yielding varieties of mustard and B. *Aman* rice, and improved crop management practices. In contrast, the farmers' pattern resulted in lower REY because of prolonged fallow periods, use of low-yielding local varieties (*Tori-7* and *Furchun*), and traditional management practices. Mean REY of the improved system was 15.32 ± 0.33 t ha^{-1}, significantly higher than the existing pattern (6.10 t ha^{-1}, $P \leq 0.05$) (Table 3). Inclusion of sesame and high-yielding varieties contributed to this increase. Similar improvements in REY following cropping system intensification and oilseed inclusion in rice-based systems have been reported by Khatun *et al*. (2016) and Nazrul *et al*. (2017).

Table 1. Agronomic parameters of improved pattern and farmers' existing pattern at MLT site Chandina under Titas, Cumilla, during 2022-23 and 2023-24

Parameters	Year	Improved Pattern (IP)			Farmers' Practice (FP)		
Crop	2022-23	Mustard	Sesame	B.*Aman*	Mustard	Fallow	B.*Aman*
	2023-24	Mustard	Sesame	B.*Aman*	Mustard	Fallow	B.*Aman*
Variety	2022-23	BARI Sarisha-18	BARI Til-4	BRRI dhan91	Tori-7	--	Farchun
	2023-24	BARI Sarisha-18	BARI Til-4	BRRI dhan91	Tori-7	-	Farchun
Sowing/ planting time	2022-23	4-5 Dec	15-18 March	25 June	10 Nov	-	15 June
	2023-24	07-12 Nov.	08-16Feb.	21-25 Jul.	25 Nov.	-	26 June
Spacing (cm)	2022-23	Broadcast	Broadcast	Broadcast	Broadcast	-	Broadcast
	2023-24	Broadcast	Broadcast	Broadcast	Broadcast	-	Broadcast
Fert. dose (N-P-K-S-Zn-B kg ha^{-1})	2022-23	115-34-42.5-27.3-1.8-1.7	57.6-30-25-20-1.8-1.7	89.4-12-52-12.4-5.4-2.04	56.9-39.6-62.5-		56.9-16.5-16.5
	2023-24	115-34-42.5-27.3-1.8-1.7	57.6-30-25-20-1.8-1.7	89.4-12-52-12.4-5.4-2.04	56.9-39.6-62.5-		56.9-16.5-16.5
Harvesting time	2022-23	06-08 March	15-18 Jun	20 Nov.	15 Jan.	-	6 Nov.
	2023-24	11-25 Feb.	05-10 Jun	08 Nov.	31 Jan	-	20 Nov.
Field duration (days)	2022-23	92	90	146	66	-	144
	2023-24	95	85	139	68	-	147
TAT (days)	2022-23	15	10	12	4	-	151
	2023-24	7	25	14	5	-	145

Note: IP= Improved Pattern and FP=Farmers' Pattern.

Table 2. Seed/grain yield and by-product of Mustard-Sesame-B.*Aman* rice cropping patterns under improved and existing patterns at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year		Grain/Seed yield (t\ha)			By-product yield (t\ha)		
	Pattern	Mustard	Sesame	B.*Aman*	Mustard	Sesame	B.*Aman*
2022-23	IP	1.620	1.34	3.25	1.50	2.16	2.53
	FP	0.998	Fallow	2.50	1.45	Fallow	3.50
2023-24	IP	1.880	1.27	3.55	1.32	2.45	2.58
	FP	0.902	Fallow	2.25	1.30	Fallow	3.44
Mean	IP	1.750	1.31	3.40	1.41	2.31	2.52
	FP	0.950	Fallow	2.38	1.43	Fallow	3.47
LSD (0.05)		0.08	0.05	0.10	-	-	-
SE		0.04	-	0.05	-	-	-

Table 3. REY, production efficiency, land utilization index, and harvest index of improved pattern and existing patterns at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year	Pattern	REY (tha-^{1})	Production efficiency	Land utilization index (%)	Harvest index (%)
2022-2023	IP	13.638	18.93	89.5	50.0
	FP	6.09	16.62	61.5	41.41
2023-2024	IP	16.99	21.00	89.9	51.34
	FP	6.1	15.49	58.6	39.94
Mean	IP	15.32	19.97	89.6	50.67
	FP	6.095	16.06	60.6	40.68
LSD (0.05)		0.65	1.20	2.1	1.5
SE		0.33	0.60	1.05	0.75

Table 4. Cost and return analysis of improved cropping pattern and existing cropping pattern at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year	Pattern	Gross returns (Tkha^{-1})	Total variable cost (Tkha^{-1})	Gross margin (Tkha^{-1})	MBCR
2022-2023	IP	340950	128890	212060	4.27
	FP	152320	84722	67598	
2023-2024	IP	318563	110903	207660	4.51
	FP	114375	65640	48735	
Mean	IP	329757	119897	209860	4.39
	FP	133347	75181	58166	
LSD (0.05)		14000	-	12500	-
SE		7000	-	6250	

Note: Different letters indicate significant differences at $P < 0.05$.

Production efficiency: Production efficiency, expressed as kgha^{-1} day^{-1}, varied significantly between the two cropping patterns (Table 3). The mean production efficiency of the improved cropping pattern was 19.97 kgha^{-1}day^{-1}, which was about 24% higher than that of the farmers' existing pattern. In the improved system, production efficiency ranged from 18.93 to 21.00 kgha^{-1}day^{-1} over the two study years, whereas the corresponding values for the farmers' pattern ranged from 15.49 to 16.62 kgha^{-1}day^{-1}. The higher production efficiency in the improved pattern was attributed to greater total system yield, efficient utilization of growing days, and superior performance of improved varieties. Similar findings have been documented by Nazrul *et al.* (2013), who reported higher production efficiency in diversified rice-based cropping systems with short-duration oilseed crops. Lower production efficiency in the farmers' pattern resulted from longer crop duration combined with lower yield output, leading to reduced productivity per unit time.

Land-use efficiency: Land-use efficiency indicates the proportion of the year during which land remains occupied by crops. The results revealed that the improved cropping pattern utilized land for 89.6% of the year, whereas the farmers' existing pattern used land for only about 60% (Table 3). The significantly higher land-use efficiency in the improved pattern was primarily due to the replacement of fallow periods with sesame cultivation, thereby minimizing idle land time. Similar increases in land-use efficiency through reduction of fallow periods and inclusion of short-duration crops have been reported by Islam *et al.* (2017) and Sultana *et al*. (2021).

Harvest index: The system-level harvest index was higher under the improved cropping pattern (50.67%) compared with the farmers' existing pattern. The higher harvest index reflects a greater proportion of economic yield relative to total biological yield, resulting from varietal replacement and improved crop management. The inclusion of sesame and the use of high-yielding mustard (*BARI Sarisha-18)* and B. *Aman* rice (*BRRI dhan91*) varieties contributed to higher grain and seed yields without a disproportionate increase in biomass. Similar improvements in harvest index through varietal substitution have been reported in diversified cropping systems (Nazrul *et al.,* 2013; Mondal *et al*., 2014).

Production efficiency in the improved pattern (19.97 ± 0.60 kg ha^{-1} day^{-1}) was significantly higher than the existing pattern (16.06 ± 0.60). Land-use efficiency increased from 60.6% to 89.6% and harvest index from 40.68% to 50.67% (all $P \leq 0.05$, Table 3).

Profitability analysis: Profitability analysis based on prevailing market prices indicated a clear economic advantage of the improved cropping pattern over the farmers' existing system (Table 4). The mean gross return from the improved pattern was Tk. 329,757 ha^{-1}, compared with Tk. 133,347 ha^{-1} from the farmers' pattern, representing a 147% increase. The mean total variable cost was higher in the improved cropping pattern (Tk. 119,897 ha^{-1}) than in the farmers' pattern (Tk. 75,181 ha^{-1}), mainly due to the additional cost of sesame cultivation and improved inputs. However, the gross margin of the improved pattern was substantially higher, being approximately 2.6 times greater than that of the farmers' existing system. The marginal benefit–cost ratio (MBCR) of 4.39 further confirmed the economic superiority and financial feasibility of the improved cropping pattern. Gross return, gross margin, and MBCR were significantly higher in the improved system (Table 4). Mean gross return increased by 147% and gross margin by 2.6 times relative to the farmers' pattern, confirming economic superiority ($P \leq 0.05$. Similar profitability gains from diversified and intensified rice-based systems have been reported by Khatun *et al*. (2016) and Rahman *et al*. (2020).

Study limitation and interpretation

A limitation of the present study is that the improved pattern differed from the farmers' practice in multiple components simultaneously, including varietal replacement (BARI Sarisha-18 vs. Tori-7; BRRI dhan91 vs. Furchun), inclusion of sesame during the fallow period, and improved crop management. Consequently, the observed improvements in productivity and profitability represent the combined effect of the integrated cropping system, and the individual contributions of sesame inclusion, varietal change, or management practices cannot be separated. Therefore, the results should be interpreted as system-level benefits rather than causal effects of any single intervention. Future studies employing factorial experimental designs (e.g., variety × crop inclusion × management) would allow partitioning of these effects and provide clearer attribution of yield gains.

Conclusions and Recommendations

The Mustard (BARI Sarisha-18)–Sesame (BARI Til-4)–B. Aman rice (BRRI dhan91) pattern produced higher system productivity, resource-use efficiency, and economic returns than the farmers' existing Mustard–Fallow–B. Aman rice system in AEZ-19. These improvements reflect the combined effects of varietal replacement, crop intensification through sesame inclusion, and improved management rather than any single factor. The pattern shows strong potential as a practical option for sustainable intensification of rice-based systems in medium and medium-low lands of AEZ-19 and similar environments. However, further multi-location and factorial studies are needed to confirm its broader applicability and to quantify the contributions of individual components. Wider demonstration through collaborative efforts of the Department of Agricultural Extension and Bangladesh Agricultural Research Institute may facilitate validation and adoption.

References

Ali, M. A., M. M. Rahman and M. A. Hossain. 2019. Performance of mustard varieties under different agro-ecological zones of Bangladesh. *Bangladesh Journal of Agricultural Research* **44**(3): 421–432.

Bangladesh Meteorological Department (BMD). 2024. *Climatological Data of Bangladesh: Cumilla Station.* Ministry of Defence, Government of the People's Republic of Bangladesh, Dhaka.

BARI.2021. *Oilseed Crop Varieties of Bangladesh*. Bangladesh Agricultural Research Institute, Gazipur.

BBS. 2022. *Statistical Yearbook of Bangladesh*. Bangladesh Bureau of Statistics, Dhaka

Cassman, K.G. 1999. Ecological intensification of cereal production systems.

CIMMYT (International Maize and Wheat Improvement Centre) 1988. Agronomic Data to Farmer Recommendation: An Economic Training Manual. International Maize and Wheat Improvement Centre, Mexico, D. F. p. 79.

DAE. 2020. *Upazila-wise Cropping Pattern Database*. Department of Agricultural Extension, Ministry of Agriculture, Bangladesh.

FAO. 2021. *Sustainable Crop Intensification in Asia*. Food and Agriculture Organization of the United Nations, Rome.

FRG. 2018. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka-1215, Bangladesh. 223 p

Hossain, M. I., M. M. Rahman and A. J. M. S. Karim. 2018. Cropping pattern dynamics and land-use efficiency in Bangladesh. *Bangladesh Journal of Agricultural Economics* **41**(1): 1–15.

Islam, M. S., M. A. Z. Sarker and M. J. Uddin. 2020. Yield performance of improved rice. varieties under different management practices. *Bangladesh Journal of Agricultural Research* **45**(2): 211–223.

Khan, M. A. H., M. A. Quayyum. and M. Maniruzzaman. 2004. Development of improved cropping patterns for irrigated ecosystems. *BRRI Annual Report*, Bangladesh Rice Research Institute, Gazipur.

Khatun, A., M. A. Z. Sarker and M. A. Hossain. 2016. Productivity and profitability of improved cropping patterns. *Bangladesh Journal of Agricultural Research* **41**(3): 453–466.

Mondal, R. I., F. Begum and M. A. Aziz. 2014. Crop diversification and system productivity in Bangladesh agriculture. *Bangladesh Journal of Agricultural Research* **39**(2): 241–254.

Mondal, R. I., M. S. Islam and M. A. Rahman. 2015. Sesame-based cropping systems for increased cropping intensity. *Bangladesh Agronomy Journal* **18**(1): 33–41.

Nazrul, M. I., M. A. Z. Sarker and M. A. Hossain. 2013. Productivity and profitability of improved rice-based cropping systems. *Bangladesh Journal of Agricultural Research* **38**(1): 35–48.

Rahman, M. A., R. Sultana, R. and M. S. Alam, M. S. 2020. Economic performance of intensified rice-based systems. *Journal of Crop and Weed* **16**(3): 45–52.

Rahman, M. M., M. H. Khan, R. N. Mallick and R. E. Hudgens. 1989. Guidelines for Farming Systems Research Methodology. Bangladesh Agricultural Research Council, Farmgate, Dhaka-1215. https://doi.org/xxxx

Singh, R. P. and P. K. Ghosh. 1999. Residual effects of oilseed crops on soil fertility and succeeding cereals. *Indian Journal of Agronomy* **44**(2): 248–252.

Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature* ***418***(6898): 671–677.

Tomer, S. S. and A. S. Tiwari. 1990. Production potential and economics of different crop sequences. *Indian J. of Agron.* **35**(1, 2): 30-35.

Verma, S. P and S. C. Modgal. 1983. Production potential and economics of fertilizer application as resource constraints in maize, wheat crop sequence. *Himachal J. Agric. Res.* **9**(2): 89-92.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 489-499, March 2026

EFFECT OF NITROBENZENE AND GIBBERELLIC ACID ON GROWTH, YIELD AND ECONOMIC RETURNS OF LATE-SOWN LENTIL (*LENS CULINARIS* L.)

M. M. Rahman[1], T. Tasmima[2], S. Ahmed[3], M. A. Razzak[4] and M. A. H. Khan[5]

Abstract

Plant Growth Regulators (PGRs) mitigate yield losses in late-sown lentils (*Lens culinaris* L.) by enhancing nutrient uptake and photosynthetic efficiency. A field experiment was conducted during the Rabi season of 2024-25 to evaluate the effects of different PGRs on growth, yield and economic performance of late sown lentil. The experiment utilized a Randomized Complete Block Design with five treatments and four dispersed replications. Treatments were T_1: Flora (20% nitrobenzene) @ 2 ml L^{-1} sprayed twice (35 and 50 DAS), T_2: Flora @ 2 ml L^{-1} sprayed once (50 DAS), T_3: GA_3 @ 0.2 g L^{-1} sprayed twice (25 and 50 DAS), T_4: GA_3 @ 0.2 g L^{-1} sprayed once (50 DAS) and T_5: control. Results indicated that PGR application significantly enhanced the growth, yield and yield contributing characters. The highest seed yield (1.94 t ha^{-1}) was obtained from T_1 due to the highest number of pods $plant^{-1}$ (50.6), while the lowest yield (1.43 t ha^{-1}) was achieved in control (T_5). Treatment T_1 providing a 35.7% yield increase over the control. T_1 also exhibited the maximum value of harvest index (63.8%) and the most profitable, obtaining the highest gross return (BDT 180,100 ha^{-1}), gross margin (BDT 100,300 ha^{-1}), and benefit–cost ratio (2.26). Results suggest that two foliar applications of 20% nitrobenzene @ 2 ml L^{-1} (at 35 and 50 DAS) are more effective than gibberellic acid for maximizing the yield and profitability of late-sown lentil.

Keywords: Gibberellic acid, late-sown, lentil, nitrobenzene, profitability, yield.

Introduction

Lentil (*Lens culinaris* L.) is one of the most important pulse crops of the Fabaceae family and has been consumed by humans since ancient times (Montejano-Ramírez and Valencia-Cantero, 2024; Hossain *et al.,* 2019). It is widely cultivated in South Asia, particularly in Bangladesh and India, due to its high nutritional value and adaptability to diverse agro-ecological conditions. Lentil seeds are a rich source of protein (about 25%), carbohydrates, dietary fiber, vitamins and essential

---

[1]Principal Scientific Officer, On-Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Faridpur, [2]Scientific Officer, On-Farm Research Division, BARI, Tangail, [3]Principal Scientific Officer, Regional Pulse Research Station, BARI, Madaripur, [4]Major, Remount Veterinary & Farms Corps (RVFC), Bangladesh Army, Savar, and [5]Principal Scientific Officer, On-Farm Research Division, BARI, Mymensingh, Bangladesh.

minerals, making them an affordable and nutritious food for human diets (Dhull *et al.,* 2023; Hossain *et al.,* 2019). In Bangladesh, increasing population pressure has led to intensive cultivation of cereal crops on fertile lands, forcing pulse crops like lentil to be grown mostly on marginal, low-fertility soils under rainfed conditions. Despite this limitation, lentil remains vital for human nutrition and livestock feed, offering higher digestible protein, calcium, and phosphorus than cereal residues (Samaranayaka, 2017). Lentil cultivation contributes significantly to soil health improvement and sustainability of cropping systems. As a leguminous crop, lentil can fix atmospheric nitrogen through symbiotic association with Rhizobium bacteria, thereby enriching soil nitrogen and organic matter. This biological nitrogen fixation reduces dependence on chemical fertilizers and enhances soil fertility, particularly in intensive cropping systems (Tairo and Ndakidemi, 2013). Approximately 85% of the nitrogen requirement of lentil is met through this natural process, which can substantially improve crop growth, grain quality and yield potential, reaching up to 2.0 t ha^{-1} under favorable management conditions (Ferdous, 2019). In the Faridpur region, lentil is cultivated on about 44 thousand hectares with a total production of nearly 57 thousand metric tons; however, the average yield remains relatively low (BSS, 2026). One of the major constraints to higher yield is delayed sowing caused by unexpected rainfall before or after the recommended sowing period. Late sowing shortens the vegetative phase and forces the crop to enter the reproductive stage prematurely, resulting in poor growth, reduced pod formation and ultimately lower yield (Jianghui Yu *et al*., 2024). To mitigate the adverse effects of late sowing, farmers in the Faridpur region often apply plant growth regulators (PGRs) without proper knowledge of appropriate dose and timing, which may increase production costs and pose potential environmental risks. Plant growth regulators such as nitrobenzene and gibberellic acid (GA_3) are widely used to manipulate plant physiological processes including vegetative growth, branching, flowering and yield formation (Vishnu and Brar, 2020; Kohombange *et al*., 2019).

Nitrobenzene, commonly formulated as 20% liquid, acts as a plant energizer and flowering stimulant. It enhances nutrient uptake efficiency, promotes vigorous vegetative growth and improves flower retention, resulting in increased pod formation and yield (Deb *et al.,* 2012). Nitrobenzene is readily absorbed by plant tissues and influences biochemical pathways associated with nutrient assimilation and reproductive development. Gibberellins, particularly GA_3, are known for their role in promoting stem elongation and shoot growth, especially during early developmental stages. They are also involved in seed germination by breaking dormancy and stimulating enzyme activity for mobilization of stored food reserves. In addition, gibberellins regulate flowering by influencing the transition from vegetative to reproductive growth and contribute to seed size and weight through regulation of cell division and reserve accumulation (Hedden and Sponsel, 2015; Mahmood *et al.,* 2023 a,b). Although the use of gibberellic acid has been reported in various crops, the application of nitrobenzene-based PGRs such as Flora (20% EW) in lentil cultivation is still limited, particularly under late sowing conditions. There is insufficient scientific information regarding the comparative effectiveness of nitrobenzene and GA_3 on growth, yield and economic performance of late sown lentil. Therefore, the present study was undertaken to evaluate the effects of Flora (nitrobenzene 20% EW) and gibberellic acid (GA_3) at different spraying frequencies on yield performance and profitability of late sown lentil in the Faridpur region of Bangladesh.

Materials and methods

The experiment was conducted during the Rabi season of 2024–2025 at the Farming Systems Research and Development (FSRD) site of the Bangladesh Agricultural Research Institute (BARI) in Faridpur, Bangladesh. Geographically, the site is situated in a subtropical agro-ecological region at approximately 23°36' N latitude and 89°50' E longitude, with an elevation between 8 and 12 m above mean sea level. The study site is characterized by calcareous soil with a clay loam texture, classified as an Inceptisol order (specifically a Haplaquept suborder) within the Gopalpur soil series of the Low Ganges River Floodplain (AEZ-12) (Quddus *et al.,* 2020). Topographically, the site occupies medium-high to high land. The soil exhibits a pH of 6.8–7.2, providing an optimum environment for lentil cultivation. With an organic matter content of 1.0–1.2% and electrical conductivity (EC) between 0.30 and 0.45 dS m^{-1}. However, the soil is categorized as low organic matter content and non-saline. The overall fertility status is moderate to low (FRG, 2018). The area is experienced a subtropical monsoon climate. During the crop growing period from November to March, the mean monthly temperature ranged from 17.5 to 25.8 °C, while the average relative humidity fluctuated between 65% and 78%. Precipitation was negligible throughout the growing season; consequently, the crop was cultivated under rainfed conditions, relying primarily on residual soil moisture.

The study utilized BARI Masur-8, a high-yielding lentil variety. The seeds were officially sourced from the Regional Pulses Research Station (RPRS) of the Bangladesh Agricultural Research Institute, located in Madaripur. The experimental plot was prepared using an engine-operated power tiller. The process involved four tilling followed by leveling to achieve a fine tilth. To maintain a clean experimental environment, all weeds and previous crop stubble were manually removed. The experiment was laid out using a Randomized Complete Block Design (RCBD), consisting of five distinct treatments replicated four times across dispersed blocks. Each unit plot was measured at 6m × 5m. The treatments were T_1: Flora (20% Nitro Benzene) spray @ 2 ml/L 2 times (35 and 50 DAS), T_2: Flora @ 2 ml/L 1 times (50 DAS), T_3: GA_3 Foliar spray 0.2g/litter 2 times (25 and 50 DAS), T_4: GA_3 Foliar spray 0.2g/litter 1 times (50 DAS), and T_5: control.

Blanket fertilizer doses of N-P-K-S-Zn-B were applied at a rate of 28-24-14-9-2-1.2 kg ha^{-1}, respectively, following the Fertilizer Recommendation Guide-2018 (FRG-2018). The elemental nutrients like N, P, K, S, Zn and B were sourced from urea, triple superphosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate, and boric acid, all of which were applied as basal doses during final land preparation. The plant growth regulators like nitrobenzene and gibberellic acid (Lab grade), were procured from a local commercial supplier.

Lentil seeds were treated with the fungicide Provex 200 (at a rate of 2.5 g kg^{-1}) prior to sowing to control root rot disease. The treated seeds were manually sown on 02 December 2024 at a rate of 40 kg ha^{-1}, with a 30 cm row spacing and continuous seeding within the rows. The application of growth regulators followed a specific treatment schedule. For T_1, the initial nitrobenzene spray was administered at 35 days after sowing (DAS). At 50 DAS, a second nitrobenzene spray was applied to T_1, corresponding with the first nitrobenzene application for T_2. Regarding the treatments of gibberellic acid, T_3 received its first spray at 25 DAS. Subsequently, at 50 DAS, a second spray was applied to T_3, while T_4 received its initial application.

Manual weeding was performed three times at 25, 45, and 60 days after sowing (DAS). To manage fungal diseases, the fungicide Amister Top 325 SC was applied at a concentration of 1 ml per liter before flowering and again during the podding stage. For pest control, the insecticide Imitaf 20 SL was sprayed at 0.5 ml per liter during the vegetative and podding stages to protect against aphids and pod borers. The irrigation schedule was adjusted according to the plants' specific water requirements throughout the growth cycle. The mature lentil crop was harvested on 12 March 2025.

Seed yield (t ha^{-1}) was determined on a whole-plot basis and standardized to 10% moisture content. To determine stover yield, mature plants were collected from two 1m^2 quadrats in each plot; after sun-drying, the stover was weighed and the values were converted to t ha^{-1}. Percentage of harvest index (HI) was determined by the formula outlined by Hossain *et al.* (2019):

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \qquad (1)$$

Where, biological yield= Seed yield (t ha^{-1}) + Stover yield (t ha^{-1})

Plant population was determined by counting individuals within a 1 m^2 area in each plot. Plant height and the number of pods per plant were recorded from ten randomly selected plants per plot and subsequently averaged. The number of seeds per pod was determined by averaging the seed counts from ten randomly detached pods per plot. The 1000-seed weight (g) was calculated by weighing 100 randomly selected seeds per plot and extrapolating the total weight.

Economic analysis was performed on a per-hectare basis for late-sown lentil cultivation. The total variable cost (TVC) was calculated by aggregating expenses for agronomic operations including tillage, labor and plant protection alongside inputs such as seeds, inorganic fertilizers and PGRs. Fixed costs specifically land rent were excluded from the analysis. Gross return was determined by multiplying the seed and stover yields (converted to t ha^{-1}) by prevailing local market prices. The gross margin was then derived by subtracting the TVC from the gross return. The Benefit-Cost Ratio (BCR) was calculated according to the formula outlined by Quddus *et al.* (2026):

$$BCR = \frac{\text{Gross Return}}{\text{Total variable cost}} \times 100 \qquad (2)$$

Data regarding growth, yields and yield attributes were analyzed using R statistical software. Significant treatment effects were determined via an analysis of variance (ANOVA), with mean comparisons performed using the least significant difference (LSD) test.

Result and discussion

Growth and yield attributes of late-sown lentil

Foliar application of plant growth regulators, specifically nitrobenzene and gibberellic acid significantly influenced the growth and yield attributes of late-sown lentil (Table 1). Significant differences in plant height was observed across treatments, with T_3 (GA_3 foliar spray @ 0.2 g L^{-1} applied twice at 25 and 50 DAS), producing the tallest plants (47.7 cm) followed by T_4 (45.3 cm) treatment. The control (T_5) treatment was produced the shortest plant (38.4 cm). The tallest plant observed in T_3 (GA_3 foliar spray @ 0.2 g L^{-1} applied twice at 25 and 50 DAS) highlighted the efficiency of gibberellic acid in promoting sub-apical meristem activity. This is consistent with the findings of Taiz *et al.,* 2015, who reported that foliar application of gibberellic acid (GA_3) enhances the endogenous hormonal level, leading to rapid cell division and elongation in pulse crops. Similar findings were reported by Rahman *et al.* (2016), who observed that GA_3 application increased plant height in lentil. This trend is consistent with results seen in other grain legumes (Solaimalai *et al.,* 2001; Vaishnavi and Mehera, 2022). While GA_3 is an effective stimulator of cell elongation and internode expansion, this enhanced vegetative vigor did not translate into a commensurate increase in seed yield under late-sown conditions. In this study, although GA_3 treatments producing the tallest plants, they did not achieve the highest seed yield. This indicates that under the shortened growing windows and terminal heat stress typical of late sowing, reproductive efficiency specifically pod setting and grain filling becomes the key determinant of yield (Alam, 2016). Excessive vegetative growth in these environments may act as a "metabolic drain," diverting photo-assimilates away from reproductive sinks and toward stem elongation (Ozga *et al.*, 2017; Kywe *et* *al.,* 2025). Consequently, while the plant appears healthier, the Harvest Index (HI) often declines. This occurs because the source (leaves and stems) outcompetes the sink (seeds) for limited carbohydrates during the critical reproductive phase.

Plant population m^{-2} did not vary significantly among treatments, indicating that PGR application had no effect on crop establishment. This finding indicates that the observed yield differences were mainly due to changes in reproductive traits rather than plant stand density. However, the number of pods $plant^{-1}$ was significantly affected by the treatments. The maximum number of pods $plant^{-1}$ (50.6) was obtained from T_1 (Flora @ 2 ml L^{-1} applied twice at 35 and 50 DAS) which was statistically superior to all other treatments, while the lowest number was recorded in T_5 (34.3). This increase may be attributed to improved flower retention and reduced pod abscission caused by nitrobenzene application. Earlier studies reported that nitrobenzene enhances reproductive efficiency by improving source–sink relationship and reducing flower drop in pulses (Sivasubramanian *et al.,* 2008; Patel *et al.,* 2019). Under late sowing conditions, lentil often faces higher temperature and moisture stress during flowering and pod setting. Such stress accelerates flower drop and reduces pod formation. Therefore, treatments (T_1) that improve reproductive stability, such as nitrobenzene application, become particularly effective in sustaining pod development. The number of seeds pod^{-1} ranged from 1.60 to 1.70. Although the number of seeds pod^{-1} showed statistically significant variation, the range was narrow, indicating that this trait is relatively stable and less responsive to PGR application. Similar observations were reported by Yadav *et al.* (2017) in lentil. Thousand seed weight was also not significantly affected by PGR treatments, suggesting that seed size is largely governed by genetic factors rather than external hormonal application, as also reported by Kumar *et al.* (2016).

Table 1. Effect of nitrobenzene and gibberellic acid on growth and yield attributes of late-sown lentil

Treatment	Plant height (cm)	Plant population m^{-2}	No. of pods $plant^{-1}$	No. of seeds pod^{-1}	Thousand seed wt. (g)
T_1	42.7 c	121.3 a	50.6 a	1.63 ab	20.9 a
T_2	40.6 d	121.8 a	43.2 c	1.60 b	20.8 a
T_3	47.7 a	121.5 a	46.4 b	1.65 ab	20.8 a
T_4	45.3 b	120.0 a	39.9 d	1.70 a	20.8 a
T_5	38.4 e	121.0 a	34.3 e	1.70 a	20.8 a
LSD_{005}	1.24	3.87	2.52	0.05	0.08
CV (%)	1.87	2.07	3.82	2.19	0.27

T_1: Flora (20% Nitro Benzene) spray @ 2 ml/L 2 times (35 and 50 DAS), T_2: Flora @ 2 ml/L 1 times (50 DAS), T_3: GA3 Foliar spray 0.2g/litter 2 times (25 and 50 DAS), T_4: GA3 Foliar spray 0.2g/litter 1 times (50 DAS) and T_5= control

Yields and harvest index of late-sown lentil

Seed yield, stover yield and harvest index were significantly influenced by the different PGR treatments (Table 2). The highest seed yield (1.94 t ha^{-1}) was recorded in T_1, followed by T_3 (1.80 t ha^{-1}) and T_2 (1.68 t ha^{-1}), while the lowest yield was obtained from the control (1.43 t ha^{-1}). Compared to the control, seed yield was increased by 35.7%, 25.9%, and 17.5% in treatments T_1, T_3 and T_2, respectively. The higher yield under T_1 was mainly attributed to increased number of pods $plant^{-1}$, suggesting that pod number was the major contributor to yield improvement under late sowing conditions. Seed yield was significantly enhanced by PGR application, with the highest yield recorded in T_1, followed by T_3 and T_2. The superior yield performance of T_1 was mainly attributed to the significantly higher number of pods $plant^{-1}$, indicating that pod number was the major contributor to yield improvement under late sowing conditions. Strong positive associations between pod number and seed yield in lentil have also been reported by Singh *et al.* (2015) and Rahman *et al.* (2016). The results further indicated that spray frequency played a crucial role, as treatments receiving two sprays consistently outperformed those with a single spray. Repeated application at critical growth stages possibly maintained hormonal balance for a longer duration, leading to improved reproductive development. Comparison between nitrobenzene and gibberellin treatments showed that nitrobenzene was more effective than GA_3 in increasing seed yield of late sown lentil. While GA_3 mainly enhanced vegetative growth, nitrobenzene proved more efficient in improving reproductive traits, particularly pod number. Similar conclusions were drawn by Solaimalai *et al.* (2001) and Patel *et al.* (2019) in pulse crops. In this study, significant variations in stover yield were observed across treatments. The highest stover yield (1.19 t ha^{-1}) was produced by T_3 (GA_3 foliar spray @ 0.2 g L^{-1} applied twice at 25 and 50 DAS), followed by the T_1 treatment (1.10 t ha^{-1}). This represents an 11.2% increase over the control. The superior performance of T_3 might be attributed to the role of Gibberellic Acid (GA_3) in enhancing physiological activity and stimulating rapid cell division, which ultimately results in higher biomass production. These results are aligned with the findings of Taiz *et al.* (2015), who noted that exogenous GA_3 application boosts endogenous hormonal levels, promoting cell elongation during the vegetative phase of pulse crops. Also, several studies (Vishnu and Brar. 2020; Sivakumar *et al.,* 2022) confirm that GA_3 optimizes the source-to-sink relationship, significantly improving dry matter accumulation in legumes.

The application of various plant growth regulators significantly influenced the harvest index of late-sown lentils (Table 2). The highest harvest index (63.8%) was observed in treatment T_1 (Flora @ 2 ml L^{-1} applied at 35 and 50 DAS), which was significantly superior to the control. This was followed by the T_2 treatment, whereas the minimum harvest index was recorded in the T_5 (control) treatment. The significant increase in the harvest index under treatment T_1

(Nitrobenzene/Flora) suggests a more efficient translocation of photosynthates from vegetative parts (source) to the developing seeds (sink). In late-sown conditions, lentils often suffer from a shortened reproductive phase due to rising temperatures. Nitrobenzene acts as a plant energizer that enhances nutrient uptake and reduces flower drop, thereby stabilizing the sink strength even under environmental stress (Kohombange *et al*., 2018). The superiority of T_1 (Nitrobenzene/Flora) over T_3 (Gibberellic Acid) may be attributed to the specific role of nitrobenzene in increasing the number of flowers and their subsequent conversion into pods. While GA_3 (T_3) promotes vegetative elongating and initial flowering, nitrobenzene ensures the "stay-green" quality of leaves, providing a sustained supply of carbohydrates during the critical grain-filling stage (Singh *et al.,* 2022). These findings align with the studies suggesting that foliar-applied stimulants can compensate for the yield losses typically associated with delayed sowing in pulse crops (Mishra *et al.,* 2025).

Table 2. Effect of nitrobenzene and gibberellic acid on yields and harvest index of late-sown lentil

Treatment	Seed yield (t ha^{-1})	% seed yield increase over T_5	Stover yield (t ha^{-1})	Harvest index (%)
T_1	1.94 a	35.7	1.10 ab	63.8
T_2	1.68 c	17.5	0.97 c	63.4
T_3	1.80 b	25.9	1.19 a	60.2
T_4	1.59 d	11.2	1.07 b	59.8
T_5	1.43 e	-	1.07 b	57.2
LSD_{005}	0.08	-	0.07	
CV (%)	3.09	-	3.80	

T_1: Flora (20% Nitro Benzene) spray @ 2 ml/L 2 times (35 and 50 DAS), T_2: Flora @ 2 ml/L 1 times (50 DAS), T_3: GA3 Foliar spray 0.2g/litter 2 times (25 and 50 DAS), T_4: GA3 Foliar spray 0.2g/litter 1 times (50 DAS) and T_5= control.

Economic performance analysis

Economic analysis revealed that PGR application substantially improved profitability of late sown lentil (Table 3). The highest gross return (BDT 180,100 ha^{-1}) and gross margin (Tk 100,300 ha^{-1}) were obtained from T_1, followed by T_3. Although T_1 involved a higher variable cost than the control, it generated the highest benefit–cost ratio (2.26) due to its superior gross return. The control treatment (T_5) recorded the lowest gross return, gross margin and BCR (1.84), reflecting poor economic performance in the absence of PGR application. Overall, foliar application of Flora @ 2 ml L^{-1} applied twice at 35 and 50 DAS proved to be the most effective and economically profitable treatment for late sown lentil. These findings align with earlier studies reporting improved returns from PGR use in pulse crops (Patel et al., 2019).

Table3. Effect of nitrobenzene and gibberellic acid on cost and return analysis of late sown lentil

Treatment	Gross return (BDT ha^{-1})	Total variable cost (BDT ha^{-1})	Gross margin (BDT ha^{-1})	BCR
T_1	180100	79800	100300	2.26
T_2	156050	76070	79980	2.05
T_3	167950	78990	88960	2.13
T_4	148450	75620	72830	1.96
T_5	133150	72520	60630	1.84

T_1: Flora (20% Nitro Benzene) spray @ 2 ml/L 2 times (35 and 50 DAS), T_2: Flora @ 2 ml/L 1 times (50 DAS), T_3: GA3 Foliar spray 0.2g/litter 2 times (25 and 50 DAS), T_4: GA3 Foliar spray 0.2g/litter 1 times (50 DAS) and T_5= control, BCR= Benefit cost ratio.

Variable cost (input Prices+others): Seed **(**BARI Masur-8) = BDT 130 kg^{-1}, Urea= BDT 27 kg^{-1}, DAP= BDT 21 kg^{-1}, MoP= BDT 20 kg^{-1}, Gypsum= BDT 13 kg^{-1}, Zink sulphate= BDT 260 kg^{-1}, Boric acid= BDT 320 kg^{-1}, Flora= BDT 120/100 ml, GA_3= BDT 120/10 g, Provax 200 WP= BDT 450/100g, Amister Top 325 SC= BDT 400/100 ml, Imitaf 20 SL= BDT 250/50 ml , Tillage = BDT 1500 ha^{-1} (one pass), Wage rate= BDT 500 day^{-1}

Output price: Lentil seed **(**BARI Masur-8) = BDT 90 kg^{-1} and stover/straw = BDT 5.0 kg^{-1}. Gross returns were calculated based on the current market value of lentil seed and stover in Faridpur, Bangladesh.

Conclusion

Results indicate that both nitrobenzene and gibberellic acid (GA_3) effectively enhance the growth, yield, harvest index and economic performance of late-sown lentil. Among the treatments, Flora (20% nitrobenzene) applied at 2 ml L^{-1} twice at 35 and 50 DAS (T_1) resulted in a significant increase in pods per plant and yields compared to the control. Economically, this treatment (T_1) maximized gross returns and the benefit-cost ratio. Furthermore, nitrobenzene proved more effective than gibberellic acid in improving productivity of late sown lentil. These findings suggest that a double foliar application of nitrobenzene is a sustainable and effective practice for late-sown lentil cultivation.

References

Alam M.M. 2016. Effect of GA3 and nitrogen on growth, yield and protein content of mungbean. MS Thesis, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

BBS News, 2026. Lentil cultivation brings bumper yield, better returns for Barind farmers.

Deb, P., S. Chakraborty, A. Chakraborty and P.K. Saha. 2012. Effect of nitrobenzene on growth and yield of pulse crops. *J Crop Weed* **8(2):** 135–138.

Dhull, S.B, P. Punia, M. Kidwai, A. Kaur and S. Chawla. 2023. Lentil (Lens culinaris L.): nutritional profile, health benefits and food applications. *J Food Sci Nutr* **11(1):** 45–58.

Ferdous, J. 2019. Nitrogen fixation and yield potential of lentil under different management practices. *Bangladesh J Agric Res* **44(3):** 421–432.

FRG-2018 (Fertilizer Recommendation Guide-2018). Bangladesh Agricultural Research Council (BARC), Dhaka 1215, Bangladesh, 223p.

Haque, M.A, M.M. Rahman and A.J.S. Karim. 2014. Effect of plant growth regulators on growth and yield of lentil. *Bangladesh J Agric Res* **39(2):** 321–330.

Hedden, P and V. Sponsel. 2015. A century of gibberellin research. *J Plant Growth Regul* **34(4):** 740–760.

Hossain M.A., M.A. Quddus, M.A. Sattar, M.B. Anwar, S. Aktar, M.H. Sarker, M.R. Ali. 2019. Response agronomic traits of lentil varieties to zinc fertilization in calcareous and terrace soils of Bangladesh. *J. Energy Nat. Resour.* **8 (4):** 155-165.

Jianghui Yu, Du, T., Zhang, P., Ma, Z., Chen, X., Cao, J., et al. 2024. Impacts of High Temperatures on the Growth and Development of Rice and Measures for Heat Tolerance Regulation: A Review. *Agronomy 2024,* 14, 2811.

Kohombange S., H. K. L. K. Gunasekera and S. Kirindigoda. 2018. Effect of Nitrobenzene on Postharvest Quality of Bell Pepper (*Capsicum annuum* L.) Under Green House Condition. *Int. J. Res.* **5(15):** 926-929.

Kohombange S., J.P. Eeswara and R. Nandun. 2019. Effect of nitrobenzene on sweet cucumber (*Cucumis sativus* L.) yield and yield quality under greenhouse condition. *Int. J. Environ. Agric. Biotechnol.* **4(2):** 407-410.

Kumar, S, R. Singh and R.S. Yadav. 2016. Effect of plant growth regulators on yield attributes of pulses. *Indian J Agron* **61(4):** 489–494.

Kywe K.K., T. Zar, H.H. Oo and N.M. Htwe. 2025. Effect of Foliar Application of Gibberellic Acid on Growth and Yield of Mungbean (*Vigna radiata* L.). *Asian Soil Res. J.* **9(3):** 80-89.

Mahmood, A, M. Rahman, M.A. Hossain and M.S. Islam. 2023a. Physiological responses of grain legumes to gibberellic acid under stress conditions. *Legume Res* **46(2):** 178–185.

Mahmood, A, M. Rahman, M.A. Hossain and M.S. Islam. 2023b. Role of gibberellins in flowering and seed development of pulse crops. *Bangladesh J Bot* **52(1):** 89–97.

Mishra A., D. Sah, G.S. Panwar, M. Kumar and J. Pathak. 2025. Foliar application improves the productivity of the late sown chickpea (*Cicer arietinum*) in Bundelkhand region of Uttar Pradesh. *Indian J. Agron.* **70 (2):** 218-223.

Montejano-Ramírez V. and E. Valencia-Cantero. 2024. The Importance of Lentils: An Overview. *Agriculture*, 14(1):103. https://doi.org/10.3390/agriculture14010103

Ozga J.A., H. Kaur, R.P. Savada and D.M. Reinecke. 2017. Hormonal regulation of reproductive growth under normal and heat-stress conditions in legume and other model crop species. *J. Experi. Bot.* **68 (8):** 1885–1894.

Patel, R.M, P.T. Patel and B.T. Patel. 2019. Influence of nitrobenzene on growth and yield of chickpea. *Legume Res* **42(3):** 387–391.

Quddus A. R. Ahmed, S.U. Khan, S.J. Purnota, T. Islam, N.A. Sultana, S. Aktar, Z.H. Fahad, M. Rahimi and K. Uddin. 2026. Sustainable garden pea cultivation: a comprehensive evaluation of organic, inorganic, and bio-fertilizer impacts on productivity, quality and nutrient dynamics. *Int. J. Plant Prod.* 20:22. https://doi.org/10.1007/s42106-025-00398-4

Quddus M.A., H.M. Naser, M.A. Siddiky, M.R. Ali, A.T.M.A.I Mondol and M.A. Islam. 2020). Impact of zero tillage and tillage practice in chickpea production. *J. Agric. Sci.* **12 (4):** 106-118.

Rahman, M.M, M.A. Hossain and M.S. Islam. 2016. Effect of GA_3 on growth and yield of lentil. *Bangladesh J Agric Res* **41(2):** 293–302.

Samaranayaka, A.G.P. 2017. Nutritional and functional properties of pulses. *Cereal Foods World* **62(4):** 151–156.

Singh K.P., B. Singh, S. Prakash, R.S. Sengar, L.K. Gangwar, V. Kumar, A. Pal, D. Pal and V. Pandey. 2022. Effect of GA_3 and nitrobenzene on flowering parameters in different germplasm of Brinjal (*Solanum melongena* L.). Pharma Innov. 11(8): 1853-1857.

Singh, A.K, D.K Singh and A. Kumar. 2015. Yield attributes and yield of lentil as influenced by growth regulators. *J Food Legumes* 28(1): 35–38.

Sivakumar R., S. Srividya and M. Vijayakumar. 2022. Study the impact of plant growth regulators on tendril, physiological traits and flowering in *kharif* horse gram. *Pharma Innov.* **11(7):**1600-1603.

Sivasubramanian, V, G. Soundarapandian and K. Rajendran. 2008. Effect of nitrobenzene on growth and yield of pulse crops. *Crop Res* **36(1–3):** 1–5.

Tairo, E.V and P.A Ndakidemi. 2013. Biological nitrogen fixation, nutrient uptake and yield of legumes as influenced by Rhizobium inoculation. *Am J Plant Sci* **4(11):** 2091–2098.

Taiz, L, E Zeiger, I.M Møller and A. Murphy. 2015. *Plant Physiology and Development*. Sinauer Associates, Sunderland, USA. https://doi.org/10.3329/bjsr.v25i1.13049.

Vaishnavi M. and B. Mehera. 2022. Effect of GA_3 and Bio fertilizers on growth and yield of Lentil (*Lens culinaris* L.). *Pharm. Innov. J.* **11(5):** 1469-1471.

Vishnu K. and B.S. Brar. 2020. Role of plant growth regulators in pulse production: A review. *Int. J. Chem. Stud*. **8(5):** 2736-2742.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 501-521, March 2026

A COMPARATIVE ANALYSIS ON MAIZE YIELD PREDICTION USING SENTINEL 2A AND LANDSAT 8 SATELLITE IMAGE IN SUNDARGANJ, GAIBANDHA, BANGLADESH

N. MOHAMMAD[1], M. A. ISLAM[2], M. G. MAHBOOB[3]
M. M. RAHMAN[4] AND I. AHMED[5]

Abstract

Maize is an important cereal crops in Bangladesh. Over the last two decades, its cultivation has increased promisingly, especially in the Northern part of Bangladesh. The effective estimation of crop yields at a regional scale holds significant importance in facilitating decision-making within the agricultural sector, thereby ensuring grain security. The traditional ground-based measurement techniques suffer from inefficiencies, and there exists a need for a reliable, precise, and effective method for estimating regional crop yields. This study used remote sensing (RS) techniques for forecasting pre-harvest maize yield to improve the management system. Currently, the normalized difference vegetation index (NDVI) is widely used to predict crop yield including maize. However, the present study used Landsat 8 (~ 30 m) and Sentinel 2A (~ 10 m) high resolution data for 2018-2019 and 2019-2020 to predict maize yield based on the year 2020-2021 at Sundarganj Upazila in Gaibandha district. The single cloud free image acquisition date based on maximum NDVI for both satellite images was used for each maize growing period to develop a yield prediction model. A regression model was performed between NDVI values and 20 farmers field-level maize yields. The absolute mean error of prediction was about 10.30% for Landsat 8 and 6.70% for Sentinel 2A compared to the actual maize yield during 2020-2021. The study revealed that NDVI data extracted from Sentinel 2A high resolution satellite images can be successfully used to predict the maize yield with appreciable accuracy. Finally, this study has demonstrated the efficacy of combining multi-temporal remote sensing data for accurate maize yield estimation, aiding agricultural authorities and production enterprises in the timely formulation and refinement of cropping strategies and management policies for the ongoing season.

Key words: Maize, NDVI, Landsat 8, Sentinel 2A, Remote sensing and Yield prediction

---

[1,4&5]Agricultural Statistics & ICT Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, [2]Department of Agricultural and Applied Statistics, Bangladesh Agricultural University (BAU), Mymensingh, and [3]Forestry Unit, Bangladesh Agricultural Research Council (BARC), Dhaka, Bangladesh.

Introduction

Maize (*Zea mays L.*) is the second most widely grown cereal food crop in the world. It is one of the most important cereal crops in Bangladesh, as well as the third-largest crop after rice and wheat in the world. Maize is the highest yielding grain crop having multiple uses. The average production of maize in 2019 in the world was 5.82 tons per hectare as compared to 3.55 and 4.66 tons per hectare for wheat and rice, respectively (FAO, 2021). Its position is the first among the cereals in terms of yield [maize: 9.12 mt/ha, wheat: 3.69 mt/ha and rice: 3.36 mt/ha)] but in terms of area and production, it ranks the second just after rice (BBS, 2024). Maize cultivation has increased rapidly in the northern part of Bangladesh. Currently crop statistics in Bangladesh are generally gathered by the accumulation of representative field sampling data which is time-consuming and misses information on the spatial distribution of field variability. Large-scale research cannot employ traditional field-based surveys due to the substantial labour and material costs (Khan et al., 2024). Yield estimation is then carried out on ground-based field visits and reports. These are often subjective, costly, time consuming and mostly have huge errors due to incomplete ground observations (Reynolds *et al*., 2000). Crop yield estimation has been transformed by satellite remote sensing technology, which provides a broad-coverage, reliable, and non-destructive method (Wang *et al*., 2020; Lyu *et al*., 2024). The precise and timely monitoring of potential yields is crucial for decision making as it influences markets, export–import decisions and farm income budgeting (Zhao *et al*., 2020). Nonetheless, it is important to get precise predictions on time for the food security of a country (Shen *et al*., 2022). Many crop yield estimation techniques are being applied; nevertheless, the most effective one is based on using geospatial data and technologies like remote sensing. Though, the remote sensing data that are required to estimate crop yields are inadequate most of the time due to numerous problems like climate conditions (% of clouds), and low temporal resolution (Awad, 2019). In addition, yield estimations with conventional methods are no longer beneficial for planners as they take too much time. As satellite-based remote sensing is one of the best tools to provide vital information about the distribution of crops and their growing conditions over large areas, it can be applied for maize growth monitoring and yield forecasting. Currently, satellite data with higher spatial resolution (e.g. Landsat, 30m; Sentinel-2, 10m) has become freely available and offers an opportunity to improve the identification of smaller crop fields and estimation of their yield, yet to be evaluated (Bitelli *et al*., 2016).

Now-a-days, several methods are used for the prediction of crop yields at a range of scales such as observed equations, remote sensing and simulation models. Remote sensing data from satellites is more often applied as input data in crop models for grain yield predictions. AVHRR and MODIS are the most popular satellite sensors to obtain within-season information to predict final yield at the regional scale (Becker-Reshef *et al*., 2010; Zhang *et a*l., 2016 and French *et al*., 2017), while for smaller areas, the most generally applied data are extracted from Landsat and Sentinel satellites (Skakun *et al*., 2017; Mirasi *et al.,* 2019 and Fieuzal *et al*., 2020).The yield predictions can be prepared at several spatial levels, from forecasts for particular crop fields to regional forecasts for all countries or even on a worldwide scale (Basso *et al*., 2019). Researchers used crop models to predict crop growth and yields at a regional scale. Landsat 30m 16-day cloud-free imagery and Sentinel-2 10m 10-day processed satellite images were downloaded for crop yield estimation (Gumma *et al*., 2021). Several studies have been carried out on the correlation of normalized difference vegetation index (NDVI) with yield (LiuWT *et al*., 2002). Recent studies took advantage of Landsat and Sentinel 2 data to approach crop yield forecasting at a moderate spatial resolution. Landsat and Sentinel-2 data were used in recent studies to measure crop yields at a moderate spatial resolution. Lambert *et al*. (2018), for example, used Sentinel-2 data and a peak LAI technique to estimate cotton, maize, millet, and sorghum yields in Mali. Lai *et al*. (2018) applied time-integrated Landsat NDVI for wheat yield estimation in Australia. Lima et al. (2019) observed that both satellites showed the same performance in terms of accuracy for Sentinel-2 and Landsat 8, respectively. However, Landsat 8 mapped 36.9% more area of selective logging compared to Sentinel-2 data for mapping small-scale logging in the Brazilian Amazon.

In Bangladesh, Bala and Islam (2009) expanded potato yield estimations models by using NDVI, LAI (leaf area index), and fraction of photosynthetically active radiation (fPAR) vegetation indices for Munshiganj district of Bangladesh by applying Moderate Resolution Imaging Spectroradiometer (MODIS) data and noticed that an average error of estimation is about 15% for the study location. Rahman *et al.* (2012) utilized NOAA-AVHRR data for prediction of potato yields in Bangladesh. Newton *et al*. (2018) improved a potato yield prediction model by Landsat 8 data to identify the maximum NDVI value of a potato growing season in the Munshiganj district of Bangladesh. The maximum coefficient of determination (R^2) was found to be 0.81 between the mean NDVI and potato yield and revealing that the difference between predicted and actual filed yield is approximately 10.4%. Rahman *et al.* (2024) developed a potato yield prediction model based on the maximum NDVI values combined use of Landsat 8 and Sentinel 2A. The predicted percentages of the mean yield gap for Sentinel 2A were 8.58%, while for Landsat 8, these were 9.56%, respectively, at Shibganj Upazila, Bogura. Mohammad et al. (2024) generated a maize yield model and found the percentage of yield gap was 8.82% for Sentinel 2A and 10.15% for Landsat 8 at Kaharole in Dinajpur district.

However, very few studies have been conducted on the relationship between high-resolution (~ 30 m) Landsat 8 and Sentinel 2A (~ 10 m) satellite data and maize yield in Bangladesh. The objective of the present study was to construct a maize yield estimation model and forecast maize yield using satellite based remote sensing technique using high-resolution Landsat 8 and Sentinel 2A surface reflectance data at Sundarganj Upazila in Gaibandha district of Bangladesh. The high spatial resolution of both images has been used in this study to predict maize yield in the study area.

Study Area

The study was conducted at Sundarganj Upazila in Gaibandha district especially in the *Rabi* season which was a promising maize growing area of Bangladesh. Especially in char lands, the area and production of maize have been increasing rapidly over the last decades in this location. Maize grew on a project basis most of unions of Sundarganj Upazila like Kapasia, Belka, Candipur, Haripur, Tarapur and Sripur. It covered 7.34% and 3.99% maize cultivation areas in the northern part and all over Bangladesh respectively (BBS, 2020). Sundarganj Upazila lies between 25° 24′ to 25° 39′ N latitude and 89° 24′ to 89° 43′ E longitude respectively (Fig. 1). It covers 426.52 km^2 where 65% of the areas is cultivable land. The climate condition of this area is hot and humid from April to October (summer) and cool and dry from November to March (winter). This Upazila receives an annual average rainfall of 2417 mm, where 90% of rainfall occurs between May and October. The maximum and minimum mean temperature during the winter varies between 23.6 to 16.8°C and 24 to 16.8°C, respectively in the study area. During summer, the maximum and minimum mean temperatures vary between 33.2 to 26.0°C and 29.8 to 25.6°C, respectively. The average monthly minimum and maximum humidity vary from 68 to 86%, where the maximum humidity observed during the summer and the minimum humidity observed during the dry season. The agricultural pattern of this area is categorized by two growing seasons, *Rabi* and *Kharif*. *Rabi* is the main growing season, which is dominated by maize, rice and wheat that starts in late October or early November and ends in April. Again, *Kharif* is dominated by rice and jute, which starts in May and ends in September. Other food crops which include potato, pepper, onion, pulses, sugarcane, and oilseed are also cultivated in the study area. Sundarganj occupied major part of the Teesta Flood Plain. The soil condition of those areas has prevailed by non-calcareous brown floodplain soils and grey floodplain soils.

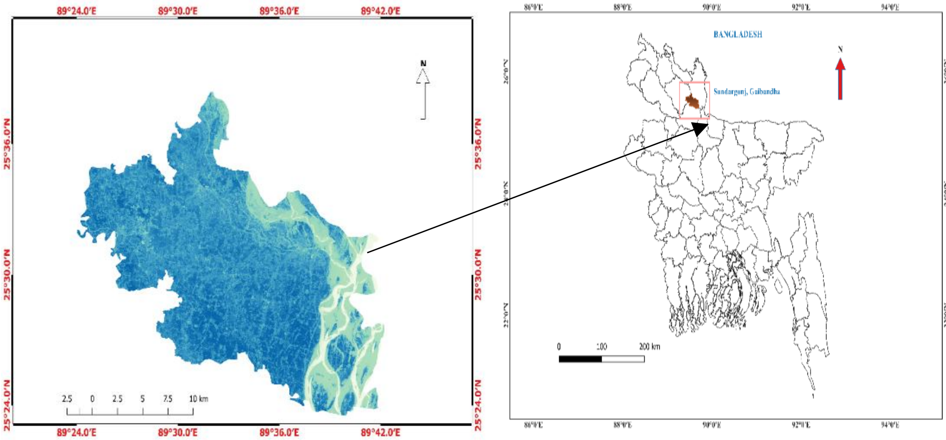


Fig. 1. Map of the study area.

Materials and Methods

Yield data collection from farmer's fields

Twenty maize fields were selected randomly from Sundarganj Upazila, Gaibandha district for the three maize growing seasons 2018-2019, 2019-2020 and 2020-2021 with the agreement of the farmers (Fig. 2). Ground truth points (GTPs) were collected from those 20 maize fields for each season. Crop information data such as field GPS locations, planting and harvesting time and yield were collected from these selected Upazilas farmers' fields.

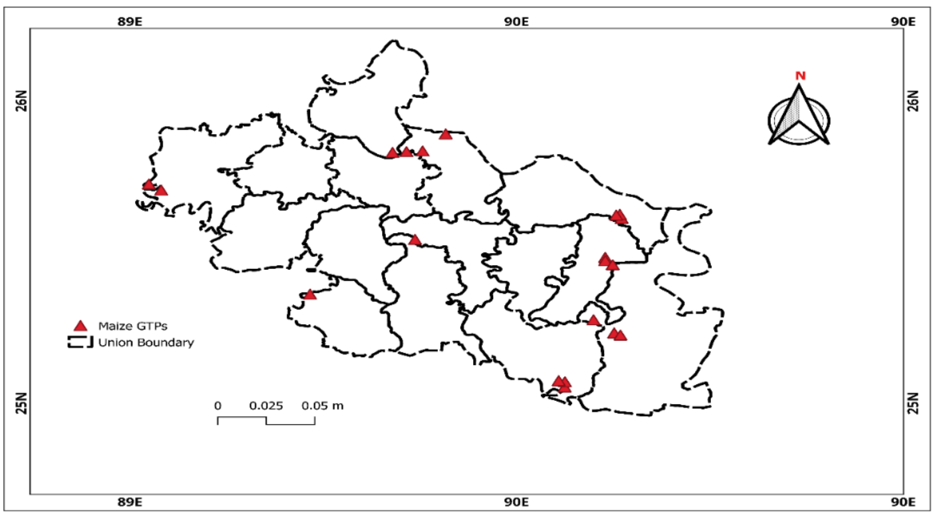


Fig. 2. GTPs of maize fields over Sundarganj, Gaibandha.

Landsat-8/OLI and Sentinel-2A /MSI Datasets

Remote sensing images adopted by the Operational Land Imager (OLI) instrument aboard Landsat-8 satellite and by the Multi-Spectral Instrument (MSI) aboard Sentinel-2A satellites were used in this study. Landsat-8/OLI were obtained from the United States Geological Survey (USGS) Earth Explorer website (http://earthexplorer.usgs.gov/) which capture images of the Earth's surface in 9 spectral bands at 30 m spatial resolution (15 m for panchromatic band) (Roy *et al*., 2014) while Sentinel-2A/MSI were obtained from the European Space Agency (ESA) Copernicus portal (https://scihub.copernicus.eu) which capture images of the Earth's surface in 13 spectral bands at 10 m, 20 m and 60 m spatial resolution (Drusch *et al*., 2012). The main bands that were used in the study are bands 4 (Red) and 5 (NIR) from Landsat-8, and bands 4 (Red) and 8 (NIR) from Sentinel-2A. Spectral response function for band 8A (Narrow NIR, ~20 m) from Sentinel-2A was not like Landsat-8's band 5 was presented in Fig. 3.

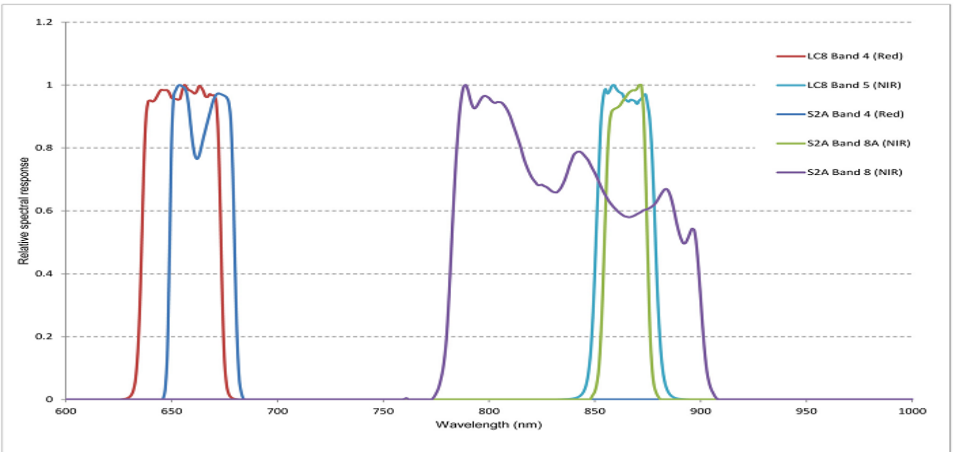


Fig. 3: Relative spectral response functions of Landsat-8/OLI and Sentinel-2A/MSI for red and near-infrared spectral bands.

However, only the Red and NIR spectral bands for Landsat 8/OLI and Sentinel 2A/MSI were used for the study purposes. So, Landsat 8 (OLI) and Sentinel 2A (MSI) with 16-day (~ 30 m) and 10-day (~ 10 m) high spatial resolution data respectively were used in this study. A total of 06 cloud free satellite images of both satellites (single image for each satellite for each growing season) were downloaded and analyzed. Among them, two images were selected from the 2018 to 2019 growing seasons and the remaining four images were selected from other growing seasons i.e., 2019-2020 and 2020-2021, respectively. The single date of image acquisition based on maximum NDVI for each growing season was used for this study. The maize plantation date was considered as the last week of November and first week of December for these locations viz. Sundarganj Upazila for each growing season for the entire study area based on the information collected from the field visits. Every single image was calculated from the starting day of the plantation. The data of image acquisition of Landsat 8/OLI and Sentinel 2A/MSI for the three maize growing seasons 2018-19, 2019-20 and 2020-21, respectively, for the study area used for this study are presented in Table 1.

Table 1. Model development using Landsat 8 and Sentinel 2A satellite image at Sundargonj Upazila, Gaibandha district

Satellite images	Landsat 8			Sentinel 2A		
Growing season	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
IAD	19/03/2019	21/03/2020	24/03/2021	16/03/2019	20/03/2020	15/03/2021
DAP	111	106	109	108	105	100

IAD=Image acquisition date; DAP= Days after plantation

Satellite Image Pre-processing

For Landsat data, raw digital numbers (DN) were modified to top-of-atmosphere (TOA) reflectance values (Simonetti et al., 2015). For Sentinel-2, we kept the inventive Level-1C TOA reflectance values. The corresponding spectral bands accessible for both sensors were considered in this process: Green blue, near infrared (NIR) and red, short-wave infrared 1 (SWIR-1), and short-wave infrared 2 (SWIR-2). The SWIR-2 band in the Sentinel-2 image has a resolution of 20 m; as a result, it was resampled using the nearest neighbor resampling method to a resolution of 10 m. For Sentinel-2 satellite imagery, considering land use and land cover maps, downscaling has been found to have superior performance compared to upscaling, even when it was based on the most straightforward technique, the nearest neighbor resampling (Zheng *et al*., 2017). Downscaling was recommended over upscaling for the reasons mentioned above as well as the fact that we planned for small-scale disturbances. All images were cropped to represent the research locations. The European Commission's image processing (IMPACT) package was used to fulfill these tasks (Simonetti *et al*., 2015). Although low cloud coverage was preferred, clouds could not be completely avoided. To mask off the clouds and cloud shadows, we employed semi-automatic object-oriented criteria. First, a multiresolution segmentation (Baatz *et al*., 2000), applying the three visible bands of the electromagnetic spectrum, was executed in eCognition®software.

Vegetation Index (VI)

The vegetation index, especially the Normalized Difference Vegetation Index (NDVI), was applied for the images acquired from Landsat-8 and Sentinel-2 for maize yield assessment. The related band combinations were illustrated in Table 2.

Table 2. Vegetation index using Sentinel-2 and Landsat-8 satellite images

Index	Sentinel 2A	Landsat 8
NDVI	$\frac{B_8 - B_4}{B_8 + B_4}$	$\frac{B_5 - B_4}{B_5 + B_4}$
	B_8=NIR Band, B_4=RED Band	B_5=NIR Band, B_4=RED Band

Where, NIR is the reflectance of near infrared light (Band 8 or Band 5), Red is the reflectance of red light (Band 4).

Maize yield prediction model by satellite-based RS technique

The red band of the calibrated images and NIR were selected from each dataset and exported into QGIS 3.28.2. A simple raster calculation was done by QGIS 3.28.2 using Table-2 to find the NDVI images. Finally, the NDVI images were masked using the shape file from different locations like Sundarganj Upazil, Gaibandha district. The field points of the location were imported, and the mean NDVI values for each point were extracted from the satellite image considering a 3×3 matrix surrounding each point on the image.

The relationship between NDVI and maize growing period was established by plotting the respective values in terms of single days from the start date of maize plantation to the harvesting period. The day of the maximum NDVI was selected from their relationship with crop yield. To establish this relationship, NDVI data from growing season 2018-2020 were used. Then, a total of four satellite images viz., two images each were collected from Landsat 8 as well as Sentinel 2A, depending on the date of the maximum NDVI, and were selected from two growing seasons, namely 2018-2019 and 2019-2020 to build a relationship between the NDVI values and field level maize yield. This relationship based on each farmer's field point NDVI values, was validated using the satellite image of the 2020-2021 growing season. NDVI values less than 0.25 and more than 0.95 were removed from the listed fields to reduce the influence of reflectance of other objects like bare soil, settlements, water bodies, non-agricultural crops, and infrastructure. The maize yield prediction workflow is presented in Fig. 4.

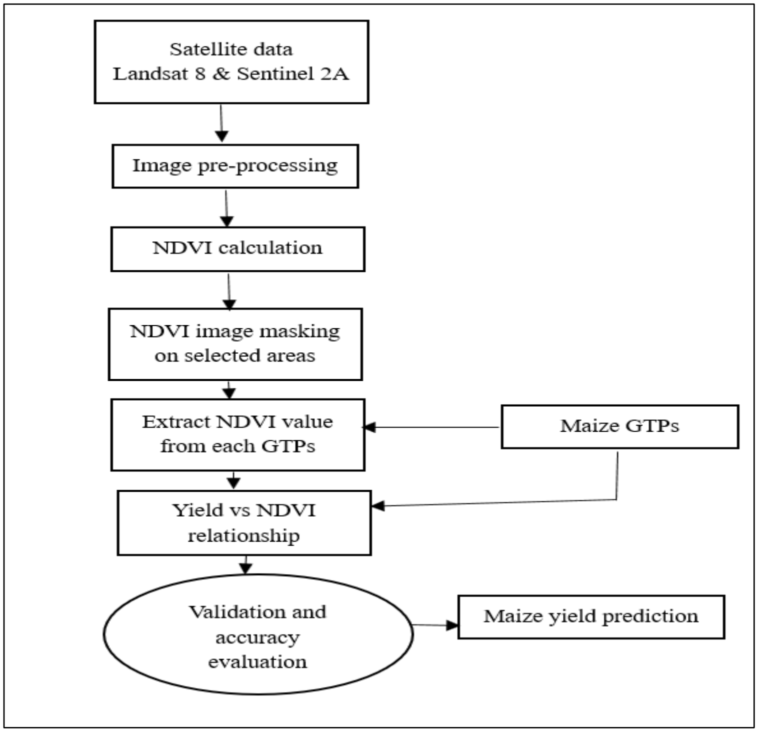


Fig. 4. Maize yield prediction workflow.

Yield forecasting model

The final step is to determine the relationship between NDVI and maize yield from farmers' fields with the equation below:

$$Y = f(X) \qquad (1)$$

Where Yand X are maize yield data collected from farmers' fields and NDVI, respectively. The relationship between NDVI and maize yield has been observed through the linear regression model, where the response variable is denoted by maize yields and the predictor by NDVIs. Several studies (Ren *et al*., 2008) applied a linear regression model to describe the relationship between NDVI and crop (wheat) yield in distinct locations. To develop the maize yield estimation model for both fields, the data of maize yield and Landsat 8 (OLI) and Sentinel 2A (MSI) images were used for 2018-2021.

Accuracy evaluation

Three metrics were employed to evaluate model performance. The coefficient of multiple determinations (R^2), the root means square error (RMSE) and the normalized RMSE (NRMSE) were selected as performance evaluation metrics

$$R^2 = \frac{\sum_{i=1}^{n}[(P_i - \bar{P})(O_i - \bar{O})]}{[\sum_{i=1}^{n}(P_i - \bar{P})^2][\sum_{i=1}^{n}(O_i - \bar{O})^2]} \ldots\ldots\ldots\ldots (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$NRMSE = \frac{\text{RMSE}}{\bar{O}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where P_i is the predicted yield, $\bar{P}$ is the predicted yield mean, O_i is the observed yield, $\bar{O}$ is the observed yield mean, and n is the sample size.

Results and Discussion

Maize yield from farmers' fields and corresponding NDVI values for different locations

Maize yield data and NDVI values from different dates satellite images of Landsat 8 and Sentinel 2A for corresponding farmers' fields have been collected from Sundarganj Upazila during the maize growing season 2018-19 and 2019-20 respectively. Twenty farmers' field yield data collected from study area and their corresponding NDVI values for two satellite images have been presented in Figure 5 and 6 for consecutive maize growing seasons 2018-19 and 2019-20 respectively.

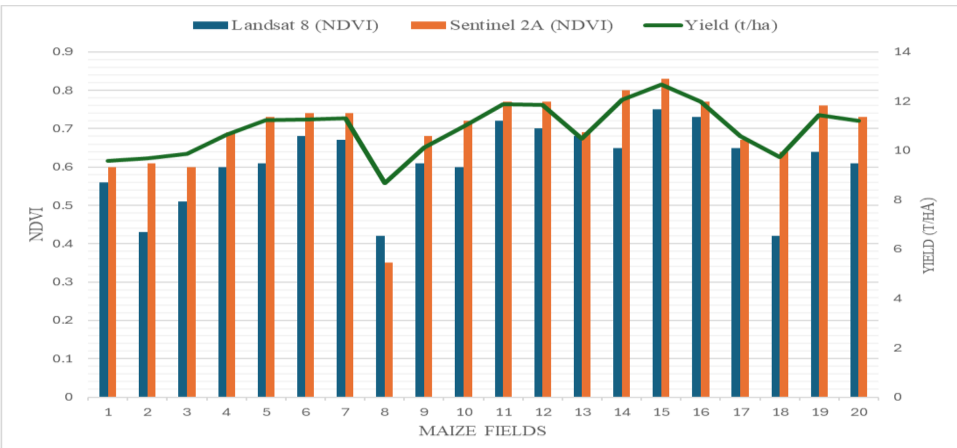


Fig. 5: NDVI values of satellite images and yields of corresponding farmers' fields at Sundarganj, Gaibandha during the season of 2018-19.

Fig. 5 shows that NDVI values are 0.75 and 0.83 which were the highest for Landsat 8 and Sentinel 2A, and the yield was a maximum of 12.68 t/ha for farmer's field 15, but the yield is a minimum of 8.67 t/ha for field 8. NDVI values are 0.42 for Landsat 8 and 0.35 for Sentinel 2, which were the lowest for farmers' fields 8 and 18 respectively during 2018-19.

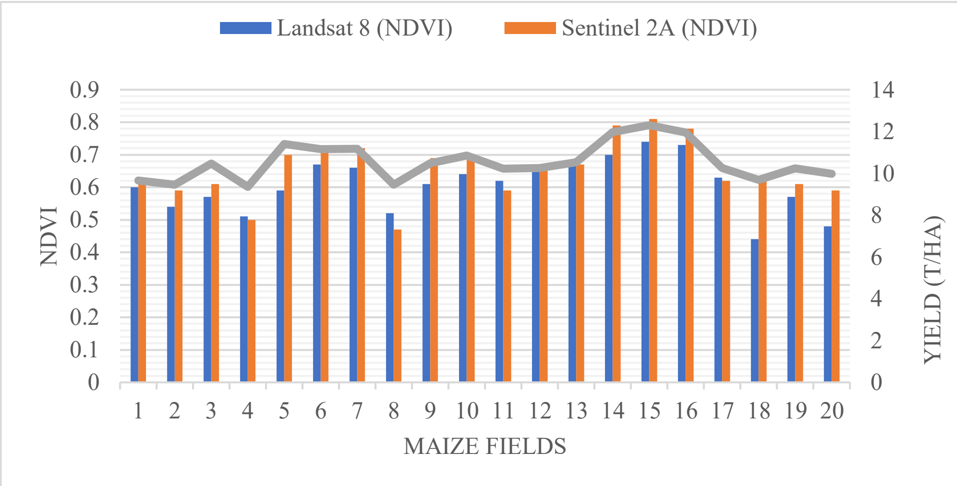


Figure 6: NDVI values of satellite images and yields of corresponding farmers' fields at Sundarganj, Gaibandha during the season of 2019-20.

Maximum NDVI for Sundargonj were 0.74 and 0.81 for farmer's field 15 and minimum NDVI were 0.44 and 0.47 for Landsat 8 and Sentinel 2A for farmer's field 18 and 8, but the highest and lowest yield were 12.30 t/ha and 9.35 t/ha for farmer's field 15 and 4, respectively during 2019-20 in Figure 6.

NDVI values over the field locations

A total of four satellite images (2 images each for Landsat 8 and Sentinel 2A) from two growing seasons during 2018-2019 and 2019-2020 were selected. Based on available images, those sowing the maximum NDVI in each growing season were found 111th, and 106th days after plantation for Sundarganj Upazila from Landsat 8 images as well as 108th, and 105th days after plantation for Sundarganj Upazila from Sentinel 2A images for 2018-2019 and 2019-2020 growing seasons, respectively. The spatial distribution of the NDVI varies from year to year. Spatial distribution of the NDVI over the selected location for selected distinct satellite images against different growing seasons is presented in Figure 7.

For Landsat 8 data, the NDVI distribution was maximum during 2018-2019 and the distribution was minimum during the season 2019-20 at Sundarganj upazila in Fig. 7. On the other hand, for Sentinel 2A data, NDVI distribution was maximum during the season 2019-2020 and minimum during the season 2018-2019 at Sundarganj upazila in Figure 7. The NDVI distribution from different locations of Sentinel 2A data outperforms Landsat 8 data during the maize growing season 2018-2019 and 2019-2020, respectively, in Fig. 7.

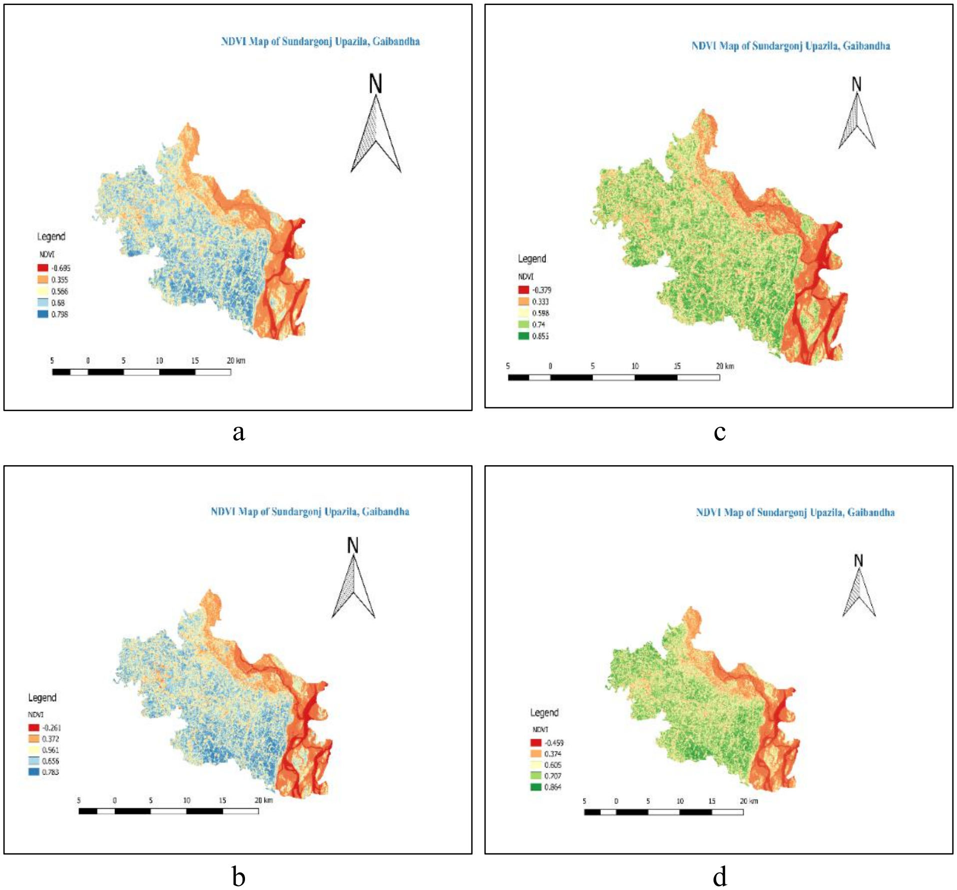


Fig. 7. Spatial distribution of the NDVI for different satellite images during the growing season 2018-19 and 2019-20. a. 111th days after plantation during 2018-19; b. 106th days after plantation during 2019-20 for Landsat 8; c. 108th days after plantation during 2018-19; d. 105th days after plantation during 2019-20 for Sentinel 2A at Sundarganj Upazila.

For two satellites viz., Landsat 8 and Sentinel 2A, the NDVI values and their corresponding yields for twenty farmers' maize fields from the study area during individual maize growing seasons 2018-2019 and 2019-2020, respectively are shown in Figures 5 and 6. From Figure 5 and 6, the mean NDVI and mean yield for two satellite data, Landsat 8 and Sentinel 2A for this location during the combined season 2018-2019 and 2019-2020 respectively were calculated which are represented below in Figure 8. Mean NDVI and mean yield are calculated for two satellite images for the combined two seasons because maize yield in each season i.e., 2018-19 and 2019-20 is mostly the same for this location. Mean NDVI and mean yield of the combined maize season performed better than NDVI and its corresponding yield of the individual maize season for each satellite image in this location because according to best model criteria viz. Multiple determination of coefficient (R^2), Mean Absolute Percentage Error **(**MAPE), Normalized Root Mean Square Error **(N**RMSE) and Root Mean Square Error **(**RMSE) fitted the best for the mean NDVI and the mean yield of the combined maize season rather than single maize growing seasons like 2018-19 and 2019-20 (Fig. 8). Mean NDVI is the largest, which is 0.75 for farmers' field 15 as well as the smallest, which is 0.43 for farmers' field 18 for Landsat 8. Similarly, the largest and lowest are 0.82 and 0.41 for farmers' field 15 and 8 for Sentinel 2A for the combined year respectively. The highest and lowest mean yields of the two-satellite data are 12.49 (t/ha) and 9.06 (t/ha) respectively, for this location in Fig. 8.

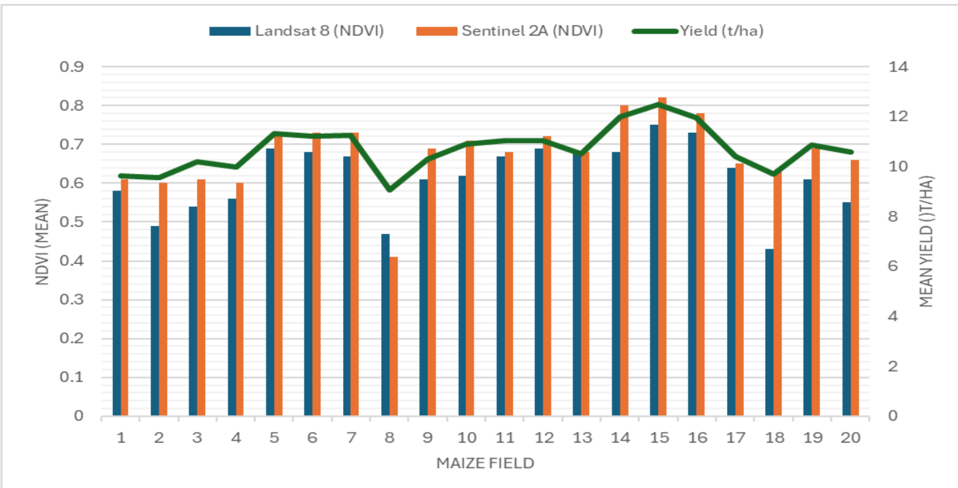


Fig. 8: Mean NDVI values for two satellite images and corresponding mean yields of farmers' maize fields at Sundarganj, Gaibandha during the combined season of 2018-19 and 2019-20.

Maize yield and NDVI relationship using a regression model

Regression analysis of maize yield against the single season basis NDVI and combined season basis mean NDVI for Sundarganj was performed for two satellite images, Landsat 8 and Sentinel 2A, and are graphically presented in Fig. 9.

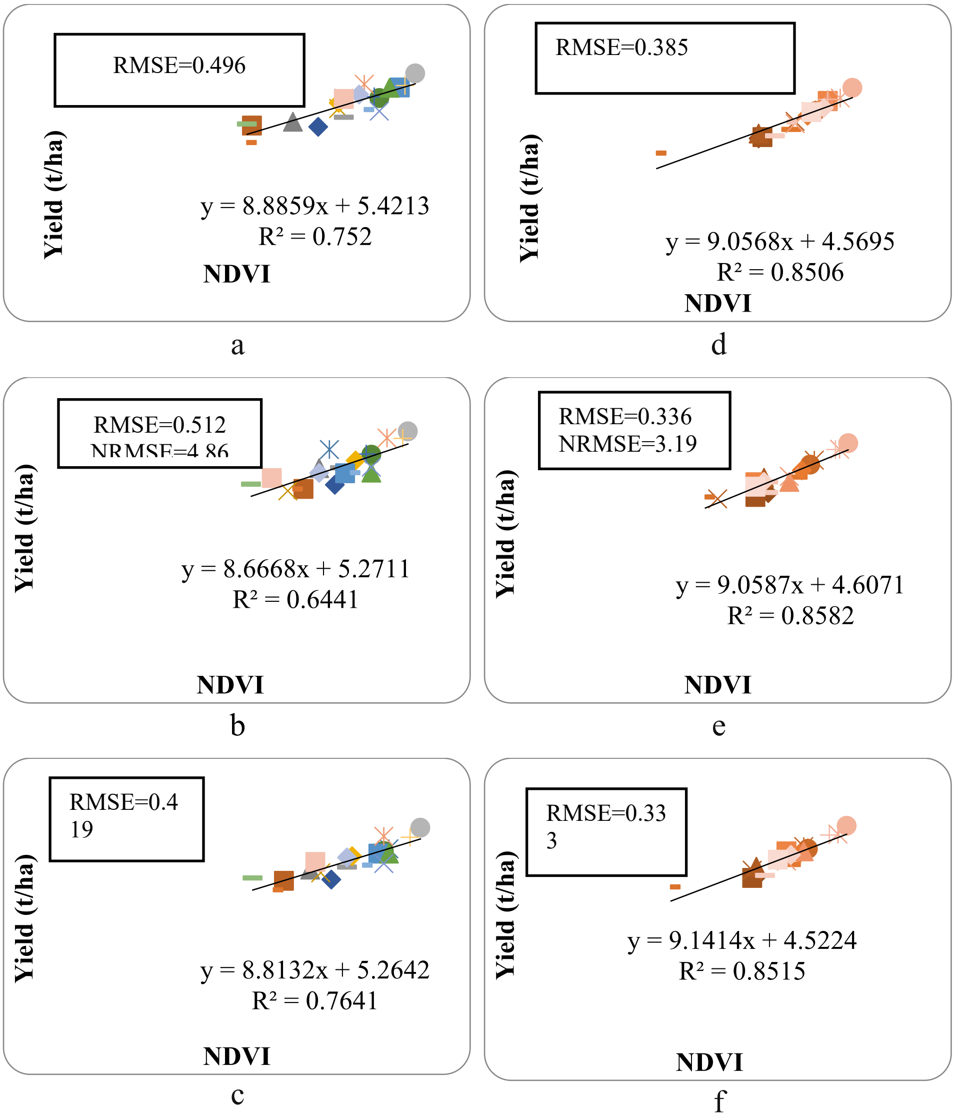


Fig. 9. Yield prediction model established from regression analysis between yield data collected from 20 farmers' maize fields for different images; [a. yield vs NDVI, 2018-19 b. yield vs NDVI, 2019-20 c. yield vs NDVI (mean), combined 2018-19 and 2019-20 for Landsat 8.] ; [d. yield vs NDVI, 2018-19 e. yield vs NDVI, 2019-20 f. yield vs NDVI (mean), combined 2018-19 and 2019-20 for Sentinel 2A] at Sundarganj Upazila.

The yield vs. NDVI relationship for Landsat 8 and Sentinel 2A satellite images is shown in Fig. 9, revealing that R^2 is the highest and other accuracy criteria like MAPE, RMSE and NRMSE of mean NDVI for the combined maize growing season i.e., 2018-2019 and 2019-2020, respectively for the selected location. The parameters of the regression analysis estimated from the yield vs. NDVI relationship for the combined season, together with the value of R^2, MAPE, RMSE and NRMSE are presented in Table 3. The relationship between mean NDVI for the combined two maize growing seasons and yield is compared well to the single-season basis NDVI vs. yield relationship for two satellite images.

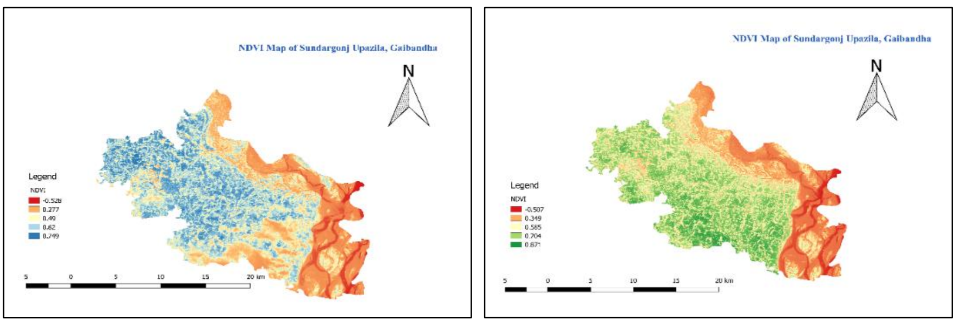
Table 3: Regression parameter and model criterion for the combined season at Farmers' maize field

Location	Satellite data	Regression parameter for mean value				Best model criteria			
		β_0	β_1	SE(β_1)	P-Value	MAPE	RMSE	NRMSE	R^2
Sundargonj	Landsat 8	5.26	8.81	1.15	0.0000	0.032	0.419	3.92	0.76
	Sentinel 2A	4.52	9.14	0.89	0.0000	0.023	0.333	3.11	0.85

Here, the regression coefficients of all the fitted models of two satellite images show a highly significant effect for Sundarganj Upazila in Table 7. Multiple determination of coefficient (R^2=0.898) along with MAPE (0.023), RMSE (0.333) and NRMSE (3.11) perform better for Sentinel 2A satellite image than Landsat 8 satellite image for Sundarganj Upazila, Gaibandha that are shown in Table 3.

Development and validation of the yield prediction model

The yield prediction model based on the regression analysis was developed based on the yield data collected from the 2018–2019 and 2019–2020 maize growing season. Evaluating the performance of the model validation is essential. Based on the deviation from the estimated and model prediction, model performance can be determined. Hence, the model has been further validated using yield data for the 2020-2021 maize growing seasons. After 109th and 100th days after plantation, an NDVI image was selected for two satellite images *viz.*, Landsat 8 and Sentinel 2A from 2020 to 2021 growing seasons at the respected location shown in Fig. 10.



a b

Fig. 10: Spatial distribution of the NDVI over the selected location for Landsat 8 and Sentinel 2A satellite images during the growing season of 2020-2021. 109th and 100th days after plantation for Sundarganj Upazila, Gaibandha for different satellite images.

The NDVI value was extracted from each of the 20 farmers' fields for two satellite images from a selected location during the maize growing season 2020-2021, which were presented in Table 3. As the coefficient of determination (R^2) was found to be high from the relationship of the mean value of NDVI and the yield of the combined season, the validation was done using the general mean value equation (NDVI and the yield relationship of the combined maize growing season) for two satellite images. The general mean value equation that was elaborately defined in Table 3 has been used separately in two developed regression models for validation along with two satellite images for the study area. The general regression equation from the mean NDVI (combined maize growing season) is presented in equation 5.

$$\text{Yield} = \beta_0 + \beta_1 * \text{NDVI}_{\text{mean (Combined maize growing season)}} \quad (5)$$

For Landsat 8: $\text{Yield} = 5.26 + 8.81 * \text{NDVI}_{\text{mean (Combined maize growing season)}}$ (6)

For Sentinel 2A: $\text{Yield} = 4.52 + 9.14 * \text{NDVI}_{\text{mean (Combined maize growing season)}}$ (7)

The actual yield (t/ha) of maize and predicted yield (t/ha) using equations 3 and 4 for two different satellite images for the study area during the 2020-2021 maize growing season were also presented in Table 4.

Table 4: Estimated yield and predicted yield from selected farmers' Maize Fields at Sundarganj Gaibandha during the season of 2020-2021

Farmer's field	Actual yield(t/ha)	NDVI values		Predicted yield (t/ha)		Error of yield (%)	
		Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A
1	11.12	0.58	0.66	10.38	10.56	6.65	5.04
2	10.57	0.45	0.57	9.23	9.73	12.68	7.94
3	10.25	0.41	0.49	8.88	9	13.37	12.19
4	9.96	0.33	0.47	8.17	8.82	17.97	11.44
5	9.65	0.31	0.43	7.99	8.45	17.2	12.43
6	11.5	0.65	0.74	10.99	11.29	4.43	1.83
7	12.65	0.68	0.75	11.26	11.38	10.98	10.03
8	9.11	0.31	0.43	7.96	8.45	12.62	7.24
9	10.81	0.52	0.62	9.85	10.19	8.88	5.73
10	11.23	0.6	0.68	10.55	10.74	6.05	4.36
11	11.65	0.62	0.72	10.73	11.1	7.89	4.72
12	11.62	0.6	0.76	10.55	11.47	9.2	1.29
13	10.1	0.39	0.57	8.7	9.73	13.8	3.66
14	12.57	0.64	0.75	10.9	11.38	13.28	9.46
15	11.59	0.61	0.68	10.64	10.74	8.19	7.33
16	11.54	0.61	0.71	10.64	11.01	7.79	4.59
17	10.45	0.51	0.64	9.76	10.37	6.60	0.76
18	10.55	0.4	0.52	8.79	9.28	16.68	12.03
19	10.32	0.52	0.53	9.85	9.37	4.55	9.20
20	10.77	0.5	0.64	9.67	10.37	10.21	3.71

The highest and lowest observed yield of maize were 12.65 (t/ha) and 9.65 (t/ha) as well as maximum and minimum NDVI values were 0.68 and 0.31 for Landsat 8; 0.76 and 0.43 for Sentinel 2A for farmers' fields 4 7 and 12 respectively during the maize growing season 2020-2021 (Table 4). The largest and smallest predicted yield of maize for Landsat 8 were 11.26 (t/ha) and 7.99 (t/ha) as well as for Sentinel 2A these were 11.47 (t/ha) and 8.45 (t/ha) for farmers' field 5, 7 and 14 respectively during the maize growing season 2020-2021 (Table 3). Maximum and minimum yield gaps (%) for Landsat 8 were 17.97 and 4.43 for farmers' fields 4 and 6 respectively and for Sentinel 2A were 12.43 and 0.76 for farmers' fields 5 and 18 respectively in selected areas during the maize growing season 2020-2021 (Table 4). The predicted yield of maize for two satellites was less than the actual yield of maize (underestimated) in each farmer's field for the study areas shown in Table 8. Depending on the value of Table 5, the validation of maize yield for two satellite images viz., Landsat 8 and Sentinel 2A was presented in Table 5 during the maize season 2020-2021.

Table 5: Validation of maize yield during the season 2020-2021

Location	Actual yield (Mean)	Predicted yield (Mean)		Mean error of yield (%)	
		Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A
Sundarganj, Gaibandha	10.90	9.77	10.17	10.30	6.70

The estimated farmers' field yield (mean) was 10.90 (t/ha) and the predicted yield (mean) for Landsat 8 and Sentinel 2A were 9.77 (t/ha) and 10.17 (t/ha) respectively in this study areas during the maize growing season 2020-2021. The percentage of mean yield error was 10.30 for Landsat 8 and 6.70 for Sentinel 2A. The error of mean yield (%) of Sentinel 2A performed better than Landsat 8 during the maize growing season 2020-2021 (Table 5). In Bangladesh, a few researchers used satellite data to forecast the yield of some crops like potatoes, rice, wheat and maize. Mohammad *et al*. (2024) developed a maize yield model using NDVI and found the percentage of the yield gap was at 8.82 Sentinel 2A and 10.15 at Kaharole in Dinajpur district. Here, we found that Sentinel 2A was performed better at Sundarganj Upazila (6.70 %) than Kaharole upazila (8.82%) for maize yield prediction. However, some researchers used the yield-NDVI relationship for maize yield prediction globally. Strong relationships (R^2 from 0.77 to 0.84) were observed between NDVI and the grain yield of maize using RapidEye imagery satellite and promising results for yield prediction were found with a 5% error of estimation in Hungary (Bu *et al.*, 2017). Feng *et al.* (2025) showed that combining these GSIs derived from the complete NDVI dataset with the third-period NDVI achieved the highest model accuracy (R^2 = 0.7, rRMSE = 12.3 %) for maize yield estimation. GSIs improved estimation accuracy (R^2 = 0.661, rRMSE = 13.2 %), increasing R^2 by 0.023 and reducing rRMSE by 0.4 %, approximately one month before harvest. Li et al. (2025) observe that the model demonstrated high accuracy ($R^2 = 0.896$, RMSE = 908.33 kg/ha) and exhibited strong robustness in both earlier years and during extreme climatic events which enables maize yield prediction 1–2 months in advance by leveraging historical patterns of environmental and agricultural variables.

Conclusion

The aim of this study was to provide an operational technique with adequate technological components for monitoring and estimating maize yield in Bangladesh. The developed system investigates the combined use of satellite based remote sensing (RS) and Geographic Information System (GIS) technology in the farmers' fields of Sundarganj Upazila, Gaibandha. The study aimed to generate a remotely sensed yield forecasting model that used the high spatial resolution of Sentinel 2A and Landsat 8 data to predict maize yield 40 to 50 days before harvest. The study has investigated the prediction capacity of remote sensing NDVI data for maize yield in the study area. It has also investigated the relationship between NDVI and yield for the study region. Here the two satellite images Landsat 8 (OLI) and Sentinel 2A (MSI) which were high spatial resolution data were used in this study in the consecutive years 2018-19, 2019-20 and 2020-21 respectively. Mean NDVI and mean yield of the combined maize season performed better than NDVI and its corresponding yield of the single maize season for each satellite image. The yield prediction equations were found based on mean values of NDVI for the combined growing season against the yield of maize. The yield against NDVI relationship for both satellite images showed that R^2 along with MAPE, RMSE and NRMSE of mean NDVI for the combined maize growing season performed better than the single maize growing season for the study area. The absolute mean error of prediction was found to be about 9.77% for Landsat 8 and 10.17% for Sentinel 2A compared to the actual yield during the maize growing season 2020-2021. The predicted yield (mean) of Sentinel 2A which is 1.33% closer to the actual yield than Landsat 8 was observed in this research. The yield prediction model for Sentinel 2A images performed better than Landsat 8 because of the high spatial resolution (~10m) that was revealed in this study. So, it can be concluded that the maize yield prediction based on Sentinel 2A images may be used to predict the yield before harvesting.

Limitations

- We could use more advanced indices like EVI (Enhanced Vegetation Index), SAVI (Soil Adjusted Vegetation Index) then the results could be more precise. But for technical issues it could not be used. So, yield prediction oriented advanced indices along with NDVI and other factors will be used in future research.

- On the other hand, we used single image selection for each season for both satellites manually, but we will be used sensitivity analysis for image selection for crop growing stage in future.

References

Awad, M. M. 2019. Toward precision in crop yield estimation using remote sensing and optimization techniques. *Agriculture* **9**: *54-56.*

Bala, S. K. and A. S. Islam. 2009. Correlation between potato yield and MODIS-derived vegetation indices.

Basso, B. and L., Liu. 2019. Seasonal crop yield forecast: Methods, applications, and accuracies. *Advances in Agronomy* **154**: 201–255.

BBS, 2024. *Yearbook of Agricultural Statistics*−2024, 36th series Statistics and Information Division, Ministry of Planning, Dhaka, Bangladesh

Becker-Reshef, I, Vermote, E., Lindeman, M., and C. Justice. 2010. A generalized regression-based model for forecasting winter wheat yields in Kansas and Ukraine using MODIS data. *Remote Sensing of Environment* **114**: 1312–1323.

Bu, H., L. K. Sharma, A. Denton, D. W. Franzen. 2017. Comparison of satellite imagery and ground-based active optical sensors as yield predictors in sugar beet, spring wheat, corn, and sunflower. *Agronomy Journal* **109**: 299–308.

FAO, 2021. Food and Agriculture Organization of the United Nations. Rome, Italy. http://faostat.fao.org/home/index.html#DOWNLOAD., Last access 24 March 2021.

Feng, D., H. Yang, K. Gao, X. Jin, Z. Li, C. Nie, G. Zhang, L. Fang, L. Zhou, H. Guo, Z. Jia, B. Ming, K. Wang and S. Li. 2025. Time-series NDVI and greenness spectral indices in mid-to-late growth stages enhance maize yield estimation. *Field Crops Research* **333**:110069.

Fieuzal, R., V. Bustillo, D. Collado, and G Dedieu. 2020. Combined Use of Multi-Temporal Landsat-8 and Sentinel-2 Images for Wheat Yield Estimates at the Intra-Plot Spatial Scale. *Agronomy* **10:** 327.

Franch, B., E. F. Vermote, J. C. Roger, E. Murphy, I. Becker-Reshef, C. Justice, M. Claverie, J. Nagol, I. Csiszar, D. Meyer, and F. Baret. 2017. A 30^{+} year AVHRR Land Surface Reflectance Climate Data Record and Its Application to Wheat Yield Monitoring. *Remote Sensing* **9:** 296-297.

Gumma, M. K., M. D. Kadiyala, P. Panjala, S. S. Ray, V. R. Akuraju, S. Dubey, A. P. Smith, R. Das, A. M. Whitbread. 2021. Assimilation of remote sensing data into crop growth model for yield estimation: a case study from India. *Journal of the Indian Society of Remote Sensing* **50**(2): 257-270.

Khan, S. N., D. Li, M. Maimaitijiang. 2024. Using gross primary production data and deep transfer learning for crop yield prediction in the US Corn Belt. *Int. J. Appl. Earth Obs*. Geoinf. **131**: 103965.

Lai, Y. R., M. J Pringle, P. M. Kopittke, N. W. Menzies, T. G. Orton and Y. P. Dang. 2018. An empirical model for prediction of wheat yield, using time-integrated Landsat NDVI. *Int. J. Appl. Earth Obs. Geoinf*. **72**: 99–108.

Lambert, M. J., P. C. S. Traoré, X. Blaes, P. Baret and P. Defourny. 2018. Estimating smallholder crop production at village level from Sentinel-2 time series in Mali's cotton belt. *Remote Sens*. *Environ*. **216**: 647–657.

Li, X., Y. Lyu, B. Zhu, L. Liu and K. Song. 2025. Maize yield estimation in Northeast China's black soilregion using a deep learning model with attention mechanism and remote sensing. *Scientific Reports* **15**:12927. https://doi.org/10.1038/s41598-025-97563-6

Lima, T. A., R. Beuchle, A. Langner, R. C. Grecchi, V. C. Griess and F. Achard. 2019. Comparing Sentinel-2 MSI and Landsat 8 OLI Imagery for Monitoring Selective Logging in the Brazilian Amazon. *Remote Sens*. **11**: 1-21; doi:10.3390/rs11080961

Liu, W. T. and F. Kogan, 2002. Monitoring Brazilian soybean production using NOAA/AVHRR based vegetation condition indices. *Int J Remote Sens* **23**(6):1161–1179.

Lyu, Y., P. Wang, X. Bai, X. Li, Ye, X., Y. Hu, and J. Zhang. 2024. Machine learning techniques and interpretability for maize yield estimation using Time-Series images of MODIS and Multi-Source data. Compute. Electron. Agric. 222, 109063. *Int J Remote Sens* **30**(10): 2491–2507.

Mirasi A, A. Mahmoudi, H. Navid, K. Valizadeh Kamran, M. A. Asoodar. 2019. Evaluation of Sum-NDVI Values to Estimate Wheat Grain Yields Using Multi-Temporal Landsat OLI Data. *Geocarto International* **20**: 1–16.

Mohammad, N., M. A. Islam, M. M. Rahman, I. Ahmed, and M. G. Mahboob. 2024. Maize yield forecasting model for using satellite multispectral imagery at Kaharole in Dinajpur district. *Bangladesh Journal of Agricultural Research* **49**(2):105-123

Newton, I. H., A. F. M. T. Islam, A. K. M. S. Islam, G. M. Tarekul, T. Anika and S. Razzaque. 2018. Yield Prediction Model for Potato Using Landsat Time Series Images Driven by Vegetation Indices. *Remote Sensing in Earth Systems Sciences.* **1**:29–38.

Rahman, M. M., M. A. Islam, M. G. Mahboob, N. Mohammad and I. Ahmed. 2024. Forecasting of potato yield estimation by satellite based remote sensing technique. *Acta Informatica Malaysia*. 8(2):45-51.

Rahman, A., K, Khan, N. Y. Krakauer, L. Roytman, and F. Kogan. 2012. Using AVHRR-based vegetation health indices for estimation of potato yield in Bangladesh. *J Civil Environ Eng* **2**:111.

Ren, J., Z. Chen, Q. Zhou and H. Tang. 2008. Regional yield estimation for winter wheat with MODIS-NDVI datain Shandong, China. *International Journal of Applied Earth Observation and Gioinformation*, 10(4), 403-413. Resolution earth observations: The Global Agriculture Monitoring (GLAM) project.

Reynolds, C. A., M. Yitayew and D. C. Slack. 2000. Estimating crop yields and production by integrating the FAO crop specific water balance model with real-time satellite data and ground-based ancillary data. *Int J Remote Sens* **21**(18):3487–3508 *Sens* 2: 1589-1609.

Shen, R., J. Dong, W. Yuan, W. Han, T. Ye, W. Zhao. 2022. A 30m resolution distribution map of maize for china based on Landsat and Sentinel images. *J. Remote Sens* 2022, 9846712.

Simonetti, D., A. Marelli and H. Eva. 2015. IMPACTool Box: Portable GIS Toolbox for Image Processing and Land Cover Mapping; *Publications Oce of the European Union: Luxembourg*, ISBN 978-92-79-50115-9.

Skakun, S., E. Vermote, J. C. Roger, and B. Franch. 2017. Combined use of Landsat-8 and Sentinel-2A images for winter crop mapping and winter wheat yield assessment at regional scale. *AIMS Geosci* **3:** 163–186.

Wang, Y., Z. Zhang, L. Feng, Q. Du, T. Runge. 2020. Combining multi-source data and machine learning approches to predict winter wheat yield in the conterminous United States. *Remote Sens.* **12** (8): 1232.

Zhang X, and Q. Zhang. 2016. Monitoring Interannual Variation in Global Crop Yield Using Long-Term AVHRR and MODIS observations. *ISPRS J. Photogramm. Remote Sensing* **114:** 191–205.

Zhao Y, A. B. Potgieter, M. Zhang, B. Wu, G. L. Hammer. 2020. Predicting wheat yield at the field scale by combining high-resolution Sentinel-2 satellite imagery and crop modelling. *Remote Sensing* **12:** 1024.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 523-532, March 2026

DEVELOPMENT OF ALTERNATE CROPPING PATTERN BY INCLUSION OF SHORT DURATION POTATO VARIETY AGAINST FARMERS' EXISTING CROPPING PATTERN FALLOW-BORO-FALLOW IN HAOR AREAS OF NETRAKONA

M. A. H. KHAN[1], N. SULTANA[2], S. AKHTAR[3] AND Q. NAHER[4]

Abstract

A trial was conducted in farmers' fields in Madan, Netrakona, by the On-Farm Research Division of the Bangladesh Agricultural Research Institute (BARI), Mymensingh, during 2023–24 and 2024–25. The study aimed to develop an alternate cropping pattern, Potato (var. Challisha)-Boro rice (var. BRRI dhan92)-Fallow and compare its productivity and profitability against the existing pattern, Fallow-Boro (var. BRRI dhan29)-Fallow, through the inclusion of potato (var. Challisha) and Boro rice (var. BRRI dhan92) using improved management practices. The experiment was laid out in a randomized complete block design with six dispersed replications. Two cropping patterns viz., alternate cropping pattern (Potato-*Boro* rice-Fallow) and farmers' existing cropping pattern (Fallow-*Boro*-Fallow) were the treatment variables of the experiment. The unit plot size was 1000-1200 m^2. The result of the study showed that two crops could be grown successfully in sequence in the tested site. Mean rice equivalent yield of alternate cropping pattern was 26.59 t ha^{-1}which was 271 % higher over existing cropping pattern (7.16 t ha^{-1}). Besides, land utilization index, harvest index and profitability of alternate cropping pattern was higher than farmers' existing cropping pattern. The mean gross return (Tk. 5,49,950 ha^{-1}) and gross margin (Tk. 2,69,148 ha^{-1}) were higher in alternate cropping pattern compared to farmers' existing cropping pattern. The marginal benefit cost ratio (2.01) was also indicated the superiority of the alternate cropping pattern over the farmers' existing cropping pattern

Key words: Rice equivalent yield, harvest index, profitability, efficiency and gross return.

Introduction

Bangladesh is almost self-sufficient in rice production but other food production such as potato, oil crops, pulses and vegetables etc. are still deficient to a large extent. The present cropping intensity of Madan Upazilla of Netrakona district is about 169 % which is very low than country's cropping intensity (198%). Potato (Challisha) is a high value cash crop with short duration which brings higher

---

[1&2]Principal Scientific Officer, On-Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Mymensingh, [3]Senior Scientific Officer, On-Farm Research Division, BARI, Mymensingh, and [4]Principal Scientific Officer, On-Farm Research Division, BARI, Joydevpur, Bangladesh.

economic return. In Fallow-Boro-Fallow cropping patterns potato may be introduced after receding flood water. Potato may be grown easily as an alternative of farmers' one. There is no alternative to meet the ever-increasing demand of food for fast growing population except increasing production from the existing available land in the country. In alignment with Sustainable Development Goal 2 (SDG-2), BARI remains committed to developing technologies that increase cropping intensity and ensure food security. Consequently, the institute BARI is working to transition single-cropped areas into double-cropped land, while similarly advancing double-cropped systems into triple or quadruple-cropping patterns

In this context, not only the modern production technology and complementary inputs are essential but also the diversification of crops throughout the country is foremost. In Bangladesh horizontal expansion is very limited, but increase in crop production could be possible with vertical expansion through increasing crop yield per unit area and by reducing production losses. A cropping pattern is the yearly sequence, temporal and spatial arrangement of crops in a given land area. Inclusion of potato variety can create opportunity to fit in the Fallow-*Boro* Rice-Fallow cropping sequence. There are seven major cropping patterns which are practiced by the farmers of Madan, under Netrakona district among which Fallow-Boro-Fallow is one of the major cropping patterns under irrigated medium low land. This pattern covers around 40 % of the net cropped area (DAE, 2024). After flood water receded 15-20% land in haor areas is suitable for crop cultivation in last week of September to third week of December. At that time farmers are waiting for cultivating *Boro* rice by irrigation with deep tube well up to third week of January. As a result, a vast area remains fallow for long time (About 90 to 100 days) before *Boro* rice cultivation. So, there is an opportunity to increase cropping intensity and crop productivity by inclusion of potato in Fallow-*Boro*-Fallow cropping pattern. If the farmers sown potato by first week of November, then it will be harvest at mid-January. After harvesting of potato farmers can easily grow *Boro* rice in proper time which will not be affected by flash flood. The present study was undertaken to develop two crop-based cropping patterns for haor areas and increase cropping intensity, productivity and income of the farmers.

Materials and Methods

The trial was conducted at the farmers' field of Madan, Netrakona by the On-Farm Research Division, Bangladesh Agricultural Research Institute, Mymensingh during 2023-24 and 2024-25 to increase cropping intensity, productivity and profitability of the farmers by inclusion of potato (var. Challisha) in the existing cropping system Fallow -*Boro*-Fallow cropping pattern. The experimental site belongs to Old Brahmaputra Floodplain Agro-ecological Zone (AEZ-9) of Netrakona.The geographical position of the area in between $24^{o}72^{/}$N latitude and

90°93′ E longitude. The land was medium low and the soil of the study area was clay loam to clay in texture with well drainage system and almost acidic in reaction having pH range of 4.3 to 5.8. The overall soil characteristics are grey clay and silty clay, which are prone to being acidic and organic matter content is medium. In general, fertility level including N, P, K and B was low. Maximum rainfall was received during the months of April to September. The highest temperature (31.8°C) in August and the lowest in January (12.6°C). The relative humidity was the highest (84.5%) in August and the lowest (75.2 %) in March. Monthly mean maximum and minimum air temperature (31.1 and 23.5°C), total rainfall (2195 mm) and relative humidity (82.7 %) were prevailing during the study period.

The experiment was laid out in a randomized complete block design with six dispersed replications. Two cropping patterns viz., alternate cropping pattern (Potato-*Boro*-Fallow) and farmers' existing pattern (Fallow-*Boro*-Fallow) were the treatment variables of the experiment. The unit plot size was 1000-1200 Sq.m. Potato was grown during *Rabi* season and it was the first crop of the sequence. Major yield contributing characters of potato has been cited in appendix 1. Soil moisture at the time of planting potato was prevailing about 60 % at dry weight basis. Potato seed was sown @ 1500 kg ha^{-1} with 40 cm × 20 cm during 22 to 25 November 2023 and 21 to 25 November 2024 in two consecutive years. Fertilizer management was followed by (Ahmmad *et. al.* 2018) and intercultural operations like weeding, irrigation and pest management were done to support the normal growth and development of the crops. Potato was harvested during 25 to 31 January, 2024 and 26 to30 January, 2025 in two successive years. *Boro* rice was the second crop of the sequence. Major yield contributing characters of BRRI dhan-92 has been given in appendix 2. Seedlings of rice were grown in adjacent plot and transplanting was done with 40 to 45 days old seedlings of rice var. BRRI dhan92 at a spacing of 20 cm × 20 cm during 08 to 16 February 2024 and 08 to 12 February 2025. Boro rice was harvested during 23 to 30 May 2024 and 20 to 28 May 2025 in two consecutive years.

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

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

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

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

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

Where, Y_i= Yield (kg) of ith crop, d_i= Duration (day) of ith crop of the pattern and i= 1, 2, 3, 4

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

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

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

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

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

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

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

Results and Discussions

Crop management: Crop management practices include date of planting/transplanting, date of harvesting, fertilizer dose used, field duration and turnaround time etc. of alternate and existing cropping pattern are shown in Table 1. The mean crop field duration of potato and *Boro* rice under improved cropping pattern Potato (var. Challisha)- *Boro* rice (var. BRRI dhan92)-Fallow were 66 and

Table 1. Agronomic practices of alternate cropping pattern and Farmers' existing cropping pattern at Madan, Netrakona MLT site during 2023-24 and 2024-25

Parameters	Years	Alternate Pattern (AP)			Farmers' Pattern (FP)		
Crop	2023-24	Potato	*Boro* rice	Fallow	Fallow	*Boro* rice	Fallow
	2024-25	Potato	*Boro* rice	Fallow	Fallow	*Boro* rice	Fallow
Variety	2023-24	Challisha	BRRI dhan92	Fallow	Fallow	BARI dhan29	Fallow
	2024-25	Challisha	BRRI dhan92	Fallow	Fallow	BARI dhan29	Fallow
Planting time	2023-24	22-25 Nov. 23	08-16 Feb.24	Fallow	Fallow	11-15 Jan.24	Fallow
	2024-25	21-25 Nov. 24	08-12 Feb.25	Fallow	Fallow	10-14 Jan.25	Fallow
Seedling age (days)	2023-24	-	40-45	Fallow	Fallow	40-45	Fallow
	2024-25	-	40-45	Fallow	Fallow	40-45	Fallow
Spacing (cm)	2023-24	40 ×20	20 ×20	Fallow	Fallow	20×15	Fallow
	2024-25	40 ×20	20 ×20	Fallow	Fallow	20×15	Fallow
Fertilizer dose	2023-24	160-44-150-21-2-1	138-20-60-20	Fallow	Fallow	140-20-60-20	Fallow
(NPKSZnB kg ha^{-1})	2024-25	160-44-150-21-2-1	138-20-60-20	Fallow	Fallow	140-20-60-20	Fallow
Harvesting time	2023-24	25-31 Jan.24	22-30 May 24	Fallow	Fallow	06-14 May 24	Fallow
	2024-25	26-30 Jan.25	20-28 May 25	Fallow	Fallow	06-12 May 25	Fallow
Field duration (days)	2023-24	65	103	Fallow	Fallow	118	Fallow
	2024-25	66	105	Fallow	Fallow	117	Fallow
TAT (days)	2023-24	183	14	Fallow	Fallow	247	Fallow
	2024-25	184	13	Fallow	Fallow	248	Fallow

104 days, respectively while, in existing cropping pattern Fallow- *Boro* (BRRI dhan29)- was 118 days for *Boro* rice. Total field duration of alternate cropping pattern and existing cropping pattern were 168-170 and 117-118 days, respectively in 2023-24 and 2024-25. The crop duration of *Boro* rice under existing cropping pattern was higher (117-118 days) than that of alternate cropping pattern (103-104 days) due to use of long duration BRRI dhan29 variety in farmers' pattern. But in alternate cropping pattern *Boro* rice (var. BRRI dhan92) was cultivated and it was at least 15 days earlier harvested in both years. Turnaround time for Potato and *Boro* rice were 182-183 and 13-14 days, respectively in alternate cropping pattern whereas in existing cropping pattern it was 247-248 days in both the years.

Tuber/grain and straw yield: Tuber/grain and foliage/straw yield of the study have been presented in Table 2. Tuber yield of Potato (Challisha) was 12.8 and 12.93 tha^{-1} and sundry foliage yields were 3.49 and 3.59 tha^{-1} in two successive years, respectively. Two years average, tuber yield and foliage yield of potato in alternate cropping pattern was 12.87 and 3.54 t ha^{-1}, respectively. Grain yield of *Boro* rice was 7.43 t ha^{-1} in 1^{st} year and 7.53 t ha^{-1} in 2^{nd} year. Two years average, grain and straw yields of *Boro* rice were 7.48 and 7.13 t ha^{-1} in alternate cropping pattern, respectively which was 4.47 and 1.0 % higher than existing pattern *Boro* rice (var. BRRI dhan29) due to change of variety with improved production technologies. Similar results were also obtained by Nazrul *et al*. 2013. Farmers' cropping pattern gave lower yield due to imbalance use of fertilizers and poor management practices. It was revealed that the entire component crops of Potato-*Boro*-Fallow cropping pattern under alternate practices (AP) gave higher yield as well as by-product yield in two consecutive years. Inclusion of Potato (Challisha) and BRRI dhan92 with modern production technologies increased the total yield over the farmers existing practice. Similar results were also obtained by Nazrul *et al*., 2013.

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

Parameters	Years	Alternate Cropping Pattern (AP)			Farmers' Existing Pattern (FP)		
		Potato	*Boro*	Fallow	Fallow	*Boro*	Fallow
Tuber/Grain yield (t ha^{-1})	2023-24	12.81±0.22	7.43±0.16	-	-	7.20±0.25	-
	2024-25	12.93±0.23	7.53±0.17	-	-	7.12±0.27	-
	Average	12.87±0.21	7.48±0.17	-	-	7.16±0.26	-
Foliage/Straw yield (t ha^{-1})	2023-24	3.49±0.19	7.16±0.16	-	-	7.13±0.21	-
	2024-25	3.59±0.20	7.10±0.18	-	-	7.03±0.19	-
	Average	3.54±0.18	7.13±0.17	-	-	7.08±0.20	-

Rice Equivalent Yield (REY): Total productivity of a cropping system was evaluated in terms of rice equivalent yield (REY) and it was calculated from yield of component crops. Average higher rice equivalent yield (26. 59 t ha^{-1}) was recorded with the alternate cropping system over farmer's traditional cropping system (Table 3). Rice equivalent yield increased by 271% in alternate cropping pattern due to inclusion of potato (Challisha) and a new high yielding variety of rice with improved production technologies for the component crops. The lower rice equivalent yield (7.16 t ha^{-1}) was obtained in the farmer's pattern due to single *Boro* rice with traditional management practices. It is evident from the above findings that alternate cropping pattern gave higher yield compared to existing farmers' pattern. Similar results were obtained by Nazrul *et al*., 2017.

Production Efficiency (PE): Mean maximum production efficiency 120.42 in terms of kg $ha^{-1}day^{-1}$ was obtained from alternate cropping pattern which was 97.93 % higher over farmer's existing cropping pattern (Table 3). Production efficiency of alternate cropping pattern was found 120.48 and 120.35 kg $ha^{-1}day^{-1}$ in two consecutive years while in existing cropping pattern it was found 61.02 and 60.85 kg $ha^{-1}day^{-1}$, respectively. The production efficiency was lower in farmers' existing cropping pattern might be due to only single *Boro* rice in farmer's existing cropping pattern. The lower production efficiency was observed in farmer's existing cropping pattern (Tables 3). The result indicates that crops remain standing in the field for shorter time in leading to higher production efficiency.

Land utilization index (LUI): Land use efficiency is the effective use of land in a cropping year, which mostly depends on crop duration. The average land utilization index indicated that alternate cropping pattern used the land for 46.30 % period of the year whereas farmer's pattern used the land for 32.14% period of the year (Table 3). Land utilization index was about 44 % higher in alternate cropping pattern than farmer's practice due to alternate pattern occupied the land for longer duration (170) days than farmer's pattern (118 days) in a year. This higher land use efficiency in alternate cropping pattern is due to cultivation of two component crops in the pattern.

Harvest Index: Alternate cropping pattern Potato (var. Challisha)-*Boro* rice (Var. BRRI dhan92) recorded the higher harvest index (65.26 %) and existing cropping pattern Fallow-*Boro* (var. BRRI dhan29) - Fallow) recorded the lower harvest index (50.28 %). The harvest index of alternate cropping pattern had higher value due to inclusion of potato and *Boro* rice varieties which contributed the higher economic and biological yield.

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

Year	Cropping patterns	REY (t ha^{-1})	PE (kg ha^{-1})	LUI (%)	HI (%)
2023-24	AP	26.25	120.48	46.03	65.52
	FP	7.20	61.02	32.23	50.24
2024-25	AP	26.92	120.35	46.57	65.00
	FP	7.12	60.85	32.05	50.31
Mean	AP	26.59	120.42	46.30	65.26
	FP	7.16	60.84	32.14	50.28

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

Profitability analysis: The cost and return analysis were done on the basis of prevailing market price during the crop season as shown in Table 4. The study revealed that mean gross return of the alternate and farmers' existing cropping pattern was Tk.5,49,950 and Tk. 1,58,260 ha^{-1}, respectively. The mean gross return of alternate cropping pattern was 248 % higher than farmers' existing cropping pattern and it might be due to inclusion of potato and high yielding *Boro* rice variety. The mean total variable cost of the alternate and farmers' existing cropping pattern was Tk. 2,80,802 and Tk. 85,672 ha^{-1}, respectively. About 271 % higher gross margin (Tk. 2,69,148 ha^{-1}) was calculated at alternate cropping pattern over farmer's existing cropping pattern (Tk. 72,588 ha^{-1}). The mean MBCR was found 2.01 which also indicated the superiority of alternate cropping pattern over farmer's existing cropping pattern.

Farmers' opinion: Farmers opined that cultivation of potato in a year increased cropping intensity and productivity. Harvesting of short duration potato (Challisha) can easily be grown without hampering *Boro* rice.

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

Year	Pattern	Gross return (Tk. ha^{-1})	Total variable cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})	MBCR
2023-24	AP	5,47,200	2,80,650	2,66,550	2.00
	FP	1,58,260	85,720	72,540	
2024-25	AP	5,52,700	2,80,955	2,71,745	2.02
	FP	1,58,260	85,625	72,635	
Mean	AP	5,49,950	2,80,802	2,69,148	2.01
	FP	1,58,260	85,672	72,588	

Note: Unit price (Tk. kg^{-1}): Potato =30/-, Boro rice =20/- and Rice straw=2/-

Conclusion

The total crop productivity, production efficiency, and profitability of the alternate cropping pattern, Potato (var. Challisha)-Boro rice (var. BRRI dhan92)-Fallow, were significantly higher than those of the existing pattern, Fallow-Boro (var. BRRI dhan29)-Fallow, due to the inclusion of potato and the improved Boro rice variety. Thus, the Potato-Boro-Fallow sequence is an economically and agronomically suitable technology for the haor areas of Netrakona. While the potato crop provides a harvested yield even if early flash floods affect the Boro rice, short-duration Boro varieties should be developed for this pattern in the future to further mitigate flood risks

Acknowledgement

The authors are grateful to the respected authority for their financial support to the research work under PARTNER program. The authors also thankfully acknowledge office staff and farmers who participated in this study for providing their valuable time during the study period.

References

Ahmmed S., M. Jahir Uddin, S. Razia, R. A. Begum, J. C. Biswas, A. S. M. M. Rahman, M. M. Ali, K. M. S. Islam, M. M. Hossain, M. N. Gani, G. M. A. Hossain and M. A. Satter. 2018. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka-1215. P. 223.

CIMMYT, 1988. International Maize and Wheat Improvement Centre. From Agronomic Data to Farmer Recommendations: An Economic Training Manual. International Maize and Wheat Improvement Centre, Mexico, D. F. pp.1-79.

DAE. 2024. Department of Agriculture Extension). Paper presented in the regional workshop held at Bangladesh Institute of nuclear Agriculture, Mymensingh-2200.

Nazrul, M. I., M. K. Hasan and M. R. I. Mondal. 2017. Production potential and economics of mungbean in rice-based cropping pattern in Sylhet region under AEZ- 20. *Bangladesh J. Agril. Res.* **42** (3):413-424.

Nazrul, M. I., M. R. Shaheb, M. A. H. Khan and A. S. M. M. R. Khan. 2013. On-Farm evaluation of production potential and economic returns of potato-rice based improved cropping system. *Bangladesh Agron. J.* **16** (2): 41-50.

Rahman, M. M., M. H. Khan, R. N. Mallick and R. E Hudgens. 1989. Guidelines for Farming Systems Research Methodology. Bangladesh Agricultural Research Council, Framgate, Dhaka. P. 42.

Tomer, S. S and A. S. Tiwari. 1990. Production potential and economics of different crop sequences. *Indian J. Agron.* **35** (1, 2): 30-35.

Verma, S. P and S. C. Modgal. 1983. Production potential and economics of fertilizer application as resources constraints in maize, wheat crop sequence. *Himachal J. Agric. Res.* **9**(2): 89-92.

Appendix 1. Characteristics of Potato (Challisha) at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Plant density /m^2	No. of stem /plant	No. of tubers /plant	Average wt. of tubers/plant (g)
2023-24	12.50	3.40	65.70	2.41
2024-25	11.80	3.20	67.30	2.43
Mean	12.15	3.30	66.50	2.42

Appendix 2. Characteristics of BRRI dhan92 at Madan, Netrakona MLT site during 2023-24 and 2024-25

Year	Plant density /m^2	No. of effective tillers /hill	No. of filled grain/panicle	1000-grain weight (g)
2023-24	22.23	11.28	173	21.19
2024-25	22.26	11.34	170	21.24
Mean	22.25	11.31	172	21.22

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 533-551, March 2026

EFFECT OF MAGNESIUM, ZINC AND BORON FERTILIZERS ON YIELD, FRUIT QUALITY AND PROFITABILITY OF SPONGE GOURD (*LUFFA CYLINDRICA*)

M. A. QUDDUS[1], R. AHMED[2], M. A. RAHMAN[3], K. K. SARKER[4]
AND M. EYAKUB ALI[5]

Abstract

An experiment was conducted at the research field of Soil and Water Management Section in Horticulture Research Centre, Bangladesh Agricultural Research Institute, during the summer seasons of 2020 and 2021. The study aimed to determine the influence of magnesium (Mg), zinc (Zn), and boron (B) fertilizers on the growth, yield, fruit quality, nutrient uptake and use efficiency and profitability of sponge gourd (*Luffa cylindrica L.*). The experiment followed a randomized complete block design with three replications. Nine treatment combinations were derived from three levels each of Mg (0, 4, and 8 kg ha^{-1}), Zn (0, 3, and 4 kg ha^{-1}), and B (0, 1.5, and 2 kg ha^{-1}). These were- T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-1.5 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B). Application of Mg-Zn-B at 8-4-2 kg ha^{-1} (T_9) led to the maximum fresh fruit yield (55.2 t ha^{-1}), which was 29.3% higher than the control (T_1). Treatment T_9 showed superior growth, yield attributes, and quality characteristics, recording the highest amounts of vitamin C (13.6 mg100 g^{-1}) and β-carotene (15.7 μg100 g^{-1}) and maximum uptake of Mg, Zn, and B. The apparent nutrient recovery efficiency of Mg showed inconsistent results, whereas the efficiency for Zn and B was most prominent in treatment T_9, followed by T_8. Application of Mg-Zn-B at 8-4-2 kg ha^{-1} significantly boosted profitability, leading to a maximum gross margin (BDT 962163 ha^{-1}) and the highest MRR of 920%. Results suggest that application of Mg-Zn-B at 8-4-2 kg ha^{-1} with a blanket dose of N-P-K-S at 100-30-80-20 kg ha^{-1} and 5 t ha^{-1} of cow dung could be adopted for sponge gourd cultivation in the Gazipur soil condition (AEZ-28).

Keywords: Economic return, fruit yield, growth, *Luffa cylindrica* L., nutrient uptake and use efficiency.

Introduction

Cucurbits are the common name for numerous vegetable crops in the Cucurbitaceae family. These sprawling plants are widely grown in dry and semi-

---

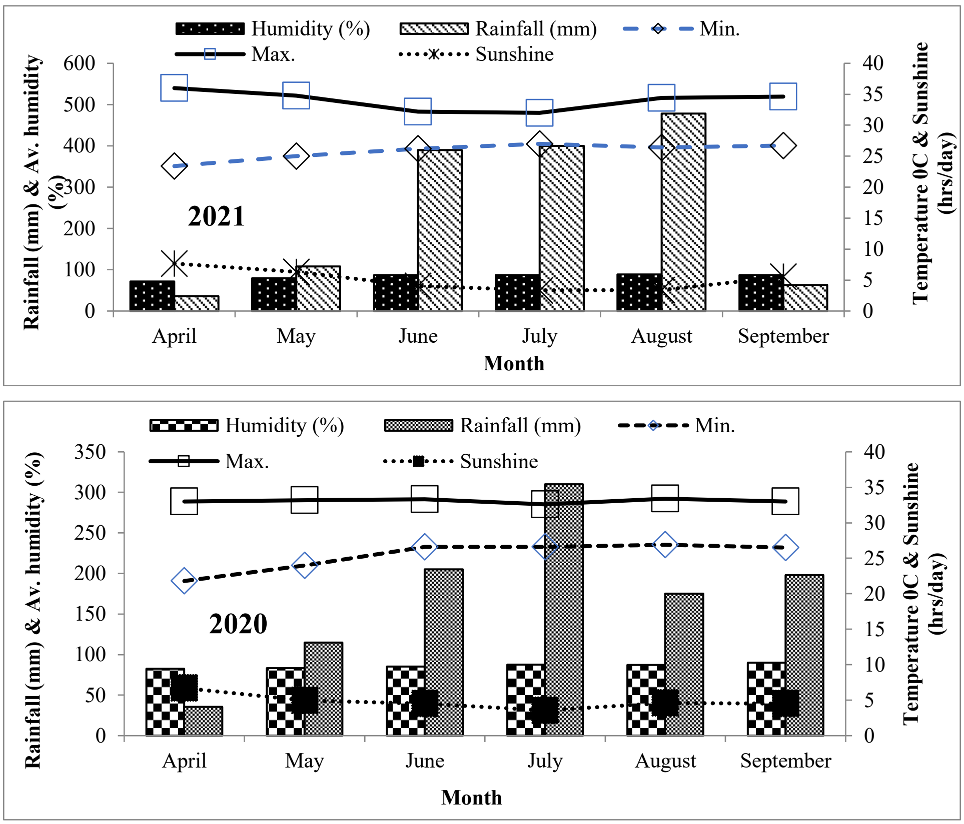
[1&2]Senior Scientific Officer, Soil and Water Management Section, HRC, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, [3]Director, T & C, BARI, Gazipur, [4]Senior Scientific Officer, Irrigation and Water Management Division, BARI, Gazipur, and [5]Principal Scientific Officer, Soil Science Division, BARI, Gazipur, Bangladesh.

dry regions and represent a large portion of vegetables produced during the summer and rainy seasons. Sponge gourd (*Luffa cylindrica* L.), known locally as 'dhundul,' is a particularly valued and essential cucurbit whose cultivation is increasing day by day in Bangladesh. As a fresh fruit, it is considered a superfood for boosting immunity, as it is rich in protein, carbohydrates, and vitamin C (Zadge *et al.,* 2024; Sonavane *et al*., 2022). The fresh tender and immature fruits are harvested for culinary purposes. Matured and fibrous sponge gourds are used as bath sponges and in various industrial applications (Sheela and Anburani, 2024; Mashilo *et al.*, 2025). Experimental grey terrace soils are habitually characterized by their acidic nature, low organic matter content, poor water-holding capacity, and a tendency toward deficiencies of micronutrients like Zn and B, and medium or deficient levels of the secondary macronutrient like Mg due to high leaching and fixation (Ishfaq *et al.,* 2022; Wang *et al.,* 2022). Such conditions can severely limit the efficacy of nitrogen, phosphorus, and potassium (NPK) fertilization, leading to suboptimal plant growth and reduced marketable yield (Wang *et al.,* 2020). While nitrogen, phosphorus, and potassium (NPK) are fundamental, the role of micronutrients like zinc and boron, along with the secondary macronutrient magnesium, is increasingly recognized as a critical factor in enhancing sponge gourd growth, yield, quality, and nutrient use efficiency.

Magnesium (Mg), Zn and B elements, though required in relatively small quantities, are vital for a multitude of physiological and biochemical processes within the plant (Sidhu *et al.,* 2019). Zinc is a key cofactor for numerous enzymes, essential for carbohydrate metabolism and protein synthesis (Ahmed *et al.,* 2024), and is directly involved in the biosynthesis of auxins, the plant hormones that regulate growth and development (Pankaj *et al.,* 2018; Yadav *et al.,* 2023). Boron, on the other hand, plays a crucial structural role in maintaining cell wall integrity and membrane function (Jeevitha, 2018). It is also indispensable for pollen tube growth and sugar translocation processes that are fundamental to successful fruit set and development (Pandav *et al.,* 2016). Magnesium, as the central atom of the chlorophyll molecule, is directly tied to the efficiency of photosynthesis and energy transfer (Plant nutrition, Wikipedia, 2025). However, deficiencies of these nutrients are prevalent in many agricultural soils, particularly in regions with intensive cultivation, leading to stunted growth, reduced fruit quality, and diminished yields (Parvin *et al.,* 2024). However, a lack of zinc can result in "little-leaf" symptoms and poor fruit set, while boron deficiency can cause distorted fruit and premature flower shedding. A magnesium deficit manifests as interveinal chlorosis, severely impacting the plant's photosynthetic capacity (Jiao *et al.*, 2023). Therefore, a deeper understanding of the specific functions of magnesium, zinc, and boron, and their synergistic interactions is essential for developing effective and sustainable fertilization strategies. The experiment was, therefore, conducted to investigate the combined effects of these nutrients (Mg-Zn-B) on sponge gourd vegetative growth, fruit yield, fruit quality metrics, and the plant's ability to efficiently utilize available nutrients with economic return.

Materials and Methods

The experiment was conducted during the summer seasons of 2020 and 2021 at the research field of Soil and Water Management Section of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur (23°.59′ N and 90°.24′E). The experimental soil was clay loam. The average minimum and maximum temperatures ranged from 21.8°C to 36.0°C. The average relative humidity varied between 71.7% and 89.9%. Daily sunshine hours ranged from 3.35 to 7.67 hours. The rainfall during the trial period was recorded between 35.6 mm and 478 mm (Fig. 1). The temperatures and humidity both increased slightly in 2021 compared to 2020. Moreover, there was more rainfall in 2021, with the exception of the month of September.



Source: Meterological Station, Gazipur under the Ministry of Defence

Fig. 1. Monthly mean values for air temperature, average humidity, sunshine, and rainfall during the experimental period of 2020 and 2021.

Before experimentation, soil samples were collected from a depth of 0 to 15 cm using a standard procedure. The chemical properties of these samples were then analyzed using the standard methods outlined by Page *et al.* (1982), with the results presented in Table 1.

Table 1. Fertility status of soil in research field before experimentation

Soil	pH	OM%	Total N%	Ca	Mg	K	P	S	Zn	B
				meq 100 g^{-1}			µg g^{-1}			
Initial	6.2	1.20	0.061	4.63	1.11	0.11	11.8	12.4	0.84	0.17
Critical level	5.5-6.5	2-3	0.12	2.0	0.50	0.12	7	10	0.6	0.20
*Interpretation	Slightly acidic	Low	Very low	Optimum	Medium	Low	Medium	Low	Low	Low

*Source: Ahmmed *et al.* (2018)

Healthy seeds of sponge gourd cv. 'BARI Dhundul-2' were sourced from Olericulture Division, HRC, BARI, Gazipur. The seeds were sown manually into 10 cm x 10 cm polythene bags containing fine clay loam soil on March 15, 2020, and March 16, 2021. Watering was done immediately after sowing, and the seedlings were irrigated twice a week. Seedlings were secured from insects and diseases using Autostin® 50 WDG (a.i. Carbendazim) fungicide and Sevin® WP 85 (a.i Carbaryl) insecticide. During the seedling growth period, the main plots were prepared using a tractor-driven chisel plow for four passes, followed by leveling with a rotavator. Remaining any weeds and debris were removed manually.

There were nine treatment combinations comprising three levels each of magnesium (0, 4 and 8 kg ha^{-1}), zinc (0, 3 and 4 kg ha^{-1}) and boron (0, 1.5 and 2 kg ha^{-1}). The experiment was laid out in a randomized complete block design with three replications. The nine treatment combinations were T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-1.5 kg ha^{-1} Mg-Zn-B), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B). The recommended dose of other fertilizers (Ahmmed *et al.,* 2018) 100-30-80-20 kg ha^{-1} N-P-K-S, respectively along with decomposed cow dung 5 t ha^{-1} were used in all treatments. The unit plot size for sponge gourd was 2.8 m×1.5 m. Each plot consisted of two plants. The plant-to-plant distance within the plot was 1.4 m. Plots were separated by a 1.0 m space. Blocks were also separated by a 1.0 m distance. The effective row-to-row distance (which includes the inter-plot space) was 2.5 m. This 2.5 m distance is the sum of: 0.75 m (from the plot boundary to the row) + 1.0 m (plot separation space) + 0.75 m (from the next plot's boundary to the row) =2.5 m. The 1.0 m gap serves as a guard area to prevent competition between neighboring plots and blocks, which is vital for maintaining the integrity of the treatment effects. The sources of N, P, K, S, Mg, Zn and B were urea (46% N), triple super phosphate (20% P, 1.3% S, 14% Ca), muriate of potash (50% K), gypsum (18% S and 20% Ca), magnesium sulphate (12.5% S, 9.5% Mg), zinc sulphate heptahydrate (10.5% S, 21% Zn) and boric acid (17% B), respectively. The half amount of decomposed cow dung, full amount of TSP, gypsum, and half of MoP were applied manually at final plot preparation. Rest half amount of the decomposed cowdung, treatment wise magnesium sulphate, zinc sulphate and boric acid were applied in pit 5 days before planting, and all were manually mixed thoroughly with soil. Twenty-five days old seedlings were transplanted on 10 April 2020 and 11 April 2021. Only one plant was planted into a pit. One-third of urea was applied surrounding the plants after 15 days of transplanting. Half of MoP and second installment of 1/3 urea was top dressed during flower initiation to surrounding the plants. The remaining 1/3 urea was applied to the plants at fruiting stage. Irrigation, weeding, insect control, and other intercultural operations were done as and when required. Horizontal bamboo stakes were installed at the top joining of all other beds. The stakes support the climbing vines and lateral stems. Bamboo branches (kunchi) were used to secure adjoining stakes. Treatment wise young fruits of sponge gourd were harvested time to time starting from the 2nd week of June until last week of September in both years. Data on the yield and yield attributes of sponge gourd were collected. Fresh sponge gourd samples were collected from each experimental plot and brought to the Laboratory of Soil and Water Management Section, HRC, BARI and preserved the samples frozen at -30 °C. Sponge gourd fruit samples were removed from the freezer to estimate the amount of vitamin C and ß-carotene by standard method.

Plant samples analysis- Above-ground parts of sponge gourd plants were collected from each plot, sun-dried for five days, and then further dried in a digital convection oven (Human Lab Instrument Co., model Co-150, Hwaseong city, Korea) at 68°C for 48 hours. The samples were then ground to pass through a 1 mm sieve. Similarly, sponge gourd fruit samples from each treatment were washed, sliced into round or triangular shapes, and then dried and ground to pass through a 1 mm sieve. Each dry plant and fruit sample was then preserved in a polythene bag. Ground dry plant and fruit samples were digested with a di-acid mixture (HNO_3-$HClO_4$: 5:1 ratio) as described by Piper (2019) to determine their mineral content. Magnesium (Mg) was determined by atomic absorption spectrophotometry and boron (B) by spectrophotometry using the azomethine-H method. Zinc (Zn) content was directly measured from the digest using an Atomic Absorption Spectrophotometer (Varian, SpectrAA 55B, Sydney, Australia). The nutrient uptake by dry fruit and dry plant yield of sponge gourd was calculated by multiplying the nutrient content of plant part (fruit & plant) by its respective dry weight yield (Quddus *et al.,* 2023). The formula is as follow-

$$\textbf{Nutrient uptake}\ (\textbf{kg ha}^{-1}) = \frac{\textbf{\textit{Nutrient content}}\ (\%)\times \textbf{\textit{Dry fruit yield or plant yield}}\ (\textbf{kg ha}^{-1})}{\textbf{100}} \text{ ----- (1)}$$

However, the total nutrient uptake of a sponge gourd was determined by the formula such as total nutrient uptake (kg ha^{-1}) = Nutrient uptake by fruit (kg ha^{-1}) + Nutrient uptake by dry plant (kg ha^{-1}).

Apparent nutrient recovery efficiency (ANR) was determined using the dry weight-based formula established by Baligar *et al.* (2001). This metric provides a clear understanding of how effectively the plant utilizes applied nutrients.

$$\text{ANR} = \frac{\textbf{Nutrient uptake}(\textbf{kg ha}^{-1}) - \textbf{control value}}{\textbf{Applied nutrient}\ (\textbf{kg ha}^{-1})} \text{x } 100 \text{ ------------- (2)}$$

The data on growth, yield attributes, quality traits, yield, nutrient content & uptake and nutrient use efficiency of sponge gourd was statistically analyzed using a two-way analysis of variance (ANOVA) with Statistix 10 software. When significant differences were found, the means were compared using the least significant difference (LSD) test at a significance level of $P \leq 0.05$. Considering the experiment year/cultivation year as Factor A and nutrient treatment as Facor B, statistical analysis was done. So, the data presented under fertilizer/nutrient treatment in Tables and Figures are the average data of two years.

Gross margin of different fertilizer treatments was counted using fruit yield of sponge gourd from two year's mean data at average market price of 2020 and 2021 for the crops and nutrient (Mg, Zn & B fertilizers) inputs. Partial budget and marginal analyses were used to determine the most economically nutrient dose (Elias and Karim, 1984). Marginal rate of return (MRR) was calculated by the following equation:

$$\text{MRR} = \frac{\text{AdB}}{\text{AdC}}$$

Where, MRR = Marginal rate of return, AdB = Additional benefits between each pair of non-dominated treatments, AdC = Additional costs between each pair of non-dominated treatments.

Results and Discussion

Morphological growth and yield contributing characters of sponge gourd

Except individual fruit weight, sponge gourd growth and yield traits were remarkably affected by the year of cultivation (Table 2). Sponge gourd cultivated in the 2nd year exhibited superior growth and yield traits compared to those in the 1st year. The superior growth and yield of sponge gourds in the second year might be attributed to several factors. The residue of organic manure, along with residual Mg, Zn and B from the 1st year's application, likely enriched the soil. Additionally, the more favorable weather conditions during the 2nd year positively contributed to the higher sponge gourd performance. A similar result was corroborated by Quddus *et al.* (2025) in their study on bitter gourd. Sponge gourd growth and yield were significantly influenced by the application of Mg, Zn, and B. Vine length (1.1 m), root length (38.3 cm) and individual fruit weight (169 g) were found maximum from T_9 treatment closely followed by T_8 and their lowest values from T_1 treatment.The T_9 treatment gave the highest number of fruits per plant (71.4) and the control (T_1) treatment resulted in the lowest number of fruits per plant. Significantly, the increased fruit length (24.1 cm) was observed in T_9 treatment, while the decreased fruit length was found in T_1. Maximum fruit diameter was noted in T_9 treatment which was identical with most of the treatments except T_1 and T_3. These prominent advancements in sponge gourd parameters including vine and root elongation, the count of fruits per plant, fruit length, fruit diameter, and individual fruit weight are a consequence of the fundamental contributions of zinc, boron, and magnesium to plant physiology (Hamzah Saleem *et al.,* 2022). Zinc activates the various enzymes which are essential for metabolic reactions. It is directly involved in chlorophyll synthesis. Increased chlorophyll leads to more efficient energy production and, consequently, better plant growth. Zinc promotes auxin production responsible for cell elongation and division leading to the better length of plant and its roots (Hamzah Saleem *et al.*, 2022). Boron is involved to maintain the structural integrity of plants like cell wall formation and carbohydrate metabolism, which are supported to contribute the impressive length of both the vines and the roots (Bolaños *et al.,* 2023). Magnesium is a central component of plant life, serving as a catalyst for numerous biological processes, such as chlorophyll synthesis, enzyme activation and carbohydrate transport (Hermans *et al.,* 2013). These ensure the fruits receive the necessary energy and nutrients for proper development, leading to an increased number of fruits per plant. In combination, the roles of these three nutrients synergistically support chlorophyll synthesis, carbohydrate metabolism, and various other biological activities, ultimately boosting the overall growth and yield attributes of sponge gourd plants (Yadav *et al.,* 2020). All are also critical for flower retention, improving nutrient uptake and fruit set, which directly impacts the number of fruits, fruit size and weight. This view is supported by the findings of Ashraf *et al.* (2020) and Sidhu *et al.* (2019).

Table 2. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on plant growth and yield attributes of sponge gourd

Year of cultivation (Y)	Vine length (m)	Root length (cm)	No. of fruits $plant^{-1}$	Fruit length (cm)	Fruit diameter (cm)	Individual fruit wt. (g)
2020	9.60b	34.4b	48.7b	20.9b	4.09b	151a
2021	11.6a	36.4a	78.7a	22.4a	4.84a	153a
CV (%)	5.24	4.51	3.19	2.61	4.88	4.47
Treatment (T)						
T_1	9.48e	29.7e	54.3e	17.7e	4.25c	144c
T_2	10.6cd	34.0d	60.5d	21.0d	4.41a-c	150bc
T_3	10.3d	33.7d	63.0c	20.9d	4.26bc	152bc
T_4	10.5d	34.7d	64.2c	22.1c	4.47a-c	145c
T_5	10.9a-c	36.6c	64.3c	21.8cd	4.51ab	145c
T_6	10.7b-d	37.3bc	63.4c	22.4bc	4.60a	146c
T_7	10.4d	36.4c	64.4c	21.8cd	4.54a	155b
T_8	11.0ab	38.0ab	67.9b	23.0b	4.55a	165a
T_9	11.1a	38.3a	71.4a	24.1a	4.61a	169a
CV (%)	5.24	4.51	3.19	2.61	4.88	4.47
Interaction(Y×T)	ns	ns	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Marketable yield

The yields of fresh fruit, dry fruit and dry plant of sponge gourd were significantly influenced by both the years of cultivation. The yield performance of the second year was comparatively better than that of the first year (Table 3). The superior performance in the 2nd year was likely a result of two key factors: residual nutrients from the previous year's fertilizer application and more favorable weather conditions. The application of Mg, Zn, and B significantly impacted the yields of fresh fruit, dry fruit, and dry plant of sponge gourd (Table 3). The highest fresh fruit yield was recorded 55.2 t ha^{-1} in T_9 treatment (8-4-2 kg ha^{-1} Mg-Zn-B) which was statistically similar to T_8 treatment and the lowest yield was found in the control treatment (T_1). Similarly, the T_9 treatment also significantly gave maximum both the dry fruit yield (5.57 t ha^{-1}) and the dry plant yield (11.6 t ha^{-1}), closely followed by T_8 treatment. The lowest yields for both dry fruit and dry plant were observed in the control treatment (T_1). The combined application of Mg, Zn, and B registered maximum (29.3%) increase in fresh fruit yield followed by T_8

treatment. This synergistic effect of these three elements not only improves soil health but also enhances the plant's ability to absorb other essential nutrients for optimal growth and development, ultimately leading to higher yields (Ashraf *et al.*, 2020). The T_9 treatment resulted in a higher sponge gourd yield is mainly due to an increased number of fruits plant^{-1} and an increase in individual fruit weight. This improvement in yield is likely due to the significant roles of Mg, Zn, and B in key physiological processes. Such as Mg is involved in photosynthesis, Zn is crucial for carbohydrate metabolism, and B plays a vital role in pollen tube growth and fruit set. These physiological activities collectively contribute to greater biomass production, more fruit per plant, and ultimately, a significant increase in yield. This is consistent with the findings of Ahmed *et al.* (2024) in tomato, who also demonstrated the positive impact of these nutrients on crop yield.

Table 3. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on yields of sponge gourd

Cultivation year (Y)	Fresh fruit yield (t ha^{-1})	Dry fruit yield (t ha^{-1})	Dry plant yield (t ha^{-1})	% Fresh fruit yield increase over control
2020	48.4b	4.91b	10.0b	-
2021	51.7a	5.12a	10.7a	-
CV (%)	3.17	5.39	7.06	-
Treatment (T)				
T_1	42.7d	4.23d	8.39d	-
T_2	50.4bc	5.03bc	10.4bc	18.0
T_3	49.3c	4.93c	10.2c	15.5
T_4	48.8c	4.92c	10.1c	14.3
T_5	50.5bc	5.10bc	10.6bc	18.3
T_6	49.0c	4.96c	10.2c	14.8
T_7	51.5b	5.11bc	10.7bc	20.6
T_8	53.4a	5.33ab	11.1ab	25.1
T_9	55.2a	5.57a	11.6a	29.3
CV (%)	3.17	5.39	7.06	-
Interaction(Y×T)	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Quality traits of sponge gourd

The vitamin C and ß-carotene content of sponge gourd were significantly influenced by the years of cultivation. Sponge gourd in the second cultivation year had a higher content of both vitamin C and ß-carotene compared to the first year's (data not presented). Combined applications of Mg, Zn and B significantly affected vitamin C and ß -carotene content of sponge gourd fruit (Fig. 2a, and 2b). The highest vitamin C content (13.6 mg/100g) was found in T_9 treatment and the control treatment (T_1) had the lowest vitamin C content (Fig. 2a). Similarly, the T_9 treatment also produced the highest ß-carotene content (15.7 µg/100g), closely followed by the T_8 treatment (15.4 µg/100g). The control treatment (T_1) had the lowest ß-carotene content (Fig.2b). The application of Mg-Zn-B at 8-4-2 kg ha^{-1}) in the T_9 treatment resulted in a 17.2% increase in vitamin C content of sponge gourd fruit compared to the control treatment where Mg-Zn-B was not applied. This suggests a synergistic effect among these three nutrients. The result is in line with the results of Singh *et al.* (2022), who also found that foliar application of micronutrients can increase vitamin C levels in fruit vegetable. While these findings partially support the work of Thriveni *et al.* (2015) on the benefits of combined fertilizer application, the specific roles of Mg, Zn, and B in this enhancement require further investigation. Similarly, the application of these three nutrients led to an observed increase in ß-carotene content in the fruit of sponge gourd. This could be due to the known involvement of Mg and micronutrients viz. Zn and B in various physiological and biochemical processes within the fruit, as noted by Sultana *et al.* (2017). The exact mechanisms by which these nutrients influence ß-carotene production are not yet fully understood, although the results are partially supported by Mashilo *et al.* (2025).

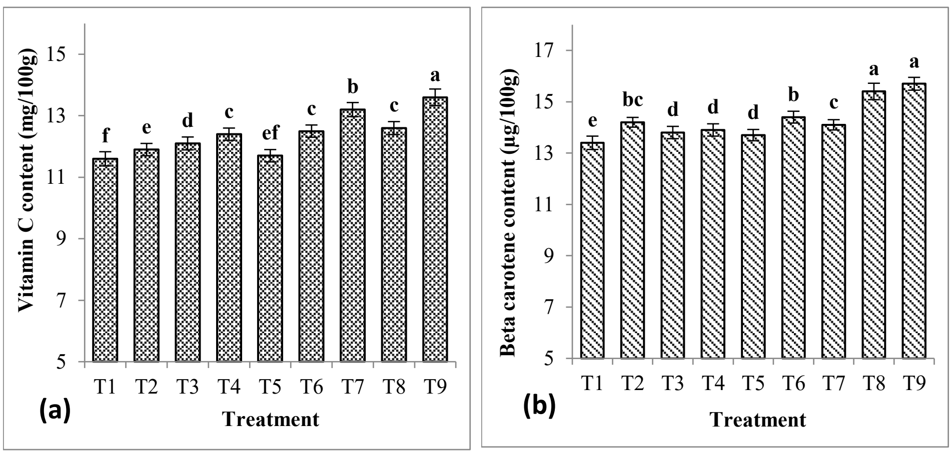


Fig. 2. Effect of Mg, Zn, and B on vitamin C content (a) and beta carotene content of sponge gourd fruit (b). The error bars represent the ± standard error of the mean (n=3). The mean values indicated by the uncommon letters in the bars are significantly different at the 5% level by the LSD test.

T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Nutrient content in dry fruit and dry plant of sponge gourd

Except for Mg content in dry fruit, the cultivation year significantly affected the contens of Mg in the dry plant, and Zn and B in both the dry fruit and plant of sponge gourd (Table 4). The concentrations of Mg, Zn and B in the dry fruit and dry plant of sponge gourd were higher in the 2nd year cultivation than in those of the 1st year. This improvement in nutrient concentration during the 2nd year might be attributed to the residual benefits of the nutrients applied in the 1st year. Moreover, a more favorable weather condition in the 2nd year may have also contributed to the plant's uptake of Mg, Zn, and B. These findings are corroborated by the findings of Quddus *et al.* (2025) on bitter gourd. The application of Mg, Zn, and B fertilizers led to a significant increase in the concentration of these nutrients in both the dry fruit and dry plant of sponge gourd (Table 4). The T_9 treatment consistently resulted in the highest nutrient accumulation. It produced the highest Mg content (7.75 g kg^{-1} in dry fruit and 11.6 g kg^{-1} in dry plant), which was statistically similar to T_8, T_7, and T_6 treatments. The maximum Mg accumulation in the T_9 treatment was likely associated with the combined application of Mg, Zn and B. This combination enhanced Mg uptake in the sponge gourd plants.

Table 4. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on nutrient content in sponge gourd

Cultivation year (Y)	Magnesium content (g kg^{-1})		Zinc content (g kg^{-1})		Boron content (g kg^{-1})	
	Dry fruit	Dry plant	Dry fruit	Dry plant	Dry fruit	Dry plant
2020	7.28a	10.8b	0.0543b	0.0673b	0.0723b	0.0652b
2021	7.38a	11.5a	0.0549a	0.0724a	0.0729a	0.0701a
CV (%)	4.42	3.29	1.63	6.49	1.00	6.25
Treatment (T)						
T_1	6.58d	10.3d	0.0476g	0.0622e	0.0648f	0.0634c
T_2	7.00c	10.9c	0.0529f	0.0677cd	0.0701e	0.0657bc
T_3	7.17c	11.1bc	0.0539ef	0.0665de	0.0728c	0.0676a-c
T_4	7.29bc	11.1bc	0.0546de	0.0685cd	0.0716d	0.0665a-c
T_5	7.37bc	11.2a-c	0.0554cd	0.0695cd	0.0734c	0.0685ab
T_6	7.56ab	11.3ab	0.0567ab	0.0705b-d	0.0746b	0.0675a-c
T_7	7.67ab	11.4ab	0.0571ab	0.0725a-c	0.0751b	0.0686ab
T_8	7.61ab	11.5ab	0.0562bc	0.0755ab	0.0752b	0.0695ab
T_9	7.75a	11.6a	0.0574a	0.0765a	0.0761a	0.0708a
CV (%)	4.42	3.29	1.63	6.49	1.00	6.25
Interaction(Y×T)	ns	ns	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Increased Mg fertilization directly boosts the plant's Mg content, which can help mitigate aluminum (Al) toxicity in soils, as reported by Cakmak (2015). Similarly, the highest Zn content (0.0574 g kg^{-1} in dry fruit and 0.0765 g kg^{-1} in dry plant) was also found in T_9, followed by T_8 in the case of dry plant, with the lowest content recorded in the control treatment (T_1). The T_9 treatment also produced the maximum B content (0.0761 g kg^{-1} in dry fruit and 0.0708 g kg^{-1} in dry plant. The lowest B content was observed in the control treatment (T_1). Combined application of 8-4-2 kg ha^{-1} MG-Zn-B significantly enhanced the content of Zn and B in sponge gourd plants. Previous studies by Ashraf *et al*. (2020) and Sultana *et al*. (2017) have confirmed the positive influence of Mg, Zn, and B application on Zn and B accumulation in plants. While the specific role of Mg on Zn and B concentration in sponge gourd remains less understood, Quddus *et al*. (2022) reported that application of 12 kg Mg ha^{-1} to the soil facilitated the maximization of Zn and B concentrations in tomato plants.

Table 5. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on total uptake of Mg, Zn and B by sponge gourd

Cultivation year (Y)	Total Mg uptake (kg ha^{-1})	Total Zn uptake (kg ha^{-1})	Total B uptake (kg ha^{-1})
2020	126b	0.946b	1.01b
2021	143a	1.063a	1.13a
CV (%)	8.44	7.92	7.29
Treatment (T)			
T_1	101d	0.724e	0.806e
T_2	132c	0.975d	1.04cd
T_3	130c	0.942d	1.05cd
T_4	131c	0.964d	1.03d
T_5	137bc	1.02cd	1.10b-d
T_6	135bc	1.00cd	1.06cd
T_7	142bc	1.07bc	1.12bc
T_8	148ab	1.14ab	1.16ab
T_9	156a	1.21a	1.25a
CV (%)	8.44	7.92	7.29
Interaction(Y×T)	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Total uptake of Mg, Zn and B (fruit + dry plant) by sponge gourd

The total uptake of Mg, Zn, and B by sponge gourd varied significantly by the cultivation year (Table 5). Particularly, sponge gourd plants demonstrated a significant increase in the total uptake of these three nutrients in 2021 compared to the previous year (Table 5). Combined application of Mg, Zn and B fertilizers significantly affected the total uptake of Mg, Zn and B nutrients by sponge gourd (Table 5). The highest total Mg uptake, 156 kg ha^{-1}, was observed in the treatment T_9, which was identical with T_8, while the lowest was noticed in the control treatment. Similarly, T_9 also led to a significant increase in the total uptake of Zn (1.21 kg ha^{-1}) and B (1.25 kg ha^{-1}), closely followed by T_8. Both Zn and B uptake were found lowest in the control (T_1). The combined application of Mg, Zn and B might have synergistically enhanced the total uptake of these nutrients by sponge gourd plants. When applied at the right time, in the right amount, and in the right way, these three nutrients can significantly build up nutrient availability in the soil. This allows for easier plant uptake, leading to better growth and proper accumulation within the plant body, which ultimately increases the uptake values of Mg, Zn, and B. This view is supported by the findings of Gerendás and Führs (2013).

Apparent recovery efficiency of Mg, Zn and B of sponge gourd

The year of cultivation had a significant effect on the apparent recovery efficiency of Mg, Zn, and B in sponge gourd (data not presented). As shown in Figures 3a-c, the combined application of Mg, Zn, and B fertilizers significantly influenced the apparent nutrient recovery (ANR) efficiencies of these elements in the sponge gourd plant. The T_5 treatment showed the highest apparent magnesium recovery efficiency at an impressive 911%, which was statistically similar to most other treatments except T_6, T_7 and T_8 treatments (Fig. 3a). This higher recovery efficiency of Mg might be attributed to variations in Mg application rate specially a lower dose of Mg in the T_5 treatment. Lower dose of Mg fertilizer is converted into vigorous plant growth and less hamper to the environment. Higher doses of magnesium fertilizer can lead to greater loss through leaching, especially since Mg is a highly mobile nutrient in soils, consequently reducing overall recovery efficiency. Furthermore, in acidic soils, high levels of competing cations like aluminum (Al), iron (Fe), manganese (Mn), and hydrogen ions (H^+) can antagonistically inhibit Mg uptake by roots (Dash *et al.,* 2023). A lower or balanced dose of Mg minimizes this competition, while a very high rate could worsen ionic imbalances. Therefore, lower Mg doses generally represent a more optimal and efficient use of the nutrient relative to crop needs, whereas higher doses result in diminishing Mg use efficiency and increased nutrient losses (Wang *et al.,* 2025). Govindasamy *et al.* (2023) reported that the degree of nutrient use efficiency (NUE) is affected by the crop yield potential, crop type, inherent soil fertility, and amount of applied fertilizer and precise crop management practices. In our study, T_9 treatment achieved the greatest apparent zinc recovery efficiency at 12.1%, with treatments T_8, T_7, and T_6 showing statistically similar results (Fig. 3b). Furthermore, the treatment T_8 attained the highest apparent boron recovery efficiency at 23.9%, with T_9 showing statistically similar results (Fig. 3c). These findings are in line with the previous studies by Quddus *et al.* (2022) in tomato. By understanding the aforesaid conditions like application timing, rate, and method of fertilizer application, we can improve the fertilizer management strategies to enhance both crop yield and nutrient use efficiency.

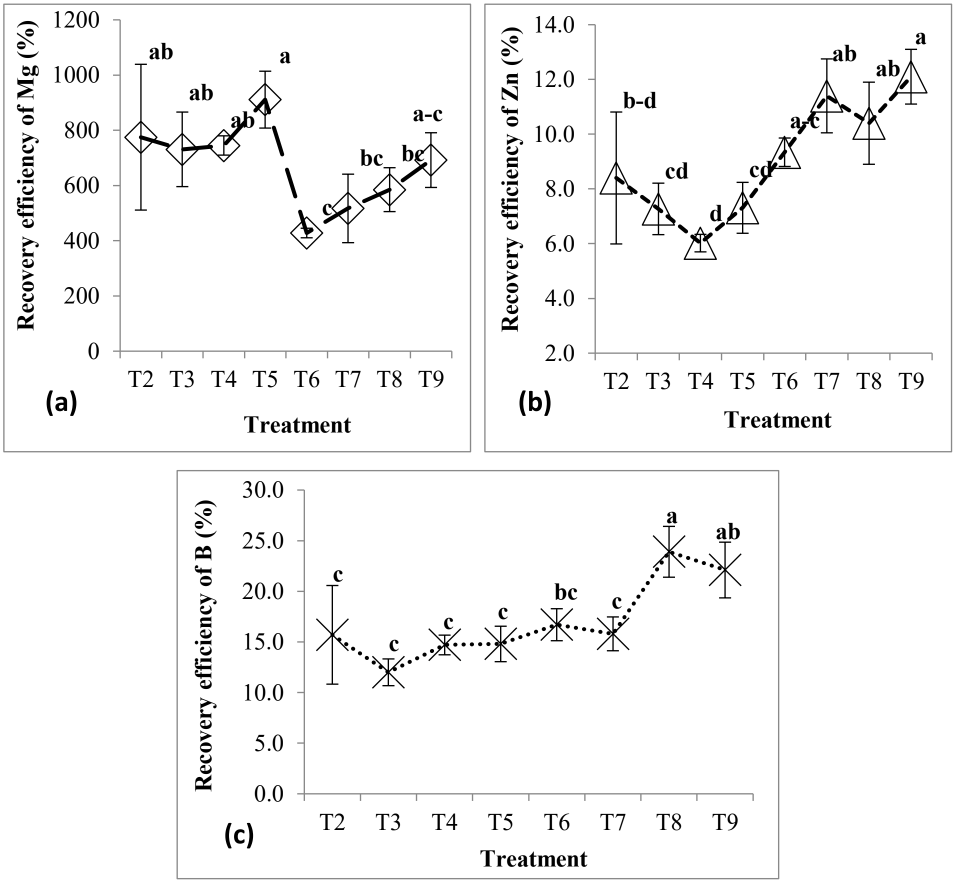


Fig. 3. Effect of Mg, Zn, and B on recovery efficiency of magnesium (a), recovery efficiency of zinc (b) and recovery efficiency of boron in sponge gourd (c). The error bars represent the ± standard error of the mean (n=3).

The mean values indicated by the uncommon letters on the bars are significantly different at the 5% level according to the LSD test, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Economic analysis

A partial budget analysis was performed as part of the economic evaluation to calculate the total variable costs and the gross margin for each fertilizer treatment. The highest gross return (BDT 1104000 ha^{-1}) and the maximum gross margin (BDT 962163 ha^{-1}) were achieved in the treatment T_9 (8−4−2 kg ha^{-1} Mg-Zn-B). Conversely, the lowest gross margin observed was BDT 854000 ha^{-1}. For the dominance analysis, the treatments (T_1 to T_9) were initially arranged in descending order of total variable costs (which, in this context, refers to nutrient or fertilizer cost). Table 7 of the analysis indicated that treatments T_3, T_4, T_5, T_6, and T_7 were cost dominated (CD), while T_1, T_2, T_8, and T_9 were determined to be cost undominated (CUD). The marginal rate of return (MRR) for changing from T_9 to T_8 was 920% (Table 7). This means, if farmers invest BDT 141837, he could recover BDT 3529, plus an additional amount of Tk 32471. In this way, other MRRs found from T_2 to T_1 treatment and T_8 to T_2 treatment were 89.85% and 4.91%, respectively. Here the highest MRR was observed from T_9 to T_8 treatment (920%) every BDT 100 of additional investment BDT 920 was returned. Application of 8-4-2 kg ha^{-1} Mg-Zn-B (T_9) plus the blanket dose of 100-30-80-20 NPKS appeared as the best treatment combination for cultivation of sponge gourd from economic poit of view when MRR was considered.

Table 6. Cost and return analysis of sponge gourd cultivation as influence by MgZnB fertilizers

Treatment	Gross return (BDT ha^{-1})	Nutrient cost (BDT ha^{-1})	Gross margin (BDT ha^{-1})	Remarks
T_1	854000	0	854000	CUD
T_2	1008000	81115	926885	CUD
T_3	986000	84644	901356	CD
T_4	976000	87781	888219	CD
T_5	1010000	91311	918689	CD
T_6	980000	131641	848359	CD
T_7	1030000	135170	894830	CD
T_8	1068000	138308	929692	CUD
T_9	1104000	141837	962163	CUD

Input price: Zinc sulfate (lab grade) = BDT 1400 kg^{-1}, Magnesium sulphate=(lab grade)= BDT 1200 kg^{-1}, Boric acid (lab grade)= BDT 1200 kg^{-1}, Average output price of cabbage: BDT 20 kg^{-1}

T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Table 7. Marginal analysis of cost undominated treatments applied in sponge gourd cultivation

CUD treatment	Nutrient cost (Tk ha^{-1})	Marginal increase in nutrient cost (BDT ha^{-1})	Gross margin (BDT ha^{-1})	Marginal increase in gross margin (BDT ha^{-1})	MRR (%)
T_1	0	-	-	-	-
T_2	81115	81115	926885	72885	89.9
T_8	138308	57193	929692	2807	4.91
T_9	141837	3529	962163	32471	920

CUD = Cost undominated, CD = Cost dominated, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Conclusion

The results of this study revealed that, application of Mg-Zn-B at 8-4-2 kg ha^{-1} fertilizer (T_9) to the soil significantly improved sponge gourd fruit yield and quality as this treatment recorded better plant growth, a greater number of fruits, heavier and larger fruits. The highest uptake of Mg, Zn, and B by the sponge gourd plants also occurred in the same treatment. The apparent recovery efficiency was high for zinc in T_9 and for boron in T_8 treatment, but the results for magnesium were inconsistent. The T_9 treatment was also the most economically viable, as indicated by its high gross margin and maximum MRR. Results suggest that the application of Mg-Zn-B at 8-4-2 kg ha^{-1} fertilizer can significantly enhance the growth, yield, fruit quality, and profitability of sponge gourd cultivation. These findings are particularly relevant for regions where imbalanced fertilization is a common practice. However, further research is needed to validate these results across different agroecological zones.

References

Ahmed, R, M. A. Quddus., M. K. Uddin., S. B. Kasim., K. H. B. Mohdyusoff., M. A. Motalib Hossain., Z. Solaima .and A. N. A. Haque. 2024. Influence of zinc oxide nanoparticles on the productivity, mineral element accumulation, and fruit quality of tomato (*Solanum lycopersicum* L.). *Journal of Experimental Biology and Agricultural Sciences* 12(6):887-904.

Ahmmed, S., M. Jahiruddin, S. Razia, R. A. Begum et al. 2018. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council (BARC), Dhaka 1215, Bangladesh, 223p.

Ashraf, M.I., B. Liaqat, K. Shahzadi, S. Kiran, L. Anam, M. B. Shaukat and N. Hussain. 2020. Effect of zinc, iron and boron on growth, yield and quality of bitter gourd (*Momordica charantia* L.) in Punjab. *International Journal of Agronomy and Agricultural Research* 16(4):11-19.

Baligar, V. C., N. K. Fageria and Z. L. He. 2001. Nutrient use efficiency in plants. *Communications in soil science and plant analysis* 32 (7-8): 921-950. [https://doi.org/10.1081/CSS-100104098]

Bolaños, L., I. Abreu, I. Bonilla, J.J. Camacho-Cristóbal and M. Reguera. 2023. What Can Boron Deficiency Symptoms Tell Us about Its Function and Regulation? *Plants* 12: 777.

Dash, M.**,** S. Thiyageshwari, D. Selvi, K. Rajan and H.K.V. Johnson. 2023. A controlled experiment to verify the effect of magnesium fertilizers on soil pH and available soil nutrients in acid soil of Nilgiris, India. *J. Appl. Nat. Sci.* **15(3):** 1119-1126.

Elias, S. and M. Karim. 1984. Application of partial budget technique on cropping system research at Chittagong. AEER No 10 April. Report of Agricultural Economics Division, BARI, Joydebpur, Gazipur. pp. 71-75.

Gerendás, J. and H. Führs. 2013. The significance of magnesium for crop quality. *Plant Soil* 368:101-128. [https://doi.org/10.1007/s11104-012-1555-2].

Govindasamy, P., S. K. Muthusamy, M. Bagavathiannan, J. Mowrer, P. T. K. Jagannadham, A. Maity, H. M. Halli, G. K. Sujayananad, R. Vadivel, T. K. Das, R. Raj, V. Pooniya, S. Babu, S. S. Rathore, L. Muralikrishnan and G. Tiwari. 2023. Nitrogen use efficiency a key to enhance crop productivity under a changing climate. *Front. Plant Sci*. 14:1121073.

Hamzah Saleem, M., K. Usman, M. Rizwan, H. Al Jabri and M. Alsafran. 2022. Functions and strategies for enhancing zinc availability in plants for sustainable agriculture. *Front. Plant Sci.* 13:1033092.

Hermans, C., S. J. Conn, J. Chen, Q. Xiao and N. Verbruggen. 2013. An update on magnesium homeostasis mechanisms in plants. *Metallomics* 5:1170-1183.

Ishfaq, M., Y. Wang, M. Yan, Z. Wang, L. Wu, C. Li and X. Li. 2022. Physiological Essence of Magnesium in Plants and Its Widespread Deficiency in the Farming System of China. *Front. Plant Sci.* 13:802274. doi: 10.3389/fpls.2022.802274

Jeevitha, S. 2018. Influence of boron and plant growth regulators on hybrid seed yield and quality of sponge gourd (*Luffa cylindrica* L.) under protected cultivation. *University of agricultural sciences* Raichur. [http://krishikosh.egranth.ac.in/handle/1/5810147575].

Jiao, J., J. Li, J. Chang, J. Li, X. Chen, Z. Li, Z. Song, D. Xie and B. Zhang. 2023. Magnesium effects on carbohydrate characters in leaves, phloem sap and mesocarp in wax gourd (*Benincasa hispida* (Thunb.) Cogn.). *Agronomy* 13(2):455.

Mashilo J., H. Shimelis and M.R. Ngwepe. 2025. Genetic improvement and innovations of sponge gourd (*Luffa cylindrica* L.): An opportunity crop. *Industrial crops & Products*, 225: 120430.

Page, A. L., R. H. Miller, and D. R. Keeny. 1982. Methods of soil and plant analysis. *Am. Soc. Agron. Madison*, WI. [https://doi.org/10.1002/jpln.19851480319].

Pandav, A.K., M. K. Nalla, T. Aslam, M. K. Rana, and J. C. Bommesh. 2016. Effect of foliar application of micronutrients on growth and yield parameters in Eggplant cv HLB 12. *Environment and Ecology* **35(3):**1745-1748.

Pankaj, P., P. K. Kujar, and S. Saravanan. 2018. Effect of different micronutrient on plant quality of broccoli (*Brassica oleracea* var. *italica*) cv Green Magic. *Journal of Pharmacognosy and Photochemistry* 1:2825-2828.

Parvin, N., N.N. Hansda and T. Ghosh. 2024. Impact of zinc and boron applications on crop growth, yield and quality: A comprehensive Review. *PlantArchives* 25 (1): 2770-2773.

Piper, C. S. 2019. Soil and plant analysis. Adelaide University Press, Adelaide, Australia.

Plant nutrition (2025). Wikipedia. [https://en.wikipedia.org/wiki/Plant_nutrition].

Quddus, M.A., M. T. Rahman, S. Tashzi, M. E. Ali, M. A. Hossain, M. R. Ali M. A. Haque, A. A. Sultana, A. Gaber, M. P. Kabir and A. Hossain A. 2025. Organic plant nutrients in combination with inorganic sources of nutrients influence the productivity, quality, soil microbes, and nutrient use efficiency of bitter gourd (*Momordica charantia* L.). *Folia Hortculturae* **37**(1**):**1-23.

Quddus, M.A., M.A. Siddiky, M.J. Hussain, M.A. Rahman, M.R. Ali and M.A.T. Masud. 2022. Magnesium influences growth, yield, nutrient uptake, and fruit quality of tomato. *International Journal of Vegetable Science* 28(5): 441-464.

Quddus, M.A., R. Ahmed, M.S. Islam, M. A. Siddiky and M.A. Rahman. 2023. Evaluation of potassium nutrition in productivity, quality and potassium use efficiency of garden pea in terrace soils. *Bangladesh Journal Agricultural Research* 48(3): 307-323.

Sheela A. J. M and A. Anburani. 2024. Effect of organic nutrients and zinc biofortification on growth and yield of sponge gourd (*Luffa Cylindrica* L.) CV. Mahy Harita. *International Journal of Plant & Soil Science* 36 (11):254–261. [https://doi.org/10.9734/ijpss/2024/v36i115140].

Sidhu, M.K., H. C. Raturi, D. S. Kachwaya, and A. Sharma. 2019. Role of micronutrients in vegetable production: A review. *Journal of Pharmacognosy and Phytochemistry* **SP1**: 332-340.

Singh, P., A. Upadhyay, P. K. Maurya, and S. Pandey, S. 2022. Effect of foliar feeding of micronutrients on growth and yield of bitter gourd (*Momordica charantia*). *Current Horticulture* **10**(1): 66-68.[https://doi.org/10.5958/2455-7560.2022.00016.4]

Sonavane, P. N., M. N. Bhalekar, S. S. Survase, and. S. Mali.. 2022. To study the chemical composition and nutritive significance of sponge gourd [*Luffa cylindrica* (Roem) L.]. *The Pharma Innovation Journal* **11(1):** 1049-1052.

Sultana, S., A. Niaz, Z. A. Ahmed Z.A., S. H. Anwer, M. A. Anjum.and M. Ilyas. 2017. Effect of boron application on growth, yield and quality of bitter gourd. *Science Letters* 5(1):1-7.

Thriveni, V., H.N. Mishra, S.K. pattanayak, G.S. sahoo and T. Thomson. 2015. Effect of inorganic, organic fertilizers and biofertilizers on growth, flowering, yield and quality attributes of bitter gourd, *Momordica charantia* L. *International Journal of Farm Sciences* 5(1): 24-29.

Wang, Y., Q. Long, Y. Li, F. Kang, Z. Fan and H. Xiong *et al.* 2022. Mitigating magnesium deficiency for sustainable citrus production: a case study in Southwest China. Sci. Hortic. 295: 110832. doi: 10.1016/j.scienta.2021.110832.

Wang, Z., M. U. Hassan, F. Nadeem, L. Wu, F. Zhang and X. Li. 2020. Magnesium fertilization improves crop yield in most production systems: a meta-analysis. Front. Plant Sci. 10: 1727. doi: 10.3389/fpls.2019.01727.

Wang, Y., F. Kang, B. Yu, Q. Long, H. Xiong, J. Xie, D. Li, X. Shi, P. Lakshmanan, Y. Zhang, F. Zhang. 2025. Magnesium supply is vital for improving fruit yield, fruit quality and magnesium balance in citrus orchards with increasingly acidic soil. *J. Integr. Agric*. **24**(9): 3641-3655.

Yadav, A., N. K. Tulluru, M. Panda, A. K. Singh, B. L. Nagar, Homeshvari, and R. Rajbhar. 2023. Impact of boron and zinc on vegetables: A Review. *International Journal of Environment and Climate Change* **13 (10):**3873–3882. [https://doi.org/10.9734/ijecc/2023/v13i103060].

Yadav, R.K., M. Sekhar, W. Khan and M. Madhu. 2020. Impact of foliar application of micronutrients on growth, yield and its attributes of bitter gourd [*Momordica charantia*] cv. F1 LHB – Swathi. *International Journal of Chemical Studies* **8(4):** 1344-1349.

Zadge, M.S., S.O. Bawkar, A.M. Sonkamble, S.M. Ghawade and S.S. Hadole. 2024. Effect of different levels of nitrogen and phosphorus on growth, yield and fruit quality of sponge gourd *(Luffa cylindrica* L.). *Plant Archives* 24 (2):1892-1898.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 553-565, March 2026

IMPACT OF POTATO VAR. BARI ALU-25 ADOPTION ON THE GROWERS' LIVELIHOOD**

S. T. JANNAT[1], M. S. I. AFRAD[2], M. E. HAQUE[3]
S. S. HASAN[4] AND N. A. IVY[5]

Abstract

BARI Alu-25 is one of the popular potato varieties released by BARI. The main objective of the study was to assess the impact of potato var. BARI Alu-25 adoption on the growers' livelihood. The study was conducted in Sirajdikhan and Tongibari upazilas under Munshiganj district and Pirgacha and Mithapukur upazilas under Rangpur district during December, 2020 to November, 2021. Eighty BARI Alu-25 growers were selected. Descriptive statistics and paired t-test were used for data analyses. The BARI Alu-25 growers' access to livelihood capitals increased by 42.0-90.8 percent. Their access to human capital was increased by 80.2 percent, access to social capital by 90.8 percent, access to natural capital by 42.0 percent, access to physical capital by 48.1 percent, and access to financial capital by 48.4 percent as adoption results of BARI Alu-25 cultivation. They experienced improvement in access to information, knowledge, employment generation, prestige, attitude, cooperation, and management. Increases or improvement were also noticed in their forestry/trees, leased cultivable land, electricity use, furniture, electronic communication devices, housing condition, annual agricultural income, and cash in hand after BARI Alu-25 cultivation. Potao var. BARI Alu-25 cultivation had a potential influence on the respondents' increase in participation in income generating activities.

Keywords: Potato, BARI Alu-25, Adoption, Impact on livelihood, Human capital, Social capital, Natural capital, Physical capital, and Financial capital.

Introduction

Bangladesh Agricultural Research Institute (BARI) generates technologies for food and nutrition, health security, and employment generations for farmers and general public. Since its inception, BARI released 104 potato varieties (Akhond *et al.,* 2025), out of which BARI Alu-25 (Asterix) becomes a promising and the most popular variety among farmers in Bangladesh. Asterix potato variety was developed as a hybrid variety of 'Cardinal' and 'VSP Ve 70-9' in Netherlands. It was later released by Bangladesh Agricultural Research Institute as BARI Alu-25

---

[1]Scientific Officer, Training and Communication Wing, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, [2,3&4]Professor, Department of Agricultural Extension and Rural Development, Gazipur Agricultural University (GAU), Gazipur-1706, [5]Professor, Department of Genetics and Plant Breeding, GAU, Gazipur, Bangladesh.

**A part of PhD Dissertation of the first Author.

in 2005 by introduction (Azad *et al*., 2020). Its yield is high (25-30 MT/ha) and it is suitable for processing. Haque *et al*. (2012) reported that 14.0 percent potato areas were covered by Binella, Asterix, Provento, Felsina, Multa and Hira in Munshiganj, Bogura and Comilla districts. Cardinal, Diamant, Granola and Asterix were the major HYV/modern varieties cultivated in Rangpur and Bogura districts (Begum *et al*., 2014, 2015). However, no research had been found so far regarding the impact of the popular potato var. BARI Alu-25 on growers' livelihoods, especially in the context of Bangladesh. Therefore, it was essential to explore the impact of BARI Alu-25 adoption on growers' livelihoods.

Materials and Methods

The study was conducted in Sirajdikhan and Tongibari upazilas under Munshiganj district and Pirgacha and Mithapukur upazilas under Rangpur district, which were purposively selected based on the abundance of cultivation of BARI Alu-25 (DAE, 2019; DAE, 2020a; DAE, 2020b; DAE, 2020c). The population of the study was the growers who cultivated BARI Alu-25 for at least three years. The sampling population under the study was 800 growers (330 and 100 in Sirajdikhan and Tongibari upazila, respectively, under Munshiganj district, and 220 and 150 in Pirgacha and Mithapukur upazila, respectively, under Rangpur district). According to Al-Zahrani *et al*. (2019), 80 growers (10.0% of the population) were selected as sample of the study. Data were collected during December, 2020 to November, 2021. Fifteen selected characteristics of the respondents, viz., age, level of education, family size, farm size, annual income, training experience, extension contact, farming experience, access to credit, off-farm activities, availability of irrigation water, organizational membership, cosmopoliteness, innovativeness, and knowledge on potato cultivation were the independent variables of the study. These variables of the study were measured by assigning scores and weights as follows: Age was measured in terms of years, level of education was measured in terms of years of schooling, family size was measured by counting the total number of family members of the respondent comprising the head of the household, his wife, children, parents, and other dependents who jointly lived and ate together, farm size was measured in terms of hectares, annual income was measured in terms of thousand Tk., training experience was measured by assigning score for each day of training participation, extension contact was measured by putting weights according to the degree of contact, farming experience was measured in terms of years, access to credit, off-farm activities, and availability of irrigation water were measured in ordinal scale where if the respondents had access to credit, it was coded as one (1), and if he/she had no access to credit, it was coded as zero (0). Similarly, if the respondents had off-farm activities, it was coded as one (1), and if he/she had no off-farm activities, it was coded as zero (0). In case of availability of irrigation water, if the respondents had available irrigation water, it was coded as one (1), and if he/she did not have available irrigation water, it was coded as zero (0). Organizational membership, cosmopoliteness, innovativeness and knowledge on potato cultivation were measured in scores. Data were coded, compiled, tabulated and analyzed according to the objectives of the study using SPSS v20. Descriptive statistical measures like number and percentage distribution, range, mean, standard deviation etc. were used. The impact of BARI Alu-25 adoption on growers' livelihood was measured in terms of five capitals namely human capital, social capital, natural capital, physical capital and financial capital known as assets pentagon (DFID, 2000). An individual owns five different types of assets to build his/her livelihood consisting of natural, social, human, physical and financial assets (Ibrahim *et al.*, 2018). The impact was measured by the changes in assets position of the growers before and after the adoption of BARI Alu-25 and the changes in assets position were measured in nominal scale where increase/improvement was denoted as (2), decrease was denoted as (1) and no change was denoted as (0). Descriptive statistics were used to express the percent of the respondents experiencing increase/improvement, decrease and no change in the assets position (Rahman *et al.*, 2019). The changes in participation in income generating activities were measured in terms of participation in different income generating activities scores before and after the adoption of BARI Alu-25. Each respondent was asked to mention the frequency of his/her extent of participation in different income generating activities. His/her participation in different income generating activities score was obtained by adding the weights for his/her responses to all the income generating activities listed in the instrument. It was measured by assigning scores based on participation categories as follows: '3', '2', '1' and '0' were assigned for 'regularly', 'occasionally', 'rarely' and 'not at all' respectively. The basis of categorization of participation in income generating activities was mean ± SD. The comparison between the participation in income generating activities scores before and after the adoption of BARI Alu-25 was assessed by paired t-test.

Results and Discussion

Results presented in Table 1 show that age of the BARI Alu-25 growers ranged from 24 - 78 years. About half (46.3%) of them were old aged, who had abundant experience of potato cultivation. As the study areas are famous for potato cultivation, each grower whether young or old, was found to be eager for BARI Alu-25 cultivation. There was no illiterate potato grower in the study areas except 17.5%, who could sign only. More than four-fifths (82.5%) of the respondents had school education ranging from primary to higher secondary level. The highest percentage (42.5%) of them belonged to secondary education level. Their academic level helped them to be innovative, cosmopolite, and social assets. However, the small sized (2-4) and medium sized (5-6) family were supposed to be more helpful for impact of BARI Alu-25 adoption. The majority of them (45.0%) had small sized family. It was found that 75% of BARI Alu-25 growers had medium and large farm. There were no landless farmers. Their average annual income was Tk. 649.4 thousand, which was much higher than the national average (Tk. 137.8 thousand) (BBS, 2021), and most of the growers (81.2%) belonged to the medium to low annual income category. So, they had no severe financial problems to fulfil input, irrigation, and plant protection demands. Training is an essential variable of the present study. It helps potato growers to learn about variety selection, seed rate, land preparation, fertilizer application, pest and disease control, intercultural operation etc. The large majority (73.8%) of the respondents received agricultural training, which offered an opportunity for the BARI Alu-25 growers in the study area. Two-fifths (40.0%) of the respondents had high training experience. Extension contact is the core variable for any field research. Extension contact is an out of school education system through which extension teaching methods are organized by DAE for the farmers. The teaching methods are individual contact, group contact and mass contact. In the present study all the potato growers had good extension contact, the score of which ranged from 11-56. Four-fifths of the respondents (80%) had medium to high extension contact that increased farmers' social and financial assets. Farming experience encourages farmers to adopt concerned technology like BARI Alu-25. All the farmers had farming experience ranging from 4-65 years. More than four-fifths of the respondents (82.5%) had medium to high farming experience. So, the respondents successfully cultivated BARI Alu-25 and could earn financial assets. Most of the respondents (86.3%) had access to credit. More than half (55.0%) of them had no off-farm activities. All the respondents (100.0%) had availability of irrigation water. Majority of the BARI Alu-25 growers were members of different social organizations. More than three-fifths of them (63.8%) had medium to high organizational membership.

Table 1. Characteristic profile of the respondents

Sl#	Characteristics (Measurement unit)	Possible and observed range	Respondents (n= 80)		Mean
			Categories	%	
01.	Age (Year)	Unknown (24-78)	Young (up to 35)	26.2	47.5
			Middle aged (36-50)	27.5	
			Old (above 50)	46.3	
02.	Level of education (Years of schooling)	Unknown (0.5-18)	Illiterate (0)	0.0	7.8
			Can sign only (0.5)	17.5	
			Primary (1-5)	20.0	
			Secondary (6-10)	42.5	
			Higher secondary (>10)	20.0	
03.	Family size (Number)	Unknown (2-16)	Small family (up to 4)	45.0	5.3
			Medium family (5-6)	32.5	
			Large family (above 6)	22.5	

Sl#	Characteristics (Measurement unit)	Possible and observed range	Respondents (n= 80)		Mean
			Categories	%	
04.	Farm size (Hectare)	Unknown (0.2-13.5)	Marginal (up to 0.2)	1.3	2.4
			Small (0.21-1.00)	23.7	
			Medium (1.01-3.00)	51.3	
			Large (above 3.00)	23.7	
05.	Annual income ('000'Tk.)	Unknown (10-3900)	Low (up to 291)	38.7	649.4
			Medium (292-1008)	42.5	
			High (above 1008)	18.8	
06.	Training experience (Number of days)	Unknown (0-330)	No training (0)	26.2	39.8
			Low (1-5)	26.3	
			Medium (6-10)	7.5	
			High (above 10)	40.0	
07.	Extension contact (Score)	0 to 80 (11-56)	Low (up to 21)	20.0	31.7
			Medium (22-42)	63.8	
			High (above 42)	16.2	
08.	Farming experience (Years)	Unknown (4-65)	Low (up to 13)	17.5	26.6
			Medium (14-40)	66.3	
			High (above 40)	16.2	
09.	Access to credit	-	No	13.8	-
			Yes	86.3	
10.	Off farm activities	-	No	55.0	-
			Yes	45.0	
11.	Availability of irrigation water	-	No	0.0	-
			Yes	100.0	
12.	Organizational membership (Score)	Unknown (0-216)	Low (up to 11)	36.2	37.7
			Medium (12-64)	48.8	
			High (above 64)	15.0	
13.	Cosmopoliteness (Score)	0 to 15 (3-15)	Low (up to 8)	18.7	10.9
			Medium (9-14)	71.3	
			High (above 14)	10.0	
14.	Innovativeness (Score)	0 to 21 (0-15)	Low (up to 3)	43.7	5.4
			Medium (4-7)	27.5	
			High (above 7)	28.8	
15.	Knowledge on potato cultivation (Score)	0 to 30 (14-28)	Low (up to 19)	18.7	22.4
			Moderate (20-26)	75.0	
			High (above 26)	6.3	

During their organizational activities they shared BARI Alu-25 cultivation knowledge, attitude and activities through which they earned social and personal prestige. Organizational membership and cosmopoliteness both have traditional bondage. Therefore, data presented in the table 1 show that like organizational membership more than four-fifths of the respondents (81.3%) had medium to high cosmopoliteness. But in case of innovativeness, about three-fourths (72.5%) of the respondents had low to high innovativeness. Comparing the scores of organizational membership and cosmopoliteness, innovativeness was supposed to be lower. However, in case of knowledge on potato cultivation more than four-fifths of the respondents (81.3%) had moderate to high knowledge on potato cultivation. It could be assumed that BARI Alu-25 growers received praise worthy training and had good farming experience.

Impact of BARI Alu-25 on growers' livelihood

Findings related to impact of BARI Alu-25 on growers' livelihood has been discussed in this section.

Perceived changes in livelihood status

The livelihood status of a grower consists of different socio-economic activities of him/her and the society in which s/he lives. The changes in the livelihood assets position of the respondents were measured before and after cultivating BARI Alu-25.

Human capital

The findings presented in the Table 2 show that 80.2 percent of the respondents' access to human capital was increased after BARI Alu-25 cultivation, which represents a good range of improvement in access to information (96.3%), knowledge (95.0%), and employment generation (self) (90.0%).

The increase in growers' access to human capital may be attributed to the enhanced solvency resulting from BARI Alu-25 cultivation. It was observed by Tadesse *et al.* (2019) that more than half of the farmers, who sold comparatively higher amount of potatoes, sent their children to private college. The farmers' potato and maize consumption were also increased due to the income earned from the new potato technology.

Table 2. Perceived changes in human capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Human Capital			
Health	85.0	1.3	13.8
Education	75.0	8.8	16.3
Training	42.5	1.3	56.3
Decision-making	83.8	2.5	13.8
Employment generation (Self)	90.0	1.3	8.8
Employment generation (Hired)	78.8	5.0	16.3
Knowledge	95.0	-	5.0
Access to information	96.3	-	3.8
Clothing	85.0	1.3	13.8
Nutrition	77.5	3.8	18.8
Dietary diversity	73.8	3.8	22.5
Quality of food intake	80.0	2.5	17.5
Average	80.2	2.6	17.2

Social capital

The results presented in the Table 3 show that 90.8 percent of the respondents' access to social capital was increased after BARI Alu-25 cultivation, which represents notable improvement in prestige (96.3%), attitude (96.3%), cooperation from others (96.3%) and management (96.3%). This may be because the growers became more solvent than before due to higher income from BARI Alu-25, thus improving their social acceptability.

Table 3. Perceived changes in social capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Social Capital			
Association/ organizational participation	60.0	1.3	38.8
Networking	88.8	-	11.3
Prestige	96.3	-	3.8
Attitude	96.3	-	3.8
Social status and respect	95.0	1.3	3.8
Involvement in social activities	95.0	1.3	3.8
Cooperation from others	96.3	-	3.8
Leadership roles	95.0	2.5	2.5
Management	96.3	-	3.8
Women empowerment	88.8	-	11.3
Average	90.8	0.6	8.6

Natural capital

The information furnished in the Table 4 indicates that 42.0 percent of the respondents' access to natural capital was increased after cultivation of BARI Alu-25 variety. Their forestry / trees (68.8%) and leased cultivable land (65.0%) were increased more compared to other natural capital.

Table 4. Perceived changes in natural capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Natural Capital			
Own cultivable land	32.5	3.8	63.8
Leased cultivable land	65.0	6.3	28.8
Homestead land	13.8	-	86.3
Pond	12.5	-	87.5
Availability of irrigation water	53.8	1.3	45.0
Safe drinking water	47.5	-	52.5
Forestry/trees	68.8	6.3	25.0
Average	42.0	2.5	55.6

Majority (55.6%) of them experienced no change in different types of natural capital. The reason could be that the natural capital, such as land, ponds, trees, and so on, of the growers typically remains unchanged. The possession of one's own land, ponds, and so on is usually fixed. They either acquired those from their parents or purchased them on a limited scale. Perhaps, therefore, a considerable portion of the respondents experienced no change in their natural capital.

Physical capital

The results presented in the Table 5 indicate that 48.1 percent of the respondents' access to physical capital was increased after cultivation of BARI Alu-25 variety. They experienced more increases in electricity use (93.8%), furniture (77.5%), digital/electronic communication devices (73.8%) and housing condition (71.3%) compared to other physical capital.

Table 5. Perceived changes in physical capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Physical Capital			
Housing condition	71.3	-	28.8
Toilet	65.0	-	35.0
Furniture	77.5	1.3	21.3
Agricultural tools	60.0	2.5	37.5
Cattle	41.3	20.0	38.8
Poultry	22.5	8.8	68.8
Personal vehicles	42.5	2.5	55.0
Digital/ electronic communication devices	73.8	-	26.3
Livelihood assets	62.5	-	37.5
Jewelry	35.0	11.3	53.8
Electricity use	93.8	2.5	3.8
Shop	17.5	3.8	78.8
Cattle/poultry farm	8.8	1.3	90.0
Biogas	1.3	-	98.8
Average	48.1	3.9	48.2

About half (48.2%) of them experienced no change in different types of physical capital. Some of the respondents experienced decrease in different types of physical capital especially in jewelry (11.3%) and living assets like cattle (20.0%) and poultry (8.8%). The reason could be that they were more engaged in crop cultivation and may not have had sufficient time for livestock rearing. Consequently, they sold their livestock resulting in decrease of their livestock number. The respondents might have sold their jewelry for different purposes or gifted those to their daughters. Tadesse *et al.* (2019) reported that the increase in yields and incomes of the farmers due to the adoption of improved potato production technologies assisted them to develop their material assets. The additional income from potato were used by the farmers in many ways. The rich farmers used the income to improve their houses and increase their livestock. The poor farmers increased their furniture, cooking utensils, tools. The farmers experienced improvement in household condition, safe drinking water i.e., presence of tube well, electricity and sanitary toilet. Farmers' housing condition, using sanitary latrine and household furniture were improved after BARI Hybrid Tomato-3 and BARI Hybrid Tomato-4 cultivation (Karim *et al*., 2009).

Financial capital

The results presented in Table 6 indicate that 48.4 percent of the respondents' access to financial capital was increased after BARI Alu-25 cultivation. The majority of the respondents experienced increases in annual agricultural income (80.0%) and cash in hand (67.5%) compared to other financial capital. The higher economic benefit from BARI Alu-25 might have assisted the growers to increase their financial capital. About half (42.3%) of them experienced no change in different types of financial capital. The reason many of the growers experienced no change in remittances from household members working outside the area (82.5%), business investment (57.5%), annual non-agricultural income (43.8%), and savings (42.5%) could be that they did not have any source of receiving remittance or business or non-agricultural income. Perhaps many of the growers could not save their money as they had to invest money gained from agricultural income in agricultural activities again. Consequently, they had no savings. Probably some growers did not experience any change in their non-agricultural income due to having a small-scale non-agricultural income source.

Table 6. Perceived changes in financial capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Financial Capital			
Annual agricultural income	80.0	10.0	10.0
Annual non-agricultural income	47.5	8.8	43.8
Cash in hand	67.5	15.0	17.5
Savings	46.3	11.3	42.5
Business investment	35.0	7.5	57.5
Remittances from household members working outside the area	13.8	3.8	82.5
Average	48.4	9.4	42.3

Some of the respondents experienced a decrease in cash in hand (15.0%) and savings (11.3%), which could be attributed to the fact that cash in hand and savings tend to fluctuate over time. They may have experienced loss in potato cultivation, leading to a decline in their cash in hand and savings. Perhaps other social and economic factors might have had an influence on their decrease in cash in hand and savings. Tadesse *et al.* (2019) reported that the increase in yields and incomes of the farmers due to the adoption of improved potato production technologies helped them to develop their financial assets. The poor farmers used their additional income from potato in the investment in small businesses such as selling (and buying) cereals, weaving products and milk products in the local markets.

Dolon (2018) observed that farmers found potato production as profitable business and potato production significantly contributed to their income.

Changes in participation in income generating activities

Findings presented in Table 7 indicate that the average score of participation in income generating activities after cultivation of BARI Alu-25 was higher than the average score of participation before cultivation of BARI Alu-25, and the changes were significant at the 1.0% level of probability. It can be concluded that cultivation of BARI Alu-25 had a potential influence on the respondents' increase in participation in income generating activities. The increased financial stability resulting from BARI Alu-25 cultivation might have assisted the growers to participate in more income generating activities and get more earnings.

Table 7. Changes in participation in income generating activities of the respondents after cultivation of BARI Alu-25

Category	Before			Category	After			% Changes	t-value (df = 79)
	No.	%	Mean		No.	%	Mean		
Low (up to 4)	16	20.0		Low (up to 6)	18	22.5			
Medium (5-14)	54	67.5	8.7	Medium (7-16)	49	61.3	11.2	28.7	5.370**
High (>14)	10	12.5		High (>16)	13	16.3			

** Significant at 0.01 level.

Conclusion

The cultivation of BARI Alu-25 has demonstrated a transformative impact on the socio-economic status of growers, significantly enhancing their access to livelihood capitals by 42.0% to 90.8%. The growers experienced improvement in access to information, knowledge, employment generation, prestige, attitude, cooperation, and management. They also experienced increases or improvement in forestry/trees, leased cultivable land, electricity use, furniture, electronic communication devices, housing condition, annual agricultural income, and cash in hand after BARI Alu-25 cultivation. BARI Alu-25 cultivation had a potential influence on the respondents' increase in participation in income generating activities. Further studies may be carried out to validate the findings of the study in the other areas of the country having similar socio-economic status. Further research may also be conducted on other BARI technologies.

Acknowledgement

This research was funded by the National Science and Technology (NST) Fellowship, Ministry of Science and Technology.

References

Akhond, M. A. Y., M. A. Rahman, A. U. Ahmed, M. R. Ahmad, M. A. Rashid and M. H. H. Rahman (Eds.). 2025. *Krishi Projukti Hatboi (Handbook on Agro-Technology)*, 10th edition. Bangladesh Agricultural Research Institute, Gazipur.

Al-Zahrani, K. H., A. Q. Khan, M. B. Baig, M. Mubushar and A. H. Herab. 2019. Perceptions of wheat farmers toward agricultural extension services for realizing sustainable biological yields. *Saudi J. Biol. Sci*. **26:** 1503-1508.

Azad, A. K., M. Miaruddin, M. A. Wahab, M. H. R. Sheikh, B. L. Nag and M. H. H. Rahman (Eds.). 2020. *Krishi Projukti Hatboi (Handbook on Agro-Technology),* 9th edition. Bangladesh Agricultural Research Institute, Gazipur.

BBS (Bangladesh Bureau of Statistics). 2021. *Yearbook of Agricultural Statistics - 2020*. Bangladesh Bureau of Statistics, Statistics & Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

Begum, M. E. A., M. A. M. Miah, M. A. Rashid, M. A. Matin and M. I. Hossain. 2014, 2015. Socioeconomic determinants of modern potato varieties adoption and resource use efficiency in Northern Bangladesh. *Bangladesh J. Agric. Econ*. **37:** 103-113.

DAE (Department of Agricultural Extension). 2019. Information on the Area and Production of BARI Varieties of Rangpur District. Deputy Director, Department of Agricultural Extension, Rangpur.

DAE (Department of Agricultural Extension). 2020a. Information on the Area and Production of BARI Varieties of Rangpur District 2020. Deputy Director, Department of Agricultural Extension, Rangpur.

DAE (Department of Agricultural Extension). 2020b. Information on the Upazila wise Cultivation of BARI Alu-25 of Rangpur District. Deputy Director, Department of Agricultural Extension, Rangpur.

DAE (Department of Agricultural Extension). 2020c. Information on the Upazila and Variety wise Cultivation of Different Crops during Rabi/2019-2020 Season. Deputy Director, Department of Agricultural Extension, Munshiganj.

DFID (Department for International Development). 2000. Sustainable Livelihoods Guidance Sheets. https://www.livelihoodscentre.org/documents/114097690/114438878/Sustainable+livelihoods+guidance+sheets.pdf/594e5ea6-99a92a4e-f288cbb4ae4bea8b?t=1569512091877. Accessed on 7th November, 2021.

Dolon, M. I. K. 2018. Potato cultivation and its effect on income generation: A study in Thakurgaon district. PhD Dissertation. Department of Development and Poverty Studies, Sher-e-Bangla Agricultural University, Dhaka.

Haque, M. A., M. A. M. Miah, S. Hossain and M. M. Rahman. 2012. Profitability of BARI released potato (*Solanum tuberosum* L.) varieties in some selected locations of Bangladesh. *Bangladesh J. Agril. Res*. **37:** 149-158.

Ibrahim, A. Z., K. H. Hassan, R. Kamaruddin and A. R. Anuar. 2018. The level of livelihood assets ownership among vulnerability group in East Coast of Malaysia. *European J. Sustain. Dev*. **7:** 157-161.

Karim, M. R., M. S. Rahman and M. S. Alam. 2009. Profitability of summer BARI hybrid tomato cultivation in Jessore district of Bangladesh. *J. Agric. Rural Dev*. **7:** 73-79.

Rahman, M. S., M. Khatun and M. A. M. Miah. 2019. Profitability analysis of mango cultivation and its impact on farmer's livelihood in some areas of Bangladesh. *Bangladesh J. Agril. Res*. **44:** 139-152.

Tadesse, Y., C. J. M. Almekinders, R. P. O. Schulte and P. C. Struik. 2019. Potatoes and livelihoods in Chencha, southern Ethiopia. *NJAS-Wageningen J. Life Sci.* **88:** 105-111.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 567-581, March 2026

PERFORMANCE OF DIFFERENT INTEGRATED PEST MANAGEMENT PACKAGES FOR THE SUPPRESSION OF CHICKPEA POD BORER

M. A. SARKAR[1], M. M. RAHMAN[2], N. K. DUTTA[3]
M. H. RASHID[4] AND A. K. M. R. H. FERDOUS[5]

Abstract

Chickpea (*Cicer arietinum* L.) is a major pulse crop in Bangladesh, but its productivity is severely constrained by the pod borer, *Helicoverpa armigera* (Hubner). This study evaluated the efficacy of four integrated pest management (IPM) packages combining pheromone-based mass trapping, microbial and plant-derived biorational insecticides, and selective chemical sprays, compared with conventional farmer practice (Cypermethrin plus Chlorpyriphos: Nitro®) and untreated control, across two Rabi seasons (2020–21 and 2021–22). Sex pheromone traps were installed to monitor and partially suppress adult *H. armigera* populations, and foliar applications of IPM components were performed during the pod formation stage, when chickpea pods are most vulnerable. All IPM packages significantly reduced pod damage relative to untreated control and conventional practices. The lowest pod infestation (2.83-3.01%) and highest yields (1.48-1.58 t ha^{-1}) were achieved in IPM packages integrating pheromone trapping with *Bacillus thuringiensis* var. *kurstaki* plus Spinosad (Spinomax®) or plant-derived *Celastrus angulatus* extract (Bio-Chamak®), outperforming the conventional farmer practice (pod damage 4.53-5.97%; yield 1.34-1.39 t ha^{-1}). Peak moth captures occurred 60-80 days after sowing, and abiotic factors, particularly temperature and relative humidity, were positively associated with moth activity. Economic analysis indicated that, despite the highest marginal benefit-cost ratio (MBCR) for farmer practice (1.87) due to lower input costs, IPM packages achieved substantial yield improvements with MBCRs up to 1.39. These results demonstrate that biorational-based IPM strategies integrated with pheromone mass trapping effectively suppress *H. armigera*, and enhance chickpea productivity.

Keywords: *Cicer arietinum, Helicoverpa armigera*, pod borer, pheromone trap, biopesticides.

Introduction

Chickpea (*Cicer arietinum* L.) is a major pulse crop in Bangladesh, ranking seventh in area and production. The crop currently occupies 3,946 ha, producing

[1,3&5]Entomology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, [2]Department of Entomology, Faculty of Agriculture, Gazipur Agricultural University (GAU), Gazipur-1706, and [4]Regional Agricultural Research Station, BARI, Burirhat, Rangpur-5410, Bangladesh.

5,048 tons at a national average yield of 1.28 t ha^{-1} (BBS, 2025). According to the FAO, in 2023, chickpea is cultivated globally on 14.1 million hecters, with an average yield of 1171 kg ha^{-1}, resulting an annual production of 16.5 million tons (FAOSTAT, 2025). Eleven species of insect pests of chickpea have been recorded in Bangladesh of which nine species attack in field and two species attack in storage. Among these, the field insect pests pod borer, *Helicoverpa armigera* (Hubner) is the most destructive and very notorious insect pests, bear polyphagous nature and serious in most of the chickpea growing areas in Bangladesh (Hossain *et al*., 2016). In the chickpea growing area pod borer (*H. armigera* Hubner) (Lepidoptera: Noctuidae), is the most common and critical challenge for successful chickpea production around the world (Ujjan *et al*., 2019; Kumar *et al*., 2019; Jai *et al*., 2020). Bajia and Bairwa (2015) reported that it causes about 75 to 90 % losses in seed yield, and it was pointed out that gram pod borer damage leaves, tender shoots, apical tips, floral buds and pods. In case of outbreaks, yield losses caused by chickpea pod borer range from 10-90% and 50-60% pod damage in the crop depending upon the insect population and susceptibility of genotypes (Sharma *et al*., 2012; Kambrekar, 2012; Iqbal *et al*., 2014; Ahmed and Awan, 2013). Single larva can damage 40 pods and it feeds on floral buds, flowers and young pods of the growing crop (Khan *et al*., 2009; Bajia and Bairwa, 2015). *H. armigera* is widely dispersed throughout the African, Asian, European and Mediterranean regions (EPPO, 2006; Zohary *et al*., 2012).

The wider host range, multiple generation, migratory behavior and high fecundity of gram pod borer made it difficult to manage. The chemical control options are still regarded as the last resort for its management due to their quick known effects (Sreekanth *et al*., 2014). In Bangladesh, synthetic insecticides are generally used to control the pest. However, continuous and indiscriminate use of synthetic pesticides has resulted in residues, development of insecticide resistance, adverse effects on non-target organisms, humans and the environment (Boulamtat *et al*., 2020; Patil *et al.*, 2017; Hossain *et al.*, 2010; Kumar and Sarada, 2015). Integrated pest management (IPM) offers an effective, environmentally compatible approach by combining multiple control tactics, including mechanical removal, biological and botanical insecticides, pheromone-based monitoring and mass trapping, and selective use of low-risk chemical molecules.

Recent advancements in biorational insecticides have demonstrated significant potential for pod borer management. Plant-derived compounds, such as *Celastrus angulatus* extract (Bio-chamak®), and microbial products, including *Bacillus thuringiensis* formulations (Spinomax® – a combination of Bt var. *kurstaki* and spinosad), exhibit high insecticidal activity while preserving ecological safety (Rahman *et al*., 2023, 2025; Rashid *et al*., 2003). These bioactive agents act through specific physiological and behavioral mechanisms, including feeding inhibition, disruption of digestion, and neuro-modulation, with minimal potential for resistance development (Wang *et al*., 2001; Wei *et al*., 2009). Nevertheless, their integration with pheromone-based technologies in field-level chickpea IPM has been poorly documented under Bangladesh agro-ecological conditions.

Pheromone traps are valuable tools for monitoring and management of *H. armigera*, enabling early detection, forecasting, and targeted control measures (Ahmed and Khalique, 2002). Compatibility of microbial and biorational insecticides with chemical sprays has also been demonstrated, reducing pest populations while minimizing environmental hazards (Khalique and Ahmed, 2003; Ahmed *et al*., 2012).

Considering the need for environmentally safe and sustainable pest management, the present study was designed to evaluate the efficacy of IPM packages incorporating biorational and microbial insecticides, pheromone-based mass trapping, and selective chemical sprays against chickpea pod borer. This approach aims to optimize yield protection while reducing reliance on conventional insecticides.

Materials and Methods

Experimental site and duration: Field experiments were conducted in two consecutive winter (*Rabi*) seasons during 2020–2021 and 2021–22 at the Entomology Research field, Bangladesh Agricultural Research Institute (BARI), Gazipur (24°00′N, 90°25′E; elevation 8.4 m above sea level). The area is characterized by a subtropical climate with distinct dry and cool winters, moderate rainfall, and an average temperature range of 15-30°C. The soil of the experimental site was silty clay loam with pH 6.8 and moderate organic matter content. The experiments were performed under irrigated conditions following standard agronomic practices recommended for chickpea cultivation in central Bangladesh.

Experimental design and crop establishment: The experiment was laid out in a randomized complete block design (RCBD) with six treatments and three replications (dispersed). Each plot measured 10.0 m × 5.0 m with 1.0 m spacing between plots and 1.5 m between blocks to prevent cross-interference of treatments. The treatments were randomly allotted in each block. The seeds of BARI Chola-9 were sown in rows with spacing of 50 cm and plant to plant distance was maintained 10 cm. The seeds were sown during the last week of November in both years. Standard agronomic practices were done as recommended. The recommended fertilizer doses were applied at 5 t ha^{-1} cow dung, 20-25-25-10-2-1.5 kg ha^{-1} of N-P_2O_5-K_2O-S-Zn-B at the time of final land preparation. Standard irrigation, weeding, and mulching operations were performed as required to maintain uniform crop growth across all treatments.

Treatments and Integrated Pest Management (IPM) Packages: Four IPM packages were formulated based on previous research findings and were evaluated alongside the farmer's practice (chemical pesticides only) and an untreated control. Each package incorporated different combinations of mechanical, biological, biorational, and insecticidal components (Table 1). Application schedules, dosages, and input materials were standardized across treatments to ensure valid and comparable assessment of efficacy.

Table 1. Details of Multi-component IPM packages applied in the experiment

Description of IPM Packages

IPM package 1: Sex pheromone trap + Spinosad (Success® 2.5 SC @ 1.2 ml L^{-1} water)

IPM package 2: Sex pheromone trap + *Bacillus thuringiensis* var. *kurstaki* (Btk) + Spinosad (Spinomax® @ 2 ml L^{-1} water)

IPM package 3: Sex pheromone trap + *Celastrus angulatus* extract (Bio-Chamak® 1% EW @ 2.5 ml L^{-1} water)

IPM package 4: Sex pheromone trap + Chlorantraniliprole (Coragen® 18.5 SC @ 0.5 ml L^{-1} water)

Farmer's practice: Weekly spraying of Cypermethrin + Chlorpyriphos (Nitro® 505EC @ 2ml L^{-1} water)

Untreated control (no pest management interventions)

Treatment application procedure: Sex pheromone traps were installed prior to foliar treatments to monitor and partially suppress adult *H. armigera* populations. Traps were deployed at a density of 40 per hectare, 45 days after sowing (DAS) with a 25 m spacing to prevent overlapping pheromone plumes and ensure representative sampling of the experimental field. BARI-developed water traps were equipped with species-specific pheromone lures and positioned slightly above the crop canopy using bamboo supports. Traps remained in the field throughout the cropping season, and captured male moths were counted weekly to track adult population dynamics, peak activity periods, and the efficacy of the integrated pest management (IPM) packages in suppressing adult moths.

Foliar applications of the pesticidal components of each IPM package were performed during the pod formation stage, the period of highest susceptibility to *H. armigera* infestation. Treatments, as specified in Table 1, were applied three times at 7-day intervals using a calibrated hand-operated knapsack sprayer to ensure uniform coverage across the entire crop canopy. This standardized application guaranteed that all plants within each plot received consistent exposure to the assigned IPM interventions, enabling accurate assessment of treatment efficacy. By integrating precise pest monitoring with strategically timed applications, this approach minimized off-target effects, preserved natural enemy populations, and maximized the effectiveness of biological and biorational control measures within the chickpea cropping system.

Assessment of pod infestation by pod borer: At maturity, all the pods were collected from randomly placed $1m^2$ quadrants in each plot and examined. The damaged (bored) and total numbers of pods were counted and the per cent pod damage was determined using the following formula:

$$\% \text{ Pod damage} = \frac{\text{Number of damaged pods}}{\text{Total number of pods}} \times 100$$

The per cent reduction of pod damage compared to the untreated control was calculated using the following formula:

$$\text{Percent reduction over control} = \frac{\text{Mean population in control} - \text{Mean population in treatment}}{\text{Men population in control}} \times 100$$

Yield production and economic analysis: Crops of the central four rows were harvested and then threshed. The grains were cleaned and dried in the bright sunshine. The grain yield obtained from each plot was converted into per hectare (t ha^{-1}). A detailed record of labor, pesticide, biopesticide, and pheromone trap costs was maintained for each treatment. The untreated control served as a reference for gross and net benefit estimation. Gross return was calculated with the marketable yield of chickpea and farm gate price. The marginal benefit-cost ratio (MBCR) was computed following the method of Ali *et al*. (1996): MBCR= Additional benefit over control/ Additional cost over control.

Adjusted net return = Net return from the treated plant – Net return from the control plant

Net return = Gross return – Cost of treatment

Statistical analysis: All data were subjected to analysis of variance (ANOVA) using R statistical software (version 4.3.1). Treatment means were separated by the least significant difference (LSD) test at a 5% probability level ($p \leq 0.05$). Data expressed in percentages were arcsine-transformed before analysis to ensure homogeneity of variance.

Results and Discussion

Effect of IPM packages on pod damage infestation and moth trapping week^{-1}trap^{-1}: The chickpea pod borer, *H. armigera*, remained the dominant pest throughout both cropping seasons (2020–2021 and 2021–2022), and pod infestation differed significantly among treatments ($p \leq 0.05$). During the 2021–2022 season, pod damage ranged from 2.83% to 8.27% (Table 2). The lowest pod damage (2.83%) was recorded in IPM package 2, which combined sex pheromone mass trapping with spraying of *Bacillus thuringiensis* var. *kurstaki* + Spinosad (Spinomax®), and statistically comparable to other IPM packages. Slightly higher pod damage (2.91%) was observed in IPM package 3 (sex pheromone trap + Bio-Chamak®), followed by IPM package 4 (sex pheromone trap + Coragen®) and IPM package 1 (sex pheromone trap + Success®), which recorded 2.95% and 3.01% pod damage, respectively. The conventional farmer's practice (weekly spraying of Nitro®) resulted in 4.53% pod damage, while untreated control plots suffered the highest infestation (8.27%).

In the 2020–21 season, pod damage ranged from 3.01% to 9.03%, with IPM package 2 again providing the lowest damage (3.01%) (Table 2). Other IPM treatments consistently resulted in significantly lower infestation than the farmer's practice, which recorded 5.97%, whereas untreated plots exhibited 9.03% damage. These findings corroborate previous studies indicating that integration of pheromone traps with bio-insecticides or biorational agents significantly reduces pod borer infestation (Madhu, 2014; Sreekanth *et al*., 2014; Tushar *et al*., 2020; Singh *et al*., 2013). The efficacy of Chlorantraniliprole, Spinosad, and Bt-based treatments aligns with reports by Balikai *et al*., 2001; Hossain *et al*., 2010; and Tiwari *et al*., 2007 confirming the superior performance of IPM strategies over conventional chemical applications. Integrated approaches combining biocontrol, biorational, and minimal-risk chemicals have been shown to reduce larval population and pod damage while maintaining compatibility with natural enemies (Jerusha and Thakur, 2018; Sarkar *et al*., 2006).

Table 2. Effect of different IPM packages on mean pod borer infestation of chickpea during two cropping seasons and moth trapped week^{-1} trap^{-1}

Cropping season	Management packages	Pod damage (%)	Pod damage reduction over control (%)	Moth trapped/ trap/week (Avg. of 16 weeks)
2021–22	IPM package-1	3.01 c	63.60	0.33
	IPM package-2	2.83 c	65.78	0.25
	IPM package-3	2.91 c	64.81	0.25
	IPM package-4	2.95 c	64.33	0.33
	Farmer's practice	4.53 b	44.37	-
	Untreated Control	8.27 a	-	-
2020–21	IPM package-1	3.99 c	55.81	1.08
	IPM package-2	3.01 d	66.67	1.25
	IPM package-3	3.82 c	57.70	1.16
	IPM package-4	3.54 c	60.79	1.12
	Farmer's practice	5.97 b	33.89	-
	Untreated Control	9.03 a	-	-

Means having same letter(s) in a column are not significantly different at $P \leq 0.05$ followed by LSD

Notes: IPM package 1: Sex pheromone trap + Success®; IPM package 2: Sex pheromone trap + Spinomax®; IPM package 3: Sex pheromone trap + Bio-Chamak®; IPM package 4: Sex pheromone trap + Coragen®; Farmer's practice: Weekly spraying of Nitro® and an Untreated Control.

Pheromone trap catches: Weekly monitoring of sex pheromone traps revealed that peak male *H. armigera* activity occurred between 60-80 days after sowing, coinciding with the chickpea podding period. IPM package integrating both pheromone traps and bio-insecticides (Package 1- Package 4) captured 0.25-0.33 moths per trap per week in 2021–2022, compared to 1.08-1.25 moths per trap per week in 2020–2021 (Table 2). Mass trapping reduced mating success, contributing to lower larval infestation and pod damage, highlighting the importance of pheromone traps as a key component of multi-tactic IPM strategies. One of the most successful applications of pheromones in pest management is mating disruption. By releasing synthetic pheromones into the environment, pest populations can be confused or overwhelmed, preventing males from locating females and reducing reproduction rates. This technique has been particularly effective against moth pests (Witzgall *et al*., 2010).

To clarify the mechanistic basis of the IPM interventions evaluated in this study, all insecticidal, biorational, and semi chemical-based components incorporated into the management packages. A semi chemical-based tool used which is highly species-specific for partial suppression of *H. armigera* populations. Captured moths provide real-time information on adult emergence, flight peaks, and infestation risk, enabling precise timing of control measures. Pheromone trapping has emerged as a promising approach in pest management technologies, offering advancements and innovations that hold great potential for effective pest control. Advancements in pheromone trapping have enabled targeted monitoring and control of specific pest populations (Awanindra *et al*., 2024). Ahmed and Khalique (2002) did experimentation and reported forecasting adult populations of *H. armigera* on chickpea through pheromone traps and its role in management of this insect. Mahmudunnabi *et al.* (2013) observed that biocontrol agent release along with installation of sex pheromone traps and spraying of HNPV an effective management of pod borer attacking chickpea. *Bacillus thuringiensis* var. *kurstaki,* a microbial bioinsecticide producing Cry δ-endotoxins that acts selectively on lepidopteran larvae. *Bt* is highly selective, environmentally benign, and compatible with most natural enemies, making it ideal for bio-intensive IPM. Extensive studies were reported by Khalique and Ahmed (2003) and found the retarded effect of spore-δ-delta endotoxin complex of *Bt* subsp. *kurstaki* Berliner strains on the development of *H. armigera* (Hubner) and reported significant retarded development in the larvae of *H. armigera* as well as impact of *Bt* on biology of *H. armigera*. Khalique and Ahmed (2001a,b) studied synergistic interaction between

Bt and pyrethroid-insecticide, they have also conducted studies evaluation of toxicity of *Bt* and its sub-lethal effect on the development of *H. armigera*. *Bt* field test results indicated that microbial insecticides can be used (with and without adjuvants) for management of *H. armigera* populations infesting chickpea and their use would reduce reliance on toxic chemicals (Ahmed *et al.,* 2006, 2012). Spinosad (Success®), a fermentation-derived bioinsecticide from *Saccharopolyspora spinosa,* is effective against borers and has minimal adverse effects on predators and parasitoids. Singh and Amit (2012) studied the efficacy of certain new molecules insecticides against gram pod borer, *H. armigera* and reported that Spinosad 45 SC was the best among all the treatments in larval population over control. *Celastrus angulatus* extract (Bio-Chamak), a botanically derived biorational insecticide containing sesquiterpenes, triterpenoids, and flavonoids. These compounds function primarily as antifeedants and stomach poisons, impairing digestive physiology and inducing starvation-mediated mortality. Rashid *et al.* (2021) did experimentation on tomato fruit worm, *H. armigera* and obtained the lowest fruit infestation, highest yield and net income from sex pheromone mass trapping + *Celastrus angulatus* (Bio Chamak®) + Matrine. Spinomax® (*Bt* + Spinosad®), a synergistic biopesticide combining *Bt* endotoxins with spinosad's neurotoxic activity. This dual-action formulation enhances larval mortality, extends residual efficacy, and reduces resistance development. It is particularly suitable for sustainable management of Fall army worm (*S. frugiperda*) of maize and other lepidopteran caterpillar pests of different crops. Bhandari *et al.* (2025) who observed that *Bacillus thuringiensis* var. *kurstaki* + *Saccharopolyspora spinosa* 15 % SC significantly increased larval mortality and effectively controlled the damage caused by *S. frugiperda*. Dutta *et al.* (2021) who reported that *Bt* + Spinosad (Spinomax®) showed higher effectiveness in reducing plant and cob infestation compared to other biopesticides against fall armyworm, *S. frugiperda*. Sarkar *et al.* (2021) observed that, *Bt* + Spinosad (Spinomax®) a new generation biopesticide was effective against the major pest brinjal shoot and fruit borer followed by *Celastrus angulatus* (Bio-Chamak®). Chlorantraniliprole (Coragen®), a diamide insecticide acting as a selective ryanodine receptor modulator. Chlorantraniliprole is widely used and highly effective against *H. armigera*, with low mammalian toxicity and reduced ecological footprint. The advent of synthetic organic insecticides enabled to gain an upper hand in struggle against insects to protect the crops, domesticated animals and ourselves from their pestiferous attack. Pagidala and Kumar (2024) did experimentation and reported that Chlorantraniliprole 18.5 SC was more effective and economical treatment in controlling larval population of *H. armigera* followed by Spinosad 45 SC. Anuradha (2023) reported that two foliar applications of Chlorantraniliprole at ten days interval period reduced significantly the larval populations of *H. armigera, S.*

litura without any phytotoxic symptoms in cotton. Chlorantraniliprole application in open field condition was found to be harmless to natural enemy (Coccinellids and Spiders). Chlorantraniliprole was found to be comparatively safer to natural enemies.

The above facts are formulating to introduce the IPM packages. The present study revealed that integration of all the components was successfully suppressed the *H. armigera* population resulted the lower pod damage (%) and significant pod damage reduction over control (%) as well as good marketable seed yield. All the IPM packages were performed better than that of farmer's conventional practice i.e., weekly spraying of toxic broad-spectrum insecticide mixture combines Cypermethrin + Chlorpyriphos (Nitro® 505EC @ 2ml L^{-1} water), a pyrethroid that disrupts voltage-gated sodium channels and causes rapid knockdown, with chlorpyriphos, an organophosphate that inhibits acetylcholinesterase and induces neuromuscular dysfunction. Although widely used in conventional chickpea cultivation, this combination poses significant environmental hazards, adversely affects non-target organisms, and contributes to the rapid development of insecticide resistance in pest populations.

Effect of IPM packages on yield: Significant differences in marketable chickpea yield were observed among the IPM packages ($p \leq 0.05$). All IPM packages produced higher yields compared with the untreated control, which yielded 1.01-1.02 t ha^{-1}. In the *Rabi* 2021–22 season, the highest yield was obtained from IPM Package 2 (1.58 t ha^{-1}), followed closely by IPM Package 3 (1.56 t ha^{-1}), IPM Package 4 (1.54 t ha^{-1}), and IPM Package 1 (1.51 t ha^{-1}), whereas the conventional chemical-based farmer practice produced 1.39 t ha^{-1} (Table 3). Similarly, in the *Rabi* 2020–21 season, the highest yield was recorded in IPM Package 2 (1.48 t ha^{-1}), followed by IPM Package 4 (1.41 t ha^{-1}), IPM Package 3 (1.39 t ha^{-1}), and IPM Package 1 (1.36 t ha^{-1}).

The enhanced yields under IPM treatments can be attributed to the integration of biorational and biological control tactics, which effectively reduced pod borer infestation and minimized crop losses. These findings are consistent with earlier reports where the use of *Helicoverpa* nuclear polyhedrosis virus (HNPV) followed by cypermethrin application significantly increased chickpea yield (Hossain *et al*., 2010; Sarkar *et al*., 2006). Similarly, Jerusha and Thakur (2018) observed that weeding, hand picking, and application of Indoxacarb improved grain yield by reducing pest pressure. Insecticide treatments combined with *B. thuringiensis* var. *kurstaki* were also reported to enhance yield while suppressing larval populations and pod damage (Tiwari and Sehgal, 2007). Furthermore, Visalakshmi *et al*. (2005) highlighted that the strategic combination of IPM components, either individually or in packages, offers a sustainable alternative to conventional chemical control of chickpea pod borer. The present study is the first to evaluate the efficacy of new generation biopesticides, biorationals, and low-toxic, environmentally safe chemical pesticides in an integrated management approach against chickpea pod borer. The results demonstrate that these IPM packages are effective in reducing pest damage and enhancing yield, providing a viable and sustainable alternative to conventional chemical-intensive practices.

Table 3. Effect of different IPM packages on seed yield of chickpea in two cropping seasons

Cropping season	Management packages	Yield (t/ha)	Yield increase over control (%)
2021–22	IPM package-1	1.51 a	32.45
	IPM package-2	1.58 a	35.44
	IPM package-3	1.56a	34.61
	IPM package-4	1.54a	33.77
	Farmers practice	1.39b	26.62
	Untreated Control	1.02c	-
2020–21	IPM package-1	1.36 b	34.65
	IPM package-2	1.48 a	46.53
	IPM package-3	1.39 b	37.63
	IPM package-4	1.41 b	39.60
	Farmer's practice	1.28 c	26.73
	Untreated Control	1.01 d	-

Means having same letter(s) in a column are not significantly different at $P \leq 0.05$ followed by LSD.

Benefit-cost analysis: Economic assessment indicated that all IPM packages achieved lower marginal benefit-cost ratios (MBCR) compared with the conventional farmer's practice (Table 4). The highest MBCR (1.87) was recorded for the farmer's practice, which involved weekly spraying of Nitro®, followed by IPM Package 1 (MBCR 1.39). Across the two-year study period, the average marketable yields of the IPM packages ranged from 1.44 to 1.53 t ha^{-1}, whereas the farmer's practice yielded 1.34 t ha^{-1}, achieving the highest MBCR primarily due to lower input costs. Although IPM Package 2 produced the highest gross and net returns as a result of maximum marketable yield, its slightly higher input costs led to a marginally lower MBCR relative to the farmer's practice.

These results demonstrate that while IPM packages may require higher initial investment, they provide substantially higher productivity and long-term sustainability benefits by reducing pest pressure through environmentally safe, bio-intensive methods. Previous studies have reported similar trends, where IPM components such as neem seed kernel extract, *Beauveria bassiana*, *B. thuringiensis*, and HNPV virus effectively reduced larval populations and pod damage, resulting in favorable cost-benefit ratios (Visalakshmi *et al*., 2005). This emphasizes that strategically integrated pest management not only enhances yield and crop protection but also provides an economically viable alternative to conventional chemical-intensive practices.

Table 4. Economic evaluation of different IPM packages for management of pod borer in chickpea

IPM packages	Average two years marketable yield (t/ha)	[1] Gross return (Tk./ha)	[2] Cost of Treatment (Tk./ha)	Net return (Tk./ha)	Adjusted net return (Tk./ha)	Marginal Benefit Cost Ratio (MBCR)
Package 1	1.44	72000	8580	63420	11920	1.39
Package 2	1.53	76500	12900	63600	12100	0.98
Package 3	1.48	74000	15150	58850	7350	0.49
Package 4	1.48	74000	17025	56975	5475	0.32
Farmer's practice	1.34	67000	5400	61600	10100	1.87
Untreated Control	1.02	51000	0	51500	-	

Cost of relevant materials/activities:

[1]Farmgate price of chickpea @ Tk. 50.00 per kg.

[2][Cost of Success 2.5SC: @ Tk. 3000/L; Cost of Bio-chamak 1% EW: @ Tk. 3000/L; Cost of Spinomax: @ Tk. 3000/L; Cost of Coragen 18.5 SC: @Tk. 17500/L; Cost of Nitro 505EC: @Tk. 900/L; Cost of *Helicoverpa* pheromone: @ 75 Tk./trap with installation (BARI developed); Cost of spray: Two laborers/spray/ha @ Tk. 450.00/labour/day; Spray volume required: 500L/ha.]

Conclusion

The study demonstrates that integrated pest management packages combining sex pheromone-based mass trapping with biorational insecticides, including *Bacillus thuringiensis* var. *kurstaki* and *Celastrus angulatus* extract, effectively suppress chickpea pod borer and enhance marketable yields. Although conventional chemical sprays showed slightly higher marginal benefit-cost ratios due to lower input costs, IPM packages provided superior yield benefits and ecological sustainability. These findings confirm that integrating biorational insecticides with pheromone-based strategies offers an efficient and practical method for sustainable chickpea production in Bangladesh.

References

Ahmed, K. and M. S. Awan. 2013. Integrated management of insect pests of chickpea *Cicer arietinum* (L. Walp) in South Asian Countries: Present status and future strategies–A review. *Pak. J. Zool.* **45**(4): 1125-1145.

Ahmed, K., F. Khalique, S. A. Durrani and K. D. Pitafi. 2012. Field evaluation of bio-pesticide for control of chickpea pod borer *Helicoverpa armigera*, a major pest of chickpea Crop. *Pakistan J. Zool.* **44**(6):1555-1560.

Ahmed, K., W. U. Kongming, G. Liang and Y. Guo. 2006. Cross resistance of Cry1Ac resistant cotton bollworm *Helicovera armigera* to various spore-delta endotoxin of *Bacillus thuringiensis* Berliner. *Pakistan J. biol. Sci.* **9**: 1639-1649.

Ahmed, K. and F. Khalique. 2002. Forecasting adult populations of *Helicoverpa armigera* Huebner on chickpea using pheromone trap and its role in insect management. *Pakistan J. biol. Sci.* **5**: 830-834.

Ali, M. I., A. K. M. Khorsheduzzaman, A. Ahmed and M. A. Karim. 1996. Effect of intercropping of coriander with brinjal on the incidence of brinjal shoot and fruit borer. Annual Report 1995-96. Entomology Division, BARI, Gazipur. pp 1-6.

Anuradha, P., M. Sudhanan, E. M. Priyanka, R. Emaiya, P. Karthik, A. Suganthi and S. V. Krishnamoorthy. 2023. Determination of chlorantraniliprole for managing *Helicoverpa armigera* and *Spodoptera litura* in cotton ecosystem, *Environmental Research*, Volume 239, Part 1.

Awanindra, K. T., K. Charitha, C. N. Anu, P. Bhavana and C. K. Panigrahi. 2024. Pheromone Trapping: Advancements and Innovations in Pest Management Technologies. *New Era Agriculture Magazine* **2**(8): 180-189.

Bajia, R. and B. Bairwa. 2015. Eco-friendly integrated pest management of gram pod borer (*Helicoverpa armigera*) (Hubner) in chickpea ecosystem. *Popular Kheti.* **3**(1): 70-72.

Balikai, R. A., A. P. Biradar, S. Yelshethy and R. G. Tegelli. 2001, Relative efficacy of some selected insecticides against chick pea pod borer, *Karnataka J. Agri. Sci*. **14**(2): 346-348.

BBS (Bangladesh Bureau of Statistics). 2025. Yearbook of Agricultural Statistics, Statistics and Informatics Division, Ministry of Planning Government of the People's Republic of Bangladesh.

Bhandari, N., D. K. Mehata, A. Bhandari and A. M. Bhattarai. 2025. Evaluation of novel insecticides against fall armyworm (*Spodoptera frugiperda*) via laboratory bioassay and field experiment findings. *J. of Nat. Pesticide Res.* **14**: 100159

Boulamtat, R., S. Lhaloui, A. Sabraoui, K. El-Fakhouri, A. Oubayoucef, A. Mesfioui and M. El-Bouhssini. 2020. Antifeedant and larvicidal activities of *Mentha pulegium* on chickpea pod borer *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Int. J. Trop. Insect Sci.* **40**:151-156.

Dutta, N. K., M. A. Mannan, M. A. Sarkar, K. Begum and A. K. M. R. H. Ferdous. 2021. Field evaluation of some new bio-pesticides against fall armyworm attacking maize. Annual Research Report, 2020-2021, Entomology Division, BARI, Gazipur. 309 p.

EPPO. 2006. Distribution maps of quarantine pests, *Helicoverpa armigera*. On-line available at www.eppo.org/QUARANTINE/insects/ *Helicoverpa_armigera*/HELIAR_map. html.

FAOSTAT. 2025. Food and Agriculture Organization of United Nation Statistics. Database faostat.fao.org/.

Hossain, M. A., M. A. Haque, M. Ahmad and M. Z. H. Prodhan. 2010. Development of an integrated management approach for pod borer, *Helicoverpa armigera* (Hubner) on chickpea. *Bangladesh J. Agril. Res*. **35**(2): 201-206.

Hossain, M., M. A. Hossain and M. M. Kamal. 2016. Plant Protection in Pulse Crops. *In*: *Pulses for sustainable food and nutrition security in SAARC Region*. (Ed. Gurung, T. R. and Bokthiar, S. M.). SAARC Agriculture Centre, SAARC Complex, Farmgate, Dhaka-1215. pp. 99-130.

Iqbal, J. S., U. Farooq, M. Jamil, H. A. A. Khan and M. Younis. 2014. Relative efficacy of selective insecticides against gram pod borer (*Helicoverpa armigera*) of chickpea. *Mycopath* **12**(2): 119-122.

Jai, B. K., V. K. Soni and H. K. Chandraker. 2020. Surveillance of pod borer, *Helicoverpa armigera* (Hubner) and its natural enemies on chickpea at Sahaspur Lohara Blocks. *J. Pharm. Phytochem.* **9**: 1995-2000.

Jerusha E. and S. Thakur. 2018. Integrated approaches for the management of gram pod borer *Helicoverpa armigera* (Hubner) in chickpea. *J. of Entomology and Zoology Studies* **6**(4): 1748-1750.

Kambrekar, D. N. 2012. Management of pod borer in chickpea. The Hindu, http:// www. the hindu.com/scitech/agriculture/management-of-pod-borer in chickpea/article 4143687. ece.

Khalique, F. and K. Ahmed. 2003. Impact of *Bacillus thuringiensis* subsp. *kurstaki* on biology of *Helicoverpa (Heliothis) armigera* Hubner. *Pakistan J. biol. Sci.* **4**:529-534.

Khalique, F. and K. Ahmed. 2001a. Synergistic interaction between *Bacillus thuringiensis* (Berliner) and lanbda-cyhalothrin (Pyrethroid) against chickpea pod borer, *Helicoverpa armigera* (Huebner). *Pakistan J. biol. Sci.* **4**:1120-1123

Khalique, F. and K. Ahmed. 2001b. Toxicity of *Bacillus thuringiensis* Berliner and sub-lethal effect on development of *Helicoverpa (Heliothis) armigera* Hubner. *Pakistan J. biol. Sci.* **4**:529-534.

Khan, S. M., M. Y. Inayatullah and M. A. Khan. 2009. Varietal screening of chickpea and the efficacy of different insecticides against chickpea pod borer *Helicoverpa armigera* (Hb). *Gomal Univ. J. Res.* **25**: 20-24.

Kumar, G. V. S. and O. Sarada. 2015. Field efficacy and economics of some new insecticide molecules against lepidopteran caterpillars in chickpea. *Curr. Biot.* **9**(2): 153-158.

Kumar, A., M. K. Tripathi, U. Chandra and R. Veer. 2019. Seasonal incidence of *Helicoverpa armigera* on chickpea crop in eastern region of Uttar Pradesh. *J. Entomol. Zool. Stud.* **7**(1): 03-05.

Madhu, T. N. 2014. Effect of sex pheromone traps against chickpea pod borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). MS Thesis, Department of Agricultural Entomology, University of Agricultural Sciences, Bengaluru, India. 107 p.

Mahmudunnabi, M., N. K. Dutta, A. K. M. Z. Rahman and S. N. Alam. 2013. Development of biorational-based integrated pest management package against pod borer, *Helicoverpa armigera* Hubner infesting chickpea. *J. Biopest.* **6**(2): 108-111.

Pagidala, S. and A. Kumar 2024. Efficacy and economics of selected chemicals and biopesticides against gram pod borer, *Helicoverpa armigera* (Hubner) on chickpea under field condition. *Int. J. of Adv. Biochem. Res.* **8**(8): 653-655.

Patil, S. B., A. Goya, S. Satish, K. Shiv and B. El Bouhssini. 2017. Sustainable management of chickpea pod borer. A review. *Agron. Sustain. Dev.* **37**: 20.

Rahman, M. M., N. K. Dutta, M. A. Sarkar, M. Nuruzzaman and M. R. Islam. 2025. Managing the invasion threat of rugose spiraling whitefly (*Aleurodicus rugioperculatus* Martin, Hemiptera: Aleyrodidae) in coconut plantations through surveillance and biorational strategies. *Appl. Fruit Sci.* **67**:1–12.

Rahman. M. M., T. Ahamed, M. A. R. Khan, M. Nuruzzaman, M. R. Islam, M. A. Sarkar and N. K. Dutta. 2023. Combined use of sticky traps and biopesticides as a sustainable tool to manage *Aleurocanthus rugosa* (Hemiptera: Aleyrodidae) infesting betel vine. *Crop. Prot.* **172**:106299.

Rashid, M. A., S. N. Alam, F. M. A. Rouf and S. N. Taleker. 2003. Socio-economic parameters of eggplant pest control in Jessore District of Bangladesh. *AVRDC Technical Bull*. **29**:1-54.

Rashid, M. H., N. K. Dutta, M. A. Sarkar, M. A. Zahid and A. K. Saha. 2021. Sustainable management options against whitefly, whitefly-vectored begomoviruses and fruit worm in tomato. Annual Research Report, 2020-2021, Entomology Division, BARI, Gazipur. 309 p.

Sarkar, M. A., N. K. Dutta, K. Begum, A. K. M. R. H. Ferdous and D. Sarker. 2021. Evaluation of new dimension management options against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee. Annual Research Report, 2020-2021, Entomology Division, BARI, Gazipur. 309 p.

Sarkar, M. A., M. A. Hossain, M. A. Rahman, J. A. Chowdhury and M. M. Ud-deen. 2006. HANPV: An effective biopesticide to control chickpea pod borer (*Helicoverpa armigera* Hubner) in Bangladesh. *Bangladesh J. Entomol*. **16**(1): 37-44.

Singh A. K. and K. Amit. 2012. Evaluation of new molecules in IPM modules against *Helicoverpa armigera* (Hubner) in chick pea. *Ann. of Pl. Protec. Sci.* **20**(1): 19-23.

Singh, P. S., R. K. Shukla and N. K. Yadav. 2013. Bio-efficacy of some insecticides against *Helicoverpa armigera* (Hubner) on chickpea (*Cicer arietinum*). *J. of food legumes* **25**(4): 291-293.

Sharma P. K., U. Kumar, S. Vyas, S. Sharma and S. Shrivastava. 2012. Monitoring of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) through pheromone traps in chickpea *Cicer arietinum* crop and influence of some abiotic factors on insect Population. *J. Environ. Sci*. **1**: 44-46.

Sreekanth, M., M. S. M. Lakshmi and Y. K. Rao. 2014. Bio-Efficacy and economics of certain new insecticides against gram pod borer, *Helicoverpa armigera* (Hubner) infesting Pigeonpea (*Cajanus cajan* L.). *Int. J. Plant Anim. Environ. Sci.* **4**(1): 11-15.

Tiwari, R. V. and K. Sehgal. 2007. Field efficacy of some insecticides and *Bt* against *Helicoverpa armigera* on chickpea. *Pantnagar J. of Res.* **5**(2):53-58.

Tushar, B. J., M. V. Ugale and S. P. Nagwe. 2020. Effect of different biopesticides and insecticides treatments on chickpea (*Cicer arientinum*) for management of *Helicoverpa armigera* (Hubner). *J. Pharmacogn. Phytochem.* **9**(5): 373-378.

Ujjan, R. L., A. M. Ahmed, A. Z. A. Alhilfi, F. N. Khoso, A. M. Rahoo, I. A. Rajput and D. M. Soomro. 2019. Performance of pheromone traps at different heights for mass trapping of *Helicoverpa armigera* (Noctuidae: Lepidoptera) in chickpea field. *Asian J. Agric. Biol.* **7**: 610-616.

Visalakshmi, V., G.V.R. Rao and P. A. Rao. 2005. Integrated pest management strategy against *Helicoverpa armigera* Hubner in chickpea. *Indian Journal of Plant Protection* **33**(1):17-22.

Wang, M., W. Wu, Z. Jinbo, W. Zhu, Z. Hu and Ji. Zhaonong. 2001. Five new insecticidal sesquiterpenoids from *Celastrus angulatus*. *J. of Natural Products* **64**(3): 364-367. doi: 10.1021/np0004193. PMID: 11277758.

Wei, S. P., J. I. Zq and J. W. Zhang. 2009. A new insecticidal sesquiterpene ester from *Celastrus angulatus*. *Molecules* **14**(4):1396-1403.

Witzgall, P., P. Kirsch and A. Cork. 2010. Sex pheromones and their impact on pest management. *J. Chem. Ecol.* **36**(1):80-100.

Zohary, D., M. Hopf and E. Weiss. 2012. Domestication of plants in the old world: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin. Oxford University Press. https://doi.org/10.1093/acprof:osobl/978019 9549061.001.0001.

ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 51(1): 583-603, March 2026

GENETIC DIVERSITY IN STEM AMARANTH BASED ON PRINCIPAL COMPONENT, CLUSTER AND BIPLOT ANALYSES

M. MONIRUZZAMAN[1], M. D. HOSSAIN[2], F. ISLAM[3] AND A. K. M. QUAMRUZZAMAN[4]

Abstract

Genetic diversity is the base line of any breeding program determining the variability of germplasm for crop improvement strategies. Approaches like principal component and cluster analysis measure the amount of genetic diversity in different characters and also assess the relative contribution of different traits to the total variation. This research was carried out at the vegetable research field of Olericulture Division of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh to study the genetic diversity and select the high yielding stem amaranth genotypes using principal component, cluster and biplot analyses. A total of 27 stem amaranth germplasms were evaluated in RCBD with two replications in consecutive two years 2020 and 2021 in summer. Principal component (PC) analysis depicted that first four PCs with Eigen-values higher than unity contributing 81.012% of total variability for different traits among 27 stem amaranth germplasm. The PC1 accounted for 37.833% variation, showed the positive loading effect of stem fresh weight (yield/plant) (0.864), leaf fresh weight (0.728), shoot fresh weight (yield) (0.968), stem dry weight (0.829), leaf dry weight (0.760) and shoot dry weight (0.980). The PC2 accounted for 24.556% of the variation and the major contributing traits were plant height (0.796), relative water content (RWC) (0.723), SPAD value (0.759) and F_v/F_m (0.694). The PC3 accounted 10.95% of the variation, and traits with high positive loading effects were observed for number of leaves/plant (0.595) and leaf area/plant (0.727). Regarding the first two PCs, germplasms were differentiated into five diverse groups. On biplot, two germplasm i.e. AM65 and AM72, were in positive side and positioned far away from the origin and were considered as diverse from the others. Cluster analysis grouped all germplasms into five clusters. The germplasms in clusters-IV and V exhibited higher stem diameter, stem fresh weight, leaf fresh weight, shoot fresh weight as well as their corresponding dry weight. The four characters *viz.,* stem diameter, stem fresh weight, stem dry weight and shoot dry weight showed maximum contribution to total divergence among 13 characters studied. The D^2 statistics confirmed the maximum inter-cluster distance between cluster-III and V followed by cluster-III and-IV, whereas the smallest inter cluster distance between clusters - I and II. Crossing between the germplasm of Cluster- III with Cluster -V and Cluster-III

---

[1]Chief Scientific Officer, Plant Physiology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, [2]Chief Scientific Officer, Research Wing, BARI, Gazipur, [3]Ex-Director General, BARI, Isurdi, Pabna, and [4]Chief Scientific Officer, Olericulture Division, HRC, BARI, Gazipur, Bangladesh.

with Cluster-IV could result better genetic recombinant and might exhibit better heterosis in F_1 for hybrid development. Selection of superior germplasm from different clusters could be used in future crop improvement program.

Keywords: Stem amaranth, *Amaranthus* spp, cluster analysis, principal component analysis, eigen value, stem diameter, stem fresh weight.

Introduction

Stem amaranth (*Amaranthu*s spp.), an important vegetable of the family Amaranthaceae is popularly known as 'danta' grown throughout Bangladesh. It is mainly grown during summer and rainy season. This vegetable is very popular in Bangladesh for its quick and vigorous growth and also for higher yield potential. Its tender stem with young leaves is used as vegetables. It is widely cultivated in Bangladesh, India, in tropical and subtropical parts of Asia, Africa and Central America (Hardwood, 1980).

Most amaranths, grain, vegetable and weedy species are diploids with 2n= 2x = 32 or 2n = 2x= 34 chromosomes. *Amaranthus dubius* is the only known naturally occurring tetraploid species in the genus *Amaranthus*, with a chromosome count of 2n=4x=64. *A. dubius* is characterized as an allotetraploid, meaning it likely originated from the hybridization of two different ancestral species followed by chromosome doubling (Greizerstein and Poggio,1994).

Amaranthus is monoecious and self-pollinating crop but outcrossing rate (5-39%) is sufficient to facilitate the gene flow in the population. Amaranth inflorescence consists of both male and female flowers (Sagar *et al*., 2023). Among the 70 species of *Amaranthus*, 17 are cultivated for edible leaves, and 3 are cultivated as food grains (Jensen, 1978). Amaranth leaves and stems are good economic sources of carotenoids, proteins, including the essential amino acids methionine and lysine, dietary fiber and minerals, such as magnesium, calcium, potassium, copper, phosphorus, zinc, iron, and manganese (Sarker *et al.*, 2014; Sarker and Oba, 2019). Amaranth leaves are anti-cancerous, it stops the irregular growth of cancer cells in the breast, colon, and liver, thus are also suitable for cancer patients (Hongyan *et al*., 2015). Besides its nutritional potential, vegetable amaranth is resistant to diseases and tolerant of extreme heat and drought (Rastogi and Shukla, 2013; Barrio and Anon, 2010). Unlike many other green vegetables, it thrives without the need for cold or specific climates, making it cultivable during the summer when other green leafy vegetables are scarce in the market (Rastogi and Shukla, 2013).

As an underutilized and genetically promising orphan crop, limited attention has been dedicated to the genetic improvement of this plant. To develop high-yielding varieties, crop improvement initiatives require genetic within the existing germplasm. Moreover, the relation of characters with yield, the extent of environmental influences on these traits and the heritability of the characters are essential (Devi *et al*., 2015).

Multivariate analyses like principal component analysis (PCA) and clustering are commonly employed to elucidate genetic variation (Hair *et al*., 1995). Morpho-physiological traits serve as key indicators for identifying genetic diversity within and among populations, as well as for assessing genetic similarities and differences (Hunter, 1993). Addressing diversity in plant breeding is essential, especially considering geographical isolation and genetic barriers (Rauf *et al.*, 2010). The cultivation of appropriate stem amaranth varieties under various agro-climatic conditions is vital for both domestic consumption and exportation. Genetic divergence analysis, utilizing techniques like Euclidean distance and Mahabalonis' D^2 values aids in grouping genotypes to ascertain their degree of variation (Bhatt *et al*., 2015). Cluster analysis categorizes genotypes based on measured variables, grouping similar ones together. Clustering involves segregating genotypes into clusters with strong internal associations and weak associations between different clusters (Crossa and Franco, 2004). Principal component analysis identifies variables and characterizes traits along differentiation axes (Sharma *et al*., 2016), assisting in the examination of genetic divergence, identification of promising cultivars, and evaluation of trait importance in total genotype variation (Jollife, 1986). Besides, variability is essential for any plant breeding program. A new variety as per requirement of the farmers can be developed from an assembled diverse genetic stocks of any crops. So success of any breeding program depends much on the genetic variability available to the breeder and judicious selection of parents. Tomoko (1991) reported that evaluation of genetic diversity is important to know the source of gene for a particular trait within the available germplasm. So, the breeder must have clear understanding about the nature and magnitude of variability among the collected genetic stocks. There is little information regarding divergence study as well as breeding work in stem amaranth in Bangladesh. This study was, therefore, carried out to estimate the genetic diversity among 27 stem (vegetable) amaranth germplasms using cluster analysis through principal component analysis (PCA) based techniques for selection of parents and to identify potential morpho-physiological traits that are better employed as selection criteria for developing high yielding vegetable amaranth germplasm which may help breeders to breed better yielding new stem amaranth varieties.

Materials and Methods

Twenty-seven germplasms of amaranth (Table 2) were studied in a two-replicated trial placed in plastic shed conditions of vegetable research field, Horticulture

Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI) in 2020(16 July 2020 to 28 August 2020) and 2021 (07 July 2021 to 19 August 2021) for 44 days. One hundred sixty- two pots (Height-29 cm, top dia-32 cm and bottom dia-21 cm; capacity 14 L) were used for this experiment. At first, soil collected from Kodda, Kalikoir Upzilla, Gazipur district, was prepared by cleaning all pieces of bricks, stones and other foreign materials and then soil was air dried. Seven kilograms of air-dried soil was mixed with 4 kg cowdung, 5 g Urea, 6 gm TSP, 6 g MoP, 3 g Gypsum and 1 g boric acid for each pot. The ultimate pot capacity was 11.00 kg soil, while moisture was 16.9%. Before sowing each pot, it was irrigated with 2 L water. At the proper moisture condition a little portion of seeds of different germplasms mixed with some fine loose soil was sown in each pot on 16 July 2020 and 13 July 2021. All the germplasms germinated within 6 days. First thinning was done on 25 July 2020 and 16 July 2021 keeping 10 seedlings/pot. The final thinning was done on 30 July 2020and 22 July 2021 keeping 6 plants/pot. Pots with all treatments were irrigated every three days' interval and continued upto experimentation. Each pot was top-dressed in 5 g Urea at 15 days' interval. Data (from 5 plants) was taken on 13 characters given in Table 1. The SPAD value was taken by SPAD meter (SPAD-500 plus, Minolta Konica Inc, Japan). The changes in fluorescence yield reflect changes in photochemical efficiency and heat dissipation. The polyphasic rise of fluorescence transients was measured by an ADC Infrared Gas Analysis Plant Efficiency Analyzer (PEA, Handsatech Instruments Ltd., King's Lynn, UK). The initial fluorescence (F_0) and maximum fluorescence (Fm) were analyzed and quantum efficiency of open photosystem II centers-quantum yield (F_v/F_m) was calculated. The leaf discs were previously adapted to the dark for 20 minutes. The fluorescence data were collected every day at 10.00 am to 12.00 pm from initial to end of the experiment. F_o is the amount of light absorbed initially to raise the fluorescence from a low level to maximum value Fm after dark adaptation. $F_v = F_m - F_0$ which is the variable. Ratio of F_v/F_m is a dark-adapted test used to determine maximum quantum yield. This ratio is also an estimate of the maximum portion of absorbed quanta used in PSII reaction centers. The plants were divided into stems and leaves, dried at 80°C and weighed.

Relative water content (RWC) was measured using leaves (4^{th} no. leaf from the tip of the plant). Immediately after cutting at the base of lamina, leaves were sealed within plastic bags and quickly transferred to the laboratory. Fresh weights were determined within 2 h after excision. Turgid weights were obtained after soaking leaves in distilled water in plastic bowls for 16 to 18 h at room temperature (about 25°C) and under the low light conditions of the laboratory. During soaking bowls are covered with polythene. After soaking, leaves were quickly and carefully blotted dry with tissue paper in preparation for determining turgid weight. Dry weights were obtained after oven drying the leaf samples for 72 h at 70°C. RWC was calculated from the equation of Schonfeld *et al*. (1988):

$$\% \text{ RWC} = \frac{\text{Fresh weight- dry weight}}{\text{Turgid weight – dry weight}}$$

Leaf area /plant was estimated according to Tongos (2016):

S = aLw, where, a= 0.5, L= length of the leaf blade and W = width of the leaf blade.

Data of 27 genotypes were taken from all pots. Mean values for each data were calculated.Genetic diversity was studied following Mahalanobis' distance (Mahalanobis, 1936) generalized Distance (D^2) extended by Rao (1952). Clustering was done according to Tocher's method (Rao, 1970). Intra and inter cluster distances were calculated by the methods of Singh and Chaudhury (1985).

The effect of levels of the characters determining principal component analysis (PCA) and Correlation Coefficient Analysis, proportion of Eigen values, and the scores of the principal components. PCA and Correlation coefficients were calculated using the XLSTAT statistical analysis program, which is a program that uses the Microsoft Excel infrastructure (XLSTAT, 2020). The dendrogram was built based on agglomerative hierarchical clustering Ward's method using XLSTAT. Principal components with Eigen values greater than one are only considered in the analysis (Chahal and Gosal, 2002).

Table 1. Studied morphological parameters along with SI units

Sl no.	Studied parameters	Abbreviations	SI unit
1.	Plant height	PH	cm
2.	Number of leaves /plant	LN	No.
3.	Leaf area/plant	LA/pl	cm^2
4.	Stem diameter at the base	STDIA	mm
5.	Stem fresh weight	STFW	g
6.	Leaf fresh weight	LFFW	g
7.	Shoot fresh weight	SHFW	g
8.	Stem dry weight	STDW	g
9.	Leaf dry weight	LFDW	g
10.	Shoot dry weight	SHDW	g
11.	Relative water content (leaf)	RWC	%
12.	SPAD value	SPAD	-
13.	Maximum quantum yield of PSII	F_v/F_m	-

Table 2. Studied stem amaranth germplasms along with their seed suppliers

Sl no	Germplasm	Seed supplier	Quantity of seed
1.	AM01	Vegetable division, HRC,	5.0 g
2.	AM02	Vegetable division, HRC, BARI	4.5 g
3.	AM03	Vegetable division, HRC, BARI	5.0 g
4.	BD8278	Plant Genetic Resources Centre, BARI	4.5 g
5.	BD8152	Plant Genetic Resources Centre, BARI	4.5 g
6.	AM51	Vegetable division, HRC, BARI	5.0 g
7.	AM53	Vegetable division, HRC, BARI	5.0 g
8.	AM54	Vegetable division, HRC, BARI	5.0 g
9.	AM55	Vegetable division, HRC, BARI	5.0 g
10.	AM57	Vegetable division, HRC, BARI	5.0 g
11.	AM58	Vegetable division, HRC, BARI	5.0 g
12.	AM61	Vegetable division, HRC, BARI	5.0 g
13.	AM62	Vegetable division, HRC, BARI	5.0 g
14.	AM63	Vegetable division, HRC, BARI	5.0 g
15.	AM64	Vegetable division, HRC, BARI	5.0 g
16.	AM65	Vegetable division, HRC, BARI	5.0 g
17.	AM66	Vegetable division, HRC, BARI	5.0 g
18.	AM67	Vegetable division, HRC, BARI	5.0 g
19.	AM68	Vegetable division, HRC, BARI	5.0 g
20.	AM69	Vegetable division, HRC, BARI	5.0 g
21.	AM71	Vegetable division, HRC, BARI	5.0 g
22.	AM72	Vegetable division, HRC, BARI	5.0 g
23.	AM73	Vegetable division, HRC, BARI	5.0 g
24.	AM75	Vegetable division, HRC, BARI	5.0 g
25.	AM77	Vegetable division, HRC, BARI	5.0 g
26.	AM78	Vegetable division, HRC, BARI	5.0 g
27.	AM79	Vegetable division, HRC, BARI	5.0 g

Note: AM01 = BARI Danta-1 (check); AM = Amaranthus, BD = Bangladesh, HRC = Horticulture Research Centre, BARI = Bangladesh Agricultural Research Institute

Results and Discussions

Summary statistics

Huge variation were observed for plant height, number of leaves/plant, leaf area/plant, stem diameter, stem fresh weight, leaf fresh weight, shoot fresh weight, stem dry weight, leaf dry weight, shoot dry weight, relative water content, SPAD value and F_v/F_m ranged from 44-76 cm, 13.50-20.50 number, 847.15 – 281.79 cm^2, 10.65 - 18.20mm, 20.70-60.25 g, 11.48-28.28 g, 35.10-80.85 g, 5.30-1.86 g, 1.62-3.96 g, 3.81-8.78 g, 82.17-93%, 29.10-42.80 and 0.70-0.78, respectively (Table 3). The difference between maximum and minimum values was found high in leaf area/pant (565.76 cm^2), shoot fresh weight (45.75 g), stem fresh weight (39.55 g), plant height (32 cm), SPAD value (13.7) and relative water content (11.23%). Standard deviation was observed higher in leaf area/pant (144.13), shoot fresh weight (10.91), plant height (9.77), stem fresh weight (9.24 and leaf fresh weight (4.91). Maximum coefficient of variation (CV) was recorded in leaf area/plant (30.75%), followed by stem dry weight (27.70%), leaf fresh weight (27.40%), leaf dry weight (25.69%), stem fresh weight (24.51%), shoot dry weight (22.08%), plant height (15.89%) and stem diameter (15.19%). The results pertaining to range, standard deviation and CV% indicated that germplasm of amaranth under investigation showed a wide range of variability among themselves in respect of leaf area/plant, stem fresh weight, shoot fresh weight, stem dry weight, stem diameter and plant height. Mandal and Dhangrah (2012) also reported variation exists in plant height (31.00-50.00 cm), stem diameter (9.3 mm-30.7 mm), number of leaves/plant (9.40-29.00) and stem fresh weight (yield)/plant (2.20-34.37 g) at 35 days after sowing while evaluating 17 vegetable amaranth genotypes. Shellikeri *et al.* (2022) obtained ranges in plant height (16.66-32.56 cm), stem diameter (3.24-8.76 mm), number of leaves/plant (6.60-12.10), fresh leaf weight (2.45-11.55 g), fresh stem weight (3.16-10.90 g/plant) and fresh green yield (7.16-24.63 g/plant) at 27.00 - 43.00 days after sowing during *kharif* season in 52 vegetable amaranths. Sharma *et al*. (2024) found the ranges in plant height at vegetative stage (15.95-24.54 cm), stem base diameter (10.2-15.8 mm), number of leaves/plant (11.75-22.08) in 22 vegetable amaranth genotypes during summer season. Rashad and Sarker (2020) obtained the ranges in plant height (19.62-32.65 cm), stem diameter (15.19-29.18 mm), leaf/plant (6.14-13.43), leaf area/plant (795.40-1361.10 cm^2) and shoot weight (66.48-131.30 g/plant) in 20 green amaranth genotypes in summer at 30 days after sowing. Shellikeri *et al.* (2022) got CV%: in plant height (6.70%), stem diameter (8.44%), no of leaves/plant (7.98%), Single leaf area (13.01%), fresh leaf weight (15.94%), fresh stem weight (19.21%), fresh green yield (14.55%). Rashad and Sarker (2020) obtained the CV, 12.51, 13.77, 18.54, 17.95 and 18.19% in plant height, stem diameter, leaf/plant, leaf area/plant and shoot weight, respectively.

Table 3. Range, mean, standard deviation and coefficient of variation (CV) in 27 stem amaranth germplasms

Traits	Range			Mean±SE	Std. deviation	CV%
	Minimum	Maximum	Difference			
PH	44.00	76.00	32	61.52±1.88	9.77	15.89
LN	13.50	20.50	7	17.42±0.31	1.61	9.22
LA/pl	281.79	847.15	565.36	468.67±27.74	144.13	30.75
STDIA	10.65	18.20	7.55	14.16±0.41	2.15	15.19
STFW	20.70	60.25	39.55	37.71±1.78	9.24	24.51
LFFW	11.48	28.28	16.8	17.92±0.95	4.91	27.40
SHFW	35.10	80.85	45.75	55.45±2.10	10.91	19.67
STDW	1.86	5.30	3.44	3.17±0.26	0.88	27.70
LFDW	1.62	3.96	2.34	2.50±0.17	0.64	25.69
SHDW	3.81	8.78	4.97	5.66±0.24	1.25	22.08
RWC	82.17	93.40	11.23	89.03±0.66	3.43	3.85
SPAD	29.10	42.80	13.7	36.16±0.68	3.54	9.80
Fv/Fm	0.70	0.78	0.08	0.73±0.006	0.03	4.23

PH = Plant height at harvesting (40 days after sowing), LN = Number of leaves/plant at harvest, LA/plant = Leaf area per plant, STDIA = Stem Diameter at the base, STFW = Stem fresh weight, LFFW = Leaf fresh weight, SHFW = Shoot Fresh weight/ plant (Yield/plant), STDW = Stem Dry Weight, LFDW = Leaf Dry weight, SHDW = Shoot Dry Weight, RWC = Relative Water Content (%), SPAD = SPAD value (Chlorophyll index), F_v/F_m = Maximum quantum yield of PSII

Patterns of correlation among traits

Simple correlation coefficient values demonstrated significant relationships to design breeding strategy (Table 4). Plant height revealed significant positive correlation with relative water content (RWC) (0.385*), SPAD value (0.711**) and Fv/Fm (Maximum quantum yield of PSII) (0.399*) (Table 4; Fig. 1). Number of leaves/plants had significant correlation with SPAD value (0.374*). However, it had significant negative association with leaf fresh weight (-0.442*) and leaf dry weight (-0.436*). Leaf area/plant showed no significant correlation with any of the characters studied. Stem diameter displayed highly significant and positive correlation with stem fresh weight (0.424**), stem dry weight (0.469**), shoot fresh weight (0.473**), and shoot dry weight (0.457**). Stem fresh weight and leaf fresh weight had significant and positive correlation with shoot fresh weight (0.909** and 0.676**), leaf dry weight (0.387* and 0.995*) and shoot dry weight (0.851** and 0.673**). Stem fresh weight displayed highly significant and positive association with stem dry weight (0.914**), but leaf fresh weight did not show correlation with stem dry weight. Shoot fresh weight demonstrated highly significant and positive correlation with stem dry weight (0.820**), leaf dry weight

(0.699**) and shoot dry weight (0.937**). Stem dry weight and leaf dry weight had highly significant and positive association with shoot dry weight (0.880** and 0.715). RWC displayed significant and positive correlation with SPAD value (0.467*) and Fv/Fm (0.656**). SPAD value showed significant and positive correlation with F_v/F_m (0.306*).

Principal Component Analysis

Principal component analysis (PCA) is one of the multivariate statistical techniques which is a powerful tool for investigating and summarizing underlying trends in complex data structures (Legendre and Legendre, 1998). The results of principal component analysis for thirteen traits of 27 stem amaranth germplasm are presented in Table 5. The variation among 27 germplasms was assessed through principal component analysis based on the physio-morphological traits. Principal components (PCs) with Eigen values greater than unity, and factor loadings greater than ± 0.500were meaningful and valuable. The first four principal components (PCs) accounted 81.012% of the total variation and the first principal component alone explained ~~(~~37.833% of the total variation having Eigen value of 4.918 (Fig. 1 and Table 5). The variation in principal component ~~(1)~~ ~~(~~PC1~~)~~ was mainly due to the positive loading effect of stem fresh weight (0.864), leaf fresh weight (0.728), shoot fresh weight (yield) (0.968), stem dry weight (0.829), leaf dry weight (0.760) and shoot dry weight (0.980). The second principal component had an eigen value of 3.912 and accounted for 24.556% of the variation and the major contributing traits were plant height (0.796), relative water content (RWC) (0.723), SPAD value (0.759) and F_v/F_m (0.694). The third principal component had an Eigen value of 1.371 and accounted for 10.95% of the variation, and traits with high positive loading effects were observed for number of leaves/plant (0.595) and leaf area/plant (0.727). In the fourth principal component, it had an Eigen value of 1.050 and accounted (8.074%) of the variation, traits with high and positive loading effect were F_v/F_m (0.582). Table 6also revealed that the first 4 principal components had most contribution to 27 stem amaranth genotypes. From PC1 it was seen that stem fresh weight (0.746), leaf fresh weight (0.530), shoot fresh weight (0.937), stem dry weight (0.687), leaf dry weight (0.578) and shoot dry weight (0.961), from PC2, plant height (0.634), RWC (%) (0.523), SPAD value(0.575) and F_V/F_m (0.481),from PC3 (leaf no./plant (0.354) and leaf area/plant (0.529) showed higher squared cosine values which also proved that plant height, leaf no./plant, leaf area/plant (cm^2), stem fresh and dry weight, leaf fresh and dry weight, shoot fresh and dry weight, RWC (%), SPAD value and Fv/Fm ratio had greater contribution to genetic divergence. Sharma *et al*. (2024) found 5 principal components when eigen values>1 during evaluating 22 vegetable amaranth genotypes in summer season.

Table 4. Correlation (Pearson) matrix showing correlation among studied traits in 27 stem amaranth germplasms

Variables	PH	LN	LA/pl	STDIA	STFW	LFFW	SHFW	STDW	LFDW	SHDW	RWC	SPAD	F_v/F_m
PH	**1**												
LN	0.314	**1**											
LA/Pl	-0.133	0.142	**1**										
STDIA	0.300	-0.081	0.065	**1**									
STFW	0.248	-0.093	0.213	0.473*	**1**								
LFFW	-0.251	-0.442*	0.197	0.182	0.351	**1**							
SHFW	0.042	-0.244	0.277	0.424**	0.909**	0.676**	**1**						
STDW	0.286	-0.046	0.275	0.469**	0.914**	0.253	0.820**	**1**					
LFDW	-0.200	-0.436*	0.211	0.202	0.387*	0.995**	0.699**	0.305	**1**				
SHDW	0.110	-0.255	0.309	0.457**	0.851**	0.673**	0.937**	0.880**	0.715**	**1**			
RWC	0.385*	0.072	-0.315	0.198	0.093	-0.170	-0.026	0.326	-0.108	0.189	**1**		
SPAD	0.711**	0.374*	-0.322	0.127	0.116	-0.207	-0.049	0.163	-0.164	0.035	0.467*	1	
F_v/F_m	0.399*	0.139	-0.059	0.061	0.043	-0.300	-0.060	0.325	-0.241	0.131	0.656**	0.306*	1

'*"& '**' indicate significant at P<0.01& P<0.05, respectively. Figures with esterix sign are non-significant.PH = Plant height at harvesting (40 days after sowing), LN = Number of leaves/plant at harvest, LA/plant = Leaf area per plant, STDIA = Stem Diameter at the base, LFFW = Leaf fresh weight, SHFW = Shoot Fresh weight/plant (Yield/plant), STFW = Stem Fresh Weight, STDW = Stem Dry weight, LFDW = Leaf Dry weight, SHDW = Shoot Dry Weight, RWC = Relative Water Content (%), SPAD = SPAD value (Chlorophyll index), F_v/F_m = Maximum quantum yield of PSI.

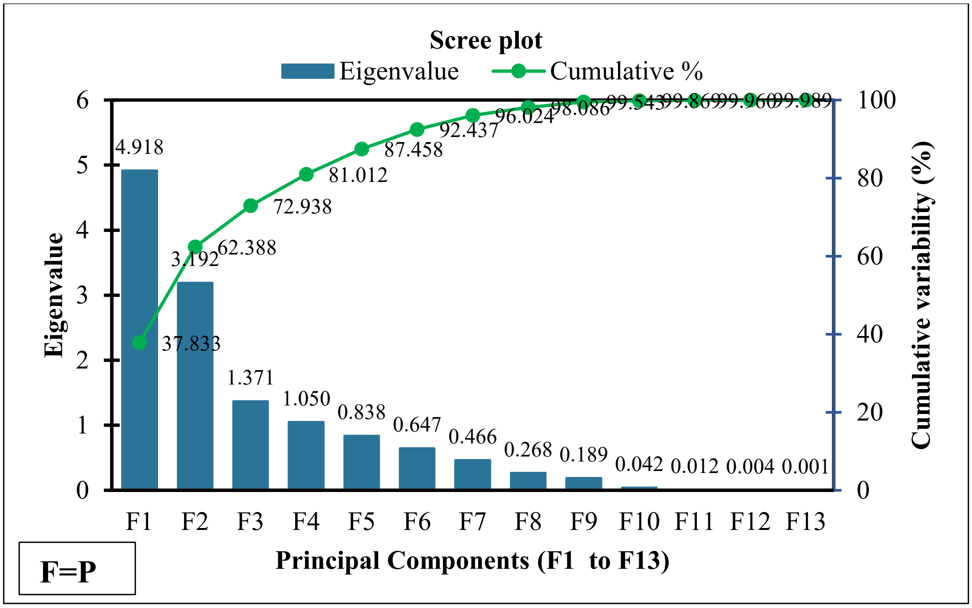


Fig. 1. Graphical representation of Eigenvalues with cumulative variability.

Table 5. Factor loadings, variance explained and Eigen values of thirteen traits and twenty-seven (27) stem amaranth germplasms evaluated at vegetable research field of HRC, BARI

Traits	PC1	PC2	PC3	PC4
Plant height (cm)	0.074	0.796	0.039	-0.358
Leaf No./plant	-0.316	0.436	0.595	-0.240
Leaf area/plant (cm^2)	0.319	-0.241	0.727	0.244
Stem diameter (mm)	0.516	0.295	0.016	-0.168
Stem fresh weight (g)	0.864	0.248	0.212	-0.052
Leaf fresh weight (g)	0.728	-0.477	-0.293	-0.172
Shoot fresh weight (g)	0.968	-0.028	0.079	-0.051
Stem dry weight (g)	0.829	0.415	0.195	0.200
Leaf dry weight (g)	0.760	-0.415	-0.297	-0.148
Shoot dry weight (g)	0.980	0.102	-0.008	0.085
Relative water content (RWC) (%)	0.077	0.723	-0.429	0.323
SPAD value	-0.030	0.759	-0.155	-0.478
Fv/Fm	0.004	0.694	-0.123	0.582
Eigen value	4.918	3.912	1.371	1.050
Variability (%)	37.833	24.556	10.550	8.074
Cumulative variability (%)	37.833	62.388	72.938	81.012

Table 6. Squared cosines of 13 characters by 4 principal components (PC) in 27 stem amaranth germplasms

Traits	PC1	PC2	PC3	PC4
Plant height (cm)	0.005	**0.634**	0.001	0.128
Leaf no./plant	0.100	0.190	**0.354**	0.058
Leaf area/plant (cm^2)	0.102	0.058	**0.529**	0.060
Stem diameter (mm)	0.266	0.087	0.000	0.028
Stem fresh weight (g)	**0.746**	0.062	0.045	0.003
Leaf fresh weight (g)	**0.530**	0.227	0.086	0.030
Shoot fresh weight (g)	**0.937**	0.001	0.006	0.003
Stem dry weight (g)	**0.687**	0.172	0.038	0.040
Leaf dry weight (g)	**0.578**	0.172	0.088	0.022
Shoot dry weight (g)	**0.961**	0.010	0.000	0.007
Relative water content (RWC) (%)	0.006	**0.523**	0.184	0.104
SPAD value	0.001	**0.575**	0.024	0.229
Fv/Fm	0.000	**0.481**	0.015	0.339

Cluster analysis

Cluster analysis was conducted following the agglomerative hierarchical clustering Ward's method, in order to categorize germplasm into different homogeneous groups. Cluster analysis classified the 27-stem amaranth germplasm into five distinct clusters (Table 7 and Figures 2 & 3). These findings indicated the presence of diversity among the germplasms tested. Cluster-III was the largest cluster which consisted of 9 germplasm~~s~~ (33.33%) followed by cluster-II (7 germplasms) (25.92%), cluster-I (5 germplasms) (18.52%) cluster-IV (4 germplasms) (14.81%), respectively. While cluster-V had the lowest number of germplasms that comprised 2 germplasms (7.41%). Similar findings were observed in stem amaranth genotypes by different researchers. Akhter *et al*. (2013) reported that 17 stem amaranth genotypes grouped into four distinct clusters like cluster-IV, cluster-II, cluster-III and Cluster-I having 6, 5, 3 and 1 genotypes, respectively. Ahammed *et al*. (2013) observed 22 genotypes were grouped into four distinct clusters for 13 characters. Joshi and Rana (1995) also reported that 20 grain amaranth genotypes were grouped into nine clusters for 11 characters. Yeshitila *et al.* (2023) obtained five clusters for 120 genotypes using 24 characters and 67amaranth germplasms were grouped into 12 clusters (Rani *et al*., 2020). Twenty-two vegetable amaranth genotypes were clustered into four distinct groups for 14 characters (Sharma *et al*., 2024).

Table. 7. The distribution of 27 stem amaranth germplasm into five clusters based on Euclidean distance

Cluster number	Number of germplasms	List of germplasms in a cluster
1	5 (18.52%)	Am01, AM02, AM03, AM62 and AM63
2	7 (25.92%)	BD8278, BD8152, AM51, AM53, AM54, AM61 and AM64
3	9 (33.33%)	AM55, AM57, AM66, AM67, AM73, AM75, AM77, AM78 and AM79
4	4 (14.81%)	AM58, AM68, AM69 and AM71
5	2 (7.41%)	AM65 and AM72

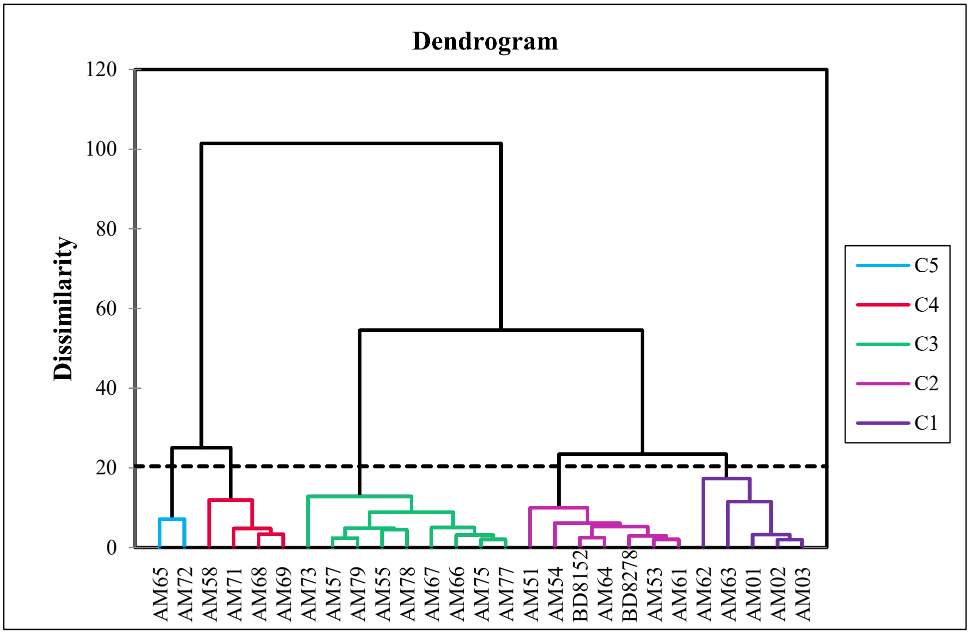


Fig. 2. Dendrogram of 27 germplasms of stem amaranth based on evaluation of 13 traits.

C1 = Cluster-I, C2 = Cluster-II, C3 = Cluster-III, C4 = Cluster-IV and C5 = Cluster-V

Analysis of inter and intra cluster distance

The results of intra and inter-cluster distance analysis are shown in Table 8. The average intra-cluster distance was the highest in cluster-II (D^2 =8.61) followed by Cluster -V (D^2 =4.856) and the lowest in cluster-III (D^2 =0.882). The maximum inter-cluster distance was observed between cluster-III and V (D^2 =59.172) followed by cluster-III and IV (D^2 = 41.197) and Cluster- I and V (D^2=37.655), whereas, the smallest inter cluster distance was recorded in between clusters-I and II (D^2=9.559) followed by clusters-II and IV (D^2=18.122) and clusters - I and IV (D^2=19.681). It is distinguished that the greater the distance between clusters, the wider the genetic diversity would be between the genotypes. Thus, the largest inter-cluster distance indicates the existence of wide proximity between these clusters as compared with other clusters. Hence, crossing genotypes between these two clusters could result better genetic recombinant. The minimum inter-cluster distances had the lowest degree of divergence between clusters showed that the genotypes were relatively close to each other than genotypes grouped in other clusters. This indicated that the existence of closer proximity between these clusters as compared with other clusters. Consequently, strategic hybridization between these two clusters is now encouraged to exploit heterosis, as increased genetic distance between parental lines is often positively correlated with hybrid vigor and transgressive segregation (Fujimoto *et al*., 2018).

Therefore, the germplasm falling in clusters between Clusters-III and V, between clusters - III and IV were genetically most divergent. The inter-cluster distances were greater than intra-cluster distances, revealing considerable amount of genetic diversity among the genotypes studied (Table 8).

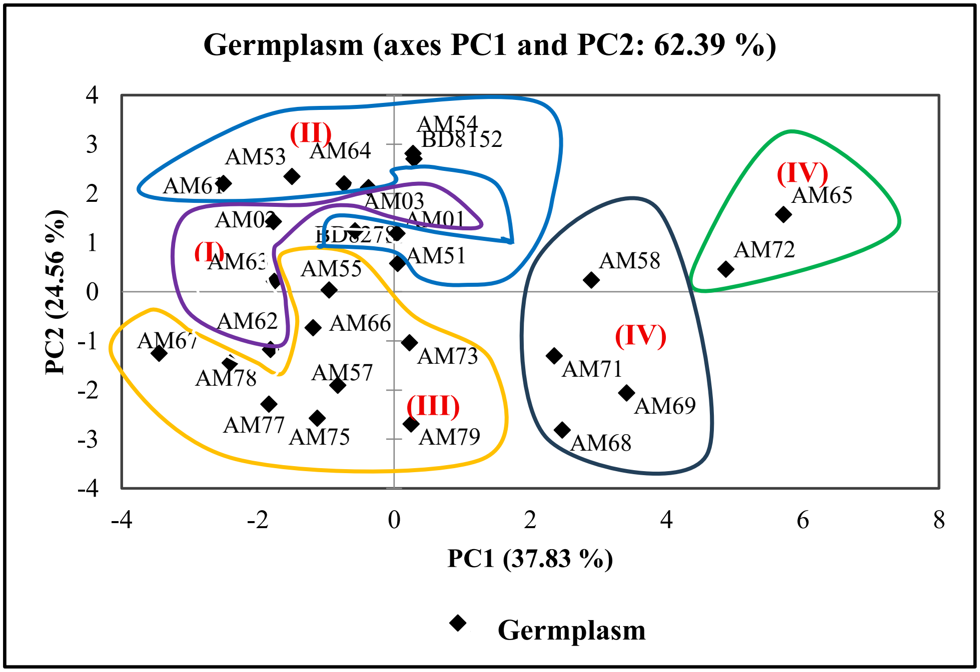


Fig. 3. Scatter distribution of 27 stem amaranth germplasms based on their principal component scores super imposed with clustering.

I = Cluster-I, II = Cluster-II, III = Cluster-III, IV = Cluster-IV and V = Cluster-V.

Table. 8. Intra (bold) and inter-cluster distances (off bold) (D^2) of 27 stem amaranth germplasms

Cluster	I	II	III	IV	V
I	**2.2258**				
II	1.55898	**8.61**			
III	21.5166	23.0756	**0.8822**		
IV	19.6805	18.1215	41.1971	**2.30924**	
V	37.6549	36.096	59.1716	17.9745	**4.85591**

Cluster mean analysis

The mean values of five clusters for 13 different traits revealed considerable differences among the clusters of 27 amaranth germplasms (Table 9). For most traits germplasms grouped in cluster -V had the maximum cluster mean values followed by genotypes assigned in cluster- I, cluster-II and cluster-IV. Minimum cluster mean values was observed in Cluster-III, for leaf area/plant (395.17 cm^2), stem diameter (13.23mm), stem fresh weight (31.74 g), shoot fresh weight (50.13 g), stem dry weight (2.40 g), shoot dry weight (4.41g) and F_v/F_m (0.703). Thus, the cluster mean analysis indicated that, genotypes in cluster-V had the maximum value of stem diameter (17.50 mm), stem fresh weight (58.30 g), leaf fresh weight (25.56 g), shoot fresh weight (79.78 g), stem dry weight (5.06 g), leaf dry weight 3.57 g), shoot dry weight (8.63 g), relative water content (93.31%) and SPAD value (39.10). Whereas, the second largest number for stem diameter (14.42 mm), stem fresh weigh (44.25 g), leaf fresh weight (24.17 g), shoot fresh weight (67.80 g), stem dry weight (3.82 g), leaf dry weight (3.31 g) and shoot dry weigh (7.13 g), the lowest plant height (57.62 g), leaf no./plant (15.20), RWC (87.24%), SPAD Value (33.63) and the highest leaf area/plant (589.30 cm^2) in cluster- -IV. Cluster -I had the highest value for plant height (67.70 cm), leaf no./plant (19.30), 2^{nd} highest for RWC (91.08%) and SPAD value (38.43) and the lowest for leaf fresh weight (13.77 g) and leaf dry weight (1.96 g). Cluster-II had the highest Fv/Fm (0.771).

Table 9. Cluster means for 13 traits of 27 stem amaranth germplasms

Traits	Cluster-I	Cluster-II	Cluster -III	Cluster- IV	Cluster-V
Plant height (cm)	67.70	67.50	63.89	57.62	67.25
Leaf no./plant	19.30	18.24	16.67	15.20	17.75
Leaf area/plant (cm^2)	500.39	454.65	395.17	589.30	528.00
Stem diameter (mm)	14.18	14.25	13.23	14.42	17.50

Traits	Cluster-I	Cluster-II	Cluster -III	Cluster- IV	Cluster-V
Stem fresh weight (g)	38.42	35.27	31.74	44.25	58.30
Leaf fresh weight (g)	13.77	14.87	18.12	24.17	25.56
Shoot fresh weight (g)	52.24	50.56	50.13	67.80	79.78
Stem dry weight (g)	3.02	3.37	2.40	3.82	5.06
Leaf dry weight (g)	1.96	2.15	2.47	3.31	3.57
Shoot dry weight (g)	4.98	5.57	4.81	7.13	8.63
Relative water content (RWC) (%)	91.08	89.25	87.43	87.24	93.31
SPAD value	38.43	37.99	33.96	33.63	39.10
F_v/F_m	0.721	0.771	0.703	0.706	0.736

Biplot analysis

In Biplot analysis, the first two PCs F1 and F2 that had Eigenvalues greater than three (4.918 and 3.192), respectively and contributing 62.39% variability (Fig. 1 and Table 5). Germplasms that are closely located on biplot, perceived as alike when rated on given attributes. More the distance between the point of origin and germplasms, more diverse the genotypes will be from others. Regarding the first two PCs, genotypes were differentiated into five diverse groups (Figure1 and Table 5). Two germplasm i.e. AM65 and AM72 were positioned far away from the origin and were considered as diverse from the others and they fell under group five (Fig. 4). Remaining genotypes were clustered into three groups. Germplasms, namelyAM01, AM02, AM03, AM62 and AM63 were clustered together and closer to origin as well, hence, these germplasms were less diverse and had less breeding value and fell under first group. Genotypes *viz.*, BD8278, BD8152, AM51, AM53, AM54, AM61 and AM64 formed the 2nd group while genotypesAM55, AM57, AM66, AM67, AM73, AM75, AM77, AM78 and AM79 were differentiated from the rest of the genotypes and clustered in third group. The fourth group had only 4germplasms i.e. AM58, AM68, AM69 and AM71. It is shown that Biplot analysis had similar result to dendrogram (Fig. 2).

The graphic in which the biplot of stem amaranth germplasm were combined with the examined morpho-physiological characteristics was given in Figure 5. In this graph, wide angles >90^0, had a negative relationship, while there was no correlation between right angles. On the other hand, similarly the Euclidian distances between cultivars were used to calculate in dry beans (Adams, 1977). When the biplot was examined (Fig. 9), there was a positive relationship between the narrow-angled features, for example STDI with STDW, STFW with STDW, SHFW with SHDW, PH with SPAD etc. Right angled features were not related to each other for example SHDW with SPAD value, etc. Wide angle features had negative relationships with each other for example LFDW with LN, SHDW with LN etc. The above relationships in biplot were proved by correlation matrix of those characters (Table 4). The biplot technique enables the determination of the relationships between the variables as well as the detailed description of a multivariate data set (Yan and Rajcan, 2002).

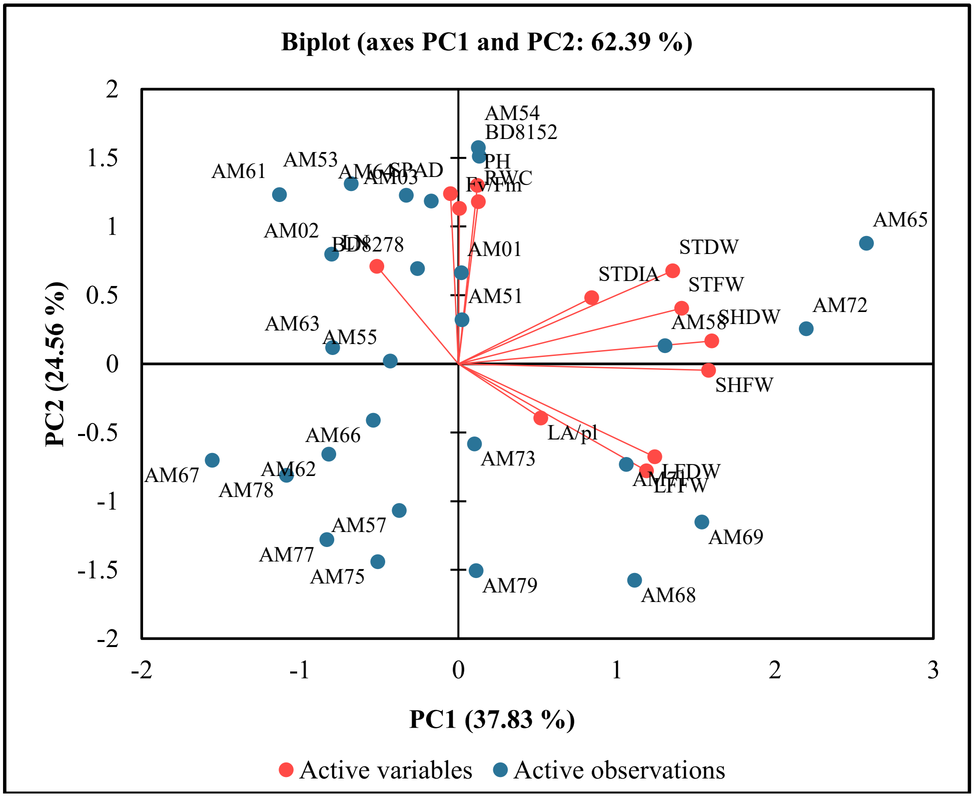


Fig. 4. Principal Component Analysis (PCA) biplot of the morpho-physiological characteristics of 27 stem amaranth germplasms for the first two principal components.

Active variables: Characteristics; Active observations: Stem amaranth germplasm

Contribution of the characters towards divergence of the 27 stem amaranth germplasm

The results of PCA revealed that in vector I the important characters responsible to genetic divergence in the major axis of differentiation were leaf area/plant (0.144), leaf fresh weight (0.328), shoot fresh weight (0.436), leaf dry weight (0.343) having positive vector values (Table 10) which played a major role while rest of the characters played a minor role in the 1st axis of differentiation (Table

10). While in vector II which was second axis of differentiation, plant height (0.446), number of leaves/plant (0.244), RWC (0.405), SPAD value (0.425) and F_v/F_m (0.388) having positive vector values played a major while rest of the characters played a minor role in the 2nd axis of differentiation. The role of stem diameter (0.233 in vector I and 0.165 in vector II), stem fresh weight (0.389 in vector I and 0.139 in vector II), stem dry weight (0.374 in vector I and 0.232 vector II) and shoot dry weight (0.442 in vector I and 0.057 in vector II) in both the vectors indicated that important components of genetic divergence among 27 germplasm of stem amaranth. These results are in partial agreement with the results of Ahammed *et al*., 2013).

Table 10. Latent vectors for 13 principal characters of stem amaranth germplasms

Traits	Vector I	Vector II
Plant height (cm)	0.033	0.446
Leaf no./plant	-0.142	0.244
Leaf area/plant (cm^2)	0.144	-0.135
Stem diameter (mm)	0.233	0.165
Stem fresh weight (g)	0.389	0.139
Leaf fresh weight (g)	0.328	-0.267
Shoot fresh weight (g)	0.436	-0.016
Stem dry weight (g)	0.374	0.232
Leaf dry weight (g)	0.343	-0.232
Shoot dry weight (g)	0.442	0.057
Relative water content (RWC) (%)	0.035	0.405
SPAD value	-0.014	0.425
F_v/F_m	0.002	0.388

Conclusion

The genetic diversity within a crop like stem amaranth is crucial for its improvement in stem yield. By identifying distinct clusters, researchers can identify germplasm with unique traits that could be valuable for breeding programs aimed at enhancing yield. The present study was an attempt to estimate the genetic divergence of 27 stem amaranth germplasms collected from different parts of Bangladesh. The results revealed germplasm had a significant level of genetic divergence. Cluster and PCA analysis were used to divide the stem amaranth germplasm into five groups. Cluster- I and II were determined to be closest, while clusters-III and had the greatest maximum distance followed by clusters -III and IV. These clusters had more divergent germplasms and highly divergent germplasms would provide a wide range of variability, allowing the crop improvement. Therefore, crossing between the germplasm ~~of~~ Cluster-III with those of Cluster -V (Cluster-III × Cluster-V) and Cluster-III with those of Cluster-IV

(Cluster-III × Cluster IV) would exhibit better heterosis and also likely to produce new recombinants with desired characters in stem amaranth.

References

Adams, M. W. 1977. An estimation of homogeneity in crop plants, with special reference to genetic vulnerability in the dry bean, *Phaseolus vulgaris*. *Euphytica* **26**: 665-679.

Ahammed, A. U., M. M. Rahman and M. A. K. Mian. 2013. Multivariate analysis in stem amaranth (*Amaranthus tricolor*). *Bangladesh J. pl. Breed. Genet.* **26** (1): 11-17.

Akther, C. A., M. Hasan, M. S. Raihan, M. M. Hossain and M. A. K. Mian. 2013. Genetic divergence in stem amaranth (*Amaranthus tricolor* L.) genotypes for yield and its component character. *The Agriculturists* **11**(1): 82-88.

Barrio, D.A., and M. C. Anon. 2010. Potential antitumor properties of a protein isolate obtained from the seeds of *Amaranthus mantegazzianus*. *European Journal of Nutrition* **49**: 73-82.

Bhatt, B., A. K. Soni, K. Jangid, and S. Kumar. 2017. A study on genetic variability, character association and path coefficient analysis in promising indigenous genotypes of garlic (*Allium sativum* L.). *Int. J. Pure. App. Biosci.* **5**(1): 679-686.

Chahal, G. and S. Gosal. 2002. *Principles and procedures of plant breeding: Biotechnological and conventional approaches.* Alpha Science Int. Ltd.

Crossa, J. and J. Franco. 2004. Statistical methods for classifying genotypes. *Euphytica* **137**: 19-37.

Devi, J., A. Sharma, Y. Singh, V. Katoch, and K. C. Sharma. 2015. Genetic variability and character association studies in French bean (*Phaseolus vulgaris* L.) under North-Western Himalayas. *Legume Research-An International Journal* **38**(2): 149-156.

Greizerstein, E.J. and L. Poggio. 1994. Karyological studies in grain Amaranths. *Cytology* **59**: 25–30.

Hair, J. R., R. E. Anderson, R. L. Tatham, and W. C. Black. 1995. *Multivariate Data Analysis with Readings*, 4th Edition, Prentice-Hall, Englewood Cliffs.

Hardwood, R. R. 1980. The present and future status of amaranth. Proc. 2nd Amaranth Conference. Rodale Press. Emmaus. pp. 55.

Hongyan L, Z. Deng, R. Liu, H. Zhu, J. Draves, M. Marcone. 2015. Characterization of phenolics, betacyanins and antioxidant activities of the seed, leaf, sprout, flower and stalk extracts of three Amaranthus species. *J Food Compos Anal*. **37**:75– 81. Doi: 10.1016/j.jfca.2014.09.003

Hunter, B. R. 1993. Science Based Identification of Plant Genetic Material. CSSA, Intellectual Property Rights: Protection of Plant Materials. *Special Publication* **21**: 93-99.

Jensen, A. 1978. Chlorophylls and carotenoids. *In* Hellebust, J. A. & Craigie J. S. (Eds.), Handbook of physiological methods and biochemical methods (pp. 5–70). Cambridge: Cambridge University Press.

Jollife, I. T. 1986. Principal component analysis. New York, Springer.

Joshi, B. D. and J. C. Rana. 1995. Genetic divergence in grain amaranth (*Amaranthus hypochondriacus*). *Indian Journal of Agricultural Sciences* **65** (8): 605-607.

Legendre P. and L. Legendre L. 1998. *Numerical Ecology*. 2nd ed., Elsevier, Amsterdam, p. 853.

Mahalanobis, P. C. 1936. On the generalized distance in statistics. Pro. Natl. Int. Sci. India. **2**:49-55.

Mondal, J. and V. K. Dhangarh. 2012. Screening vegetable amaranth under summer condition in Red and Lateritic Belt of West Bengal. *Environment & Ecology* **30** (4A): 1430-1433.

Rani, R., J. Mahato, Krishna Prasad, Hem Chandra Lal and Himanshu Raj. 2020. Studies on Genetic Divergence in Amaranthus Genotypes (*Amaranthus hypochondriacus* L.). *Int. J. Curr. Microbiol. App. Sci.* Special Issue-**10**: 53-57.

Rao, C. R. 1970. *Advanced Statistical Methods in Biometric Research* (Reprint ed.). Darien, C. T: Hafner Publishing Co. pp. 51–74.

Rashad, M. M. I. and U. Sarker. 2020. Genetic variations in yield and yield contributing traits of green amaranth. *Genetika* **52**: 393-407. Doi:10.2298/gensr2001393r

Rastogi, A. and S. Shukla. 2013. Amaranth: A New Millennium Crop of Nutraceutical Values, *Critical Reviews in Food Science and Nutrition* **53** (2): 109-125.

Rauf, S., J. T. da Silva, A. A. Khan and A. Naveed. 2010. Consequences of plant breeding on genetic diversity. *International Journal breeding* **4**(1): 1-21.

Sagar, P, S. Chatterje, M. Mishra, A. Diwakar, P. J. Bhoya, S. Pandey and Kiran Tigga. 2023. Traditional to Modern Era of Grain Amaranth (*Amaranthus* Spp.) Cultivation: Package and Practices Book Chapter). *In*: Anshuman Singh, A. A. Kumar and R. P. Singh. Eds. Recent Trends of Production, Protection and Improvement in Agriculture.1st ed. Rubicon Publications 4/4A, Bloomsbury Square, Bloomsbury Square, London, WC1A 2RP, England. 402p.

Sarker, U, M. T. Islam, M. G. Rabbani and S. Oba. 2014. Genotypic variability for nutrient, antioxidant, yield and yield contributing traits in vegetable amaranth. *J. Food Agri. Environ.* **12**:168–174.

Sarker, U. and S. Oba. 2019. Nutrients, minerals, pigments, phytochemical, and radical scavenging activity in *Amaranthus blitum*. leafy vegetable. *Sci. Rep*. **10**:3868. [doi: 10.1038/s41598-020-59848-w]

Schonfeld, M.A., R.C. Johnson, B.F. Carver, and D.W. Mornhinweg. 1988. Water relations in winter wheat as drought resistance indicator. *Crop Sci.* **28**: 526-531.

Sharma, A. K. V. Sagar, S. V. Dwivedi, R. K. Singh, V. Chugh, J. Devi and N. Rai. 2024. Assessment of genetic variability among vegetable amaranth (*Amaranthus tricolor* L.) genotypes in Indo-Gangetic plains. *Vegetable Science* **51**(1): 164-172. Doi: 10.61180/vegsci2024.v51.i1.22

Sharma, R. V., O. Komolafe, S. Malik, K. Mukesh and A. Sirohi. 2016. Character association and path analysis in garlic (*Allium sativum* L.) *International Quarterly Journal of Life science***11**(3): 1931-1935.

Shellikeri, B., T.B. Allolli, Lakshmidevamma, T.N., Satish, D., Gollagi, S.G., S. Evoor, P. Ajjapplavara and A. Kareem. 2022. Comparative growth performance of vegetable amaranth (*Amaranthus* spp.) genotypes under northern dry zone of Karnataka. *Biological Forum – An International Journal* **14**(3): 1271-1279.

Singh, P, K. and B. D. Chaudhury. 1985. *Biometrical methods in quantitative genetic analysis*. Kalayani publishers, New Delhi. P. 318.

Tomoko, N. 1991. Genetic diversity and land race differentiation of mungbean (*Vigna radiata* (L) wilczek) and evaluation of its wild relatives (The sub-genus cerato tropics) as breeding materials. Tech. Bull. Trop. Res. Centre, Japan. No. **28**. Ministry of Agric. Forestry and Fisheries, Japan, p.1.

Tongos, M. D. 2016. Yield of vegetable amaranth (*Amaranthus cruentus* L.) as influenced by row spacing and nitrogen fertilization in Mubi. Northern, Guinea Savannah Zone of Nigeria. *Int. J. Innovative Agric. & Biology Res*. **4** (91): 40-48.

XLSTAT. 2020. *A complete statistical add-in for Microsoft Excel*.-Addinsoft SARI, Paris, France. 1528p.

Yan, W. and I. Rajcan. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. *Crop Scienc* **42**:11-20.

Yeshitila, M., A. Gedebo, B. Tesfaye, H. Demissie, and T. M. Olango. 2023. Multivariate analysis for yield and yield-related traits of amaranth genotypes from Ethiopia. *Helion***9**:1-18. E18207. Doi.org/10.1016/j.heliyon.2023.e18207.

Guidelines for Contributors

Bangladesh Journal of Agricultural Research (BJAR) is a quarterly Journal highlighting original contributions on all disciplines of crop agricultural research conducted in any part of the globe. The full text of the Journal is visible in www.banglajol.info and www.bari.gov.bd websites. Contributors are requested to note the following points while preparing paper for the Journal.

- Paper submitted for publication must contain original unpublished material.
- Papers in the Journal are published on the entire responsibility of the contributors.
- Paper must be in English and type-written in Times New Roman (font size 12) with double space on one side of A4 size 80g paper.
- Margin should be 2.50 cm (1 inch) in all sides.
- Manuscript should be submitted in duplicate along with a soft copy.
- The manuscript should contain the following sub-titles in sequence: Title, Abstract, Key words, Introduction, Materials and Methods, Results and Discussion, Conclusion, Acknowledgements (if any) and References. In case of 'Short Communication' no sub-titles are necessary except Abstract and References.
- **Title:** It should be brief and specific and typed in capital letters. The manuscript will have a separate title page giving title of the paper, author(s) name and address.
- **Abstract:** It should not exceed 150 words containing the highlights of the study, but in case of short communication if should not exceed 70 words.
- **Key words: S**hould not exceed 6 words and it should be below the Abstract.
- **Text:** The text of the article should be clear and precise. Introduction should be precise and relevant to the study. Methods already published should be indicated by references. In case of modification of a method it needs explicit description. Results should be stated concisely and presented referring to Tables and Figures. Data of Tables and Figures should not be repeated in the text. Each result should be followed by discussion or interpretation with appropriate reference(s).
- **Tables and Figures:** Number of Tables and Figures should be minimum. The figures and graphs should be properly drawn with bold and solid lines. The photographs should be submitted on glossy paper or in JPG format. Black and white and colored photographs are acceptable.
- All quantitative data must be in metric units.

* Abbreviations should be as per style “Manual for Biological Editors”.
* **References:** The references and scientific names are important. The authors must be sure about the correctness of citations and spellings. In the text, references should be cited within brackets quoting author’s surname and the year of publication in the appropriate place e.g. (Bhuiyan, 1964), Khan and Rahman (1970). Two or more references when put within the same bracket should be separated by a semicolon.

For more than two authors the reference should be cited with the surname of the first author and then *et al*. (year), for example Ahmed *et al.* (1999).

References should be arranged alphabetically according to author’s surname, to be followed by year of publication and full title of the paper. Name of the Journal and Book should be in italics, to be followed by volume, number and page range.

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

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

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

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

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

* A full paper exceeding 12 typed pages and a short communication exceeding six typed pages will not be entertained.
* Principal author should take consent of the co-author(s) while including the name(s) in the article.
* The article prepared from M.S/Ph.D. thesis should be mentioned in the foot note of the article.
* Authors get no complimentary copy of the Journal. Twenty copies of reprints are supplied free of cost to the author(s).

FOR SUBMISSION OR CONTACT

Editor (Technical)
Bangladesh Journal of Agricultural Research
Bangladesh Agricultural Research Institute (BARI)
Joydebpur, Gazipur-1701
Phone: 02-49270038
E-mail: editor.bjar@gmail.com

BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

Vol. 51 **March 2026** **No. 1**

Published by the Director General, Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh. **Printed at** Nurjahan Enterprise, 69/C, Green Road, Panthapath, Dhaka.

Published: May 2026