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ADOPTION OF MANGO VAR. BARI AAM-3 BY THE GROWERS IN NAOGAON AND CHAPAINAWABGANJ DISTRICTS OF BANGLADESH*

S. T. JANNAT¹, M. S. I. AFRAD², M. E. HAQUE³
S. S. HASAN⁴ AND N. A. IVY⁵

Abstract

The mango variety 'BARI Aam-3', popularly known as 'Amrapali', represents a remarkable innovation by the Bangladesh Agricultural Research Institute. This study investigated the extent of its adoption among mango growers in the Porsha and Nachole upazilas of Naogaon and Chapainawabganj districts, respectively, selected for their high concentration of 'BARI Aam-3' cultivation. Data were gathered from 111 growers using proportionate random sampling and analyzed via descriptive statistics and multiple regression. Findings revealed that while respondents also cultivated other mango varieties except 'BARI Aam-3' among which 'Langra', 'Fazli', and 'Himsagar' ('Khirshapat') were popular, the majority had been growing 'BARI Aam-3' for 6 to 12 years. The rank order of these mango varieties cultivated by the growers was 'BARI Aam-3' > 'Langra' > 'Fazli' > 'Himsagar'. The average adoption rate of 'BARI Aam-3' was 67.8%, with most respondents exhibiting a medium level of adoption. Regression analysis indicated that the adoption of 'BARI Aam-3' was significantly influenced by the respondents' education, farm size, annual income, extension contact, innovativeness, and mango cultivation knowledge.

Keywords: Mango, 'BARI Aam-3', adoption, cultivation period, innovativeness, extension contact, training experiences.

Introduction

Mango is the national tree of Bangladesh where the production of mango was 12,22,368 MT from 2,35,348 acres area under garden (2019-20). The production of mango in Naogaon and Chapainawabganj districts was 28,780 MT from 4,457 acres area and 1,87,174 MT from 62,800 acres area under garden, respectively in 2019-20 (BBS, 2022). Among the varieties developed by Bangladesh Agricultural Research Institute (BARI), 18 mango varieties were included, which have special characteristics (Rahman *et al.*, 2022). Among the 18 different mango varieties, 'BARI Aam-3' has become exceptionally popular and is being cultivated in various locations of Bangladesh. This variety is also popularly known as 'Amrapali' in

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*A part of PhD dissertation of the first author.

Bangladesh. It was released by BARI in 1996 through introduction method of breeding from abroad (Azad *et al.*, 2020). The fruit is exceptionally delicious and possesses a high sweetness level (TSS 23.4%) exhibiting a sweet flavor when it is completely ripened. ‘BARI Aam-3’ is a late variety with a regular bearing habit with fruit yield of 20 MT/ha. The variety is commercially cultivable in all areas of Bangladesh (Azad *et al.*, 2020; Uddin, 2012). ‘BARI Aam-3’ was the most adopted variety (57.0%) among all mango varieties and 47.5 percent of the total mango production was covered by ‘BARI Aam-3’ (Rahman and Khatun, 2018). The highest 77.0 percent farmers adopted ‘BARI Aam-3’ due to its sweetness, flavor and high market demand followed by ‘BARI Aam-4’ (22.1%) and ‘BARI Aam-8’ (15.9%) (Uddin *et al.*, 2018). A few researches were conducted on the adoption of ‘BARI Aam-3’ (Amrapali) in certain locations of Bangladesh. Moreover, no studies were found so far regarding the cultivation period of ‘BARI Aam-3’. Therefore, the study on the adoption of ‘BARI Aam-3’ was undertaken in Porsha Upazila under Naogaon district and Nachole Upazila under Chapainawabganj district, which are situated in High Barind Tract characterized by drought, low rainfall and unpredictable climatic conditions, making it a challenging environment for agriculture. The present study was carried out to: (i) describe the selected socio-demographic characteristics of the growers, (ii) explore the mango varieties cultivated by them, (iii) determine the cultivation period of ‘BARI Aam-3’ cultivated by them, (iv) investigate the extent of adoption of ‘BARI Aam-3’ by them, and (v) examine the contribution of the selected characteristics of the growers to their adoption of ‘BARI Aam-3’.

Materials and Methods

The study was conducted in Porsha upazila under Naogaon district and Nachole upazila under Chapainawabganj district (Fig. 1), which were purposively selected based on the abundance of cultivation of ‘BARI Aam-3’ (Rahman and Khatun, 2018; DAE, 2019a; DAE, 2019b; DAE, 2020a; DAE, 2020b; DAE, 2021).

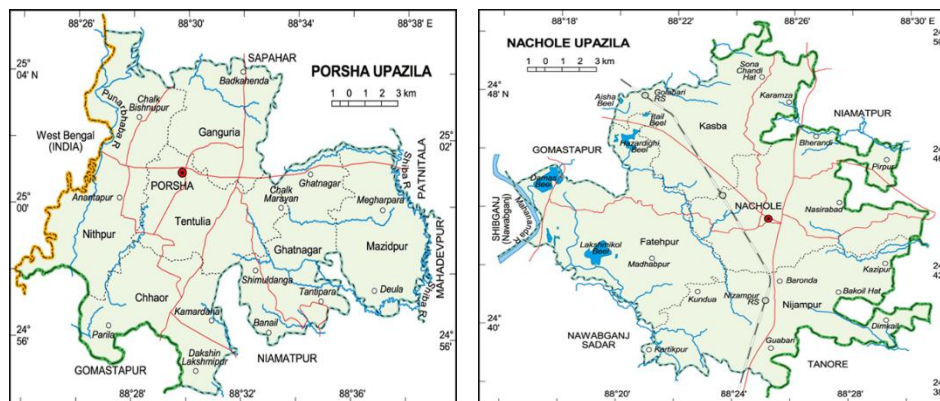


Fig. 1. Map showing Porsha upazila under Naogaon district and Nachole upazila under Chapainawabganj district.

The population of the study was the growers who cultivated 'BARI Aam-3' for at least five years. The sampling population under study was 589 (472 and 117 in Porsha and Nachole upazila, respectively). Among them 111 growers (19.0% of population) were selected as respondents (Loki *et al.*, 2019) using a proportionate random sampling technique. The data were collected during January to April, 2021. Fifteen selected characteristics of the respondents – 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, cosmopolitaness, innovativeness and knowledge on mango cultivation were the independent variables of the study. The independent variables were measured following standard procedure. Adoption of 'BARI Aam-3' was the focus variable of the study. The extent of adoption of 'BARI Aam-3' was measured following the formula used by Kashem (2004), Bhuiyan (2012) and Khalil *et al.* (2013) which is as follows:

$$\text{Extent of Adoption of 'BARI Aam-3'} = \frac{\text{Area (hectare) covered by 'BARI Aam-3'}}{\text{Potential area (hectare) for BARI Aam-3 cultivation}} \times 100$$

The basis of categorization of the extent of adoption of BARI Aam-3 was mean \pm SD). The observed extent of adoption of 'BARI Aam-3' ranged from 1.6 percent to 100.0 percent. The cultivation period of 'BARI Aam-3' cultivated by the respondents was measured by counting the years of cultivating 'BARI Aam-3' from the adoption of the technologies. A score of one (1) was assigned to each year. The basis of categorization of cultivation period of 'BARI Aam-3' was mean \pm SD. The observed cultivation period of BARI Aam-3 ranged from 5 to 23 years. 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. Multiple regression analysis was employed to examine the contribution of the selected characteristics of the respondents to their extent of adoption of 'BARI Aam-3'.

Results and Discussion

The findings presented in Table 1 showed that about half (49.5%) of the respondents were middle aged. Ninety-one percent of them were literate and the highest percentage (43.2%) of them belonged to higher secondary education level. Majority of the respondents (45.0%) had small sized family.

Table 1. Characteristic profile of the respondents

| Sl# | Characteristics (Measurement unit) | Possible and observed range | Respondents (n=111) | | Mean |
|-----|--|-----------------------------|------------------------|------|-------|
| | | | Categories | % | |
| 01. | Age (Years) | Unknown (24-73) | Young (up to 35) | 34.2 | 40.7 |
| | | | Middle aged (36-50) | 49.5 | |
| | | | Old (above 50) | 16.3 | |
| 02. | Level of education (Years of schooling) | Unknown (0-18) | Illiterate (0) | 1.0 | 10.2 |
| | | | Can sign only (0.5) | 8.1 | |
| | | | Primary (1-5) | 10.8 | |
| | | | Secondary (6-10) | 36.9 | |
| | | | Higher secondary (>10) | 43.2 | |
| 03. | Family size (Number) | Unknown (2-12) | Small (up to 4) | 45.0 | 5.2 |
| | | | Medium (5-6) | 37.0 | |
| | | | Large (above 6) | 18.0 | |
| 04. | Farm size (Hectare) | Unknown (0.3-32.8) | Small (0.21-1.00) | 8.1 | 4.7 |
| | | | Medium (1.01-3.00) | 38.7 | |
| | | | Large (above 3.00) | 53.2 | |
| 05. | Annual income (‘000’BDT) | Unknown (79-4500) | Low (up to 353) | 37.0 | 766.6 |
| | | | Medium (354-1180) | 43.2 | |
| | | | High (above 1180) | 19.8 | |
| 06. | Training experience (Number of days) | Unknown (0-276) | No training (0) | 22.6 | 18.0 |
| | | | Low (1-5) | 29.7 | |
| | | | Medium (6-10) | 11.7 | |
| | | | High (above 10) | 36.0 | |
| 07. | Extension contact (Score) | 0 to 72 (10-55) | Low (up to 28) | 18.0 | 38.9 |
| | | | Medium (29-50) | 70.3 | |
| | | | High (above 50) | 11.7 | |
| 08. | Farming experience (Years) | Unknown (5-60) | Low (up to 9) | 16.2 | 20.8 |
| | | | Medium (10-32) | 65.8 | |
| | | | High (above 32) | 18.0 | |
| 09. | Access to credit | - | No | 2.7 | - |
| | | | Yes | 97.3 | |

| Sl# | Characteristics (Measurement unit) | Possible and observed range | Respondents (n=111) | | Mean |
|-----|--|-----------------------------|---------------------|------|------|
| | | | Categories | % | |
| 10. | Off farm activities | - | No | 45.0 | - |
| | | | Yes | 55.0 | |
| 11. | Availability of irrigation water | - | No | 10.8 | - |
| | | | Yes | 89.2 | |
| 12. | Organizational membership (Score) | Unknown (0-213) | Low (up to 7) | 37.8 | 22.4 |
| | | | Medium (8-38) | 42.3 | |
| | | | High (above 38) | 19.9 | |
| 13. | Cosmopolitaness (Score) | 0 to 15 (1-15) | Low (up to 8) | 18.9 | 10.6 |
| | | | Medium (9-14) | 75.7 | |
| | | | High (above 14) | 5.4 | |
| 14. | Innovativeness (Score) | 0 to 21 (0-15) | Low (up to 3) | 50.5 | 4.6 |
| | | | Medium (4-6) | 27.9 | |
| | | | High (above 6) | 21.6 | |
| 15. | Knowledge on mango cultivation (Score) | 0 to 30 (16-30) | Low (up to 22) | 18.0 | 25.2 |
| | | | Moderate (23-28) | 68.5 | |
| | | | High (above 28) | 13.5 | |

More than ninety percent (91.9%) of the respondents had medium to large farm. The average annual income of the respondents was Tk. 766.6 thousand which was much higher than the national average (Tk. 137.8 thousand) (BBS, 2021) and most of them (80.2%) belonged to medium to low annual income category. More than one-fourths (36.0%) of the respondents had high training experience. The large majority of them (77.4%) received agricultural training which was an opportunity for the growers in the study area. The highest portion of the respondents (70.3%) had medium extension contact. Most of them (65.8%) had medium farming experience. Most of the respondents (97.3%) had access to credit. More than half (55.0%) of them had some kind of off farm activities. Most of the respondents (89.2%) had available irrigation water. Majority of them (42.3%) had medium organizational membership. Majority of the respondents (75.7%) had medium cosmopolitaness. Most of the respondents (78.4%) had low to medium innovativeness. Majority of them (68.5%) had moderate knowledge on mango cultivation.

Adoption of 'BARI Aam-3'

The findings related to the adoption of 'BARI Aam-3' by the growers in Naogaon and Chapainawabganj districts have been discussed in this section.

Mango varieties cultivated by 'BARI Aam-3' respondents

The results presented in the Table 2 indicate that all the respondents (100.0%) cultivated 'BARI Aam-3'. The majority of the 'BARI Aam-3' respondents cultivated 'Langra' (76.6%) followed by 'Fazli' (64.0%) and 'Himsagar'/ 'Khirshapat' (55.9%). The reason could be that 'BARI Aam-3', 'Langra', 'Fazli', and 'Himsagar'/'Khirshapat' were the popular mango varieties due to their better taste and high income, leading majority of the growers to cultivate those mango varieties.

Table 2. Rank order of different mango varieties cultivated by 'BARI Aam-3' respondents

| Sl.# | Mango variety | Respondents (%) | Rank |
|------|------------------------------|-----------------|------------------|
| 1. | BARI Aam-3 (Amrapali) | 100.0 | 1 st |
| 2. | Langra | 76.6 | 2 nd |
| 3. | Fazli | 64.0 | 3 rd |
| 4. | Himsagar/Khirshapat | 55.9 | 4 th |
| 5. | Ashwina | 49.5 | 5 th |
| 6. | BARI Aam-4 | 36.0 | 6 th |
| 7. | Gopalbhog | 30.6 | 7 th |
| 8. | BARI Aam-2 (Lakhkhanbhog) | 10.8 | 8 th |
| 9. | Katimon | 8.1 | 9 th |
| 10. | Gutee | 7.2 | 10 th |
| 11. | Gouramati | 5.4 | 11 th |
| 12. | Khudi gopalbhog/ Raniprashad | 3.6 | 12 th |
| 13. | Harivanga | 3.6 | 12 th |
| 14. | Banana mango | 3.6 | 12 th |
| 15. | BARI Aam-11 | 2.7 | 13 th |
| 16. | Chinimohon | 1.8 | 14 th |
| 17. | Mallika | 1.8 | 14 th |
| 18. | Bombai | 1.8 | 14 th |
| 19. | Kachamitha | 0.9 | 15 th |
| 20. | Chakukata | 0.9 | 15 th |
| 21. | Chusha | 0.9 | 15 th |
| 22. | Nepali Khirsha | 0.9 | 15 th |
| 23. | Khirsha Hybrid | 0.9 | 15 th |
| 24. | Sun Mango | 0.9 | 15 th |
| 25. | Kalibhog | 0.9 | 15 th |

Rahman and Khatun (2018) also reported that ‘BARI Aam-3’ was the most adopted mango variety (57%) followed by ‘Khirshapat’ (12.0%), ‘Langra’ (10.0%) and ‘Gobindabhog’ (6.0%).

Cultivation period

Information furnished in the Table 3 showed that the observed cultivation period of ‘BARI Aam-3’ ranged from 5 to 23 years, where 5 years indicates very low cultivation period and 23 years indicates very high cultivation period. The respondents cultivated ‘BARI Aam-3’ in the study area for 8.1 years on an average. About three-fourths of them (63.1%) cultivated ‘BARI Aam-3’ for 6-12 years (medium cultivation period) while more than one-fourths of them (25.2%) cultivated it for up to 5 years (low cultivation period) and only 11.7 percent of them cultivated this variety for more than 12 years (high cultivation period). The reason could be that the ‘BARI Aam-3’ variety was released in 1996. After that time, it was introduced in the study area. After its introduction, ‘BARI Aam-3’ became popular among the growers gradually. The growers of the study area became motivated to cultivate ‘BARI Aam-3’ watching the success of the innovator growers of that area.

Table 3. Distribution of the respondents according to their cultivation period of ‘BARI Aam-3’

| Categories | Respondents | | Mean |
|---------------------|-------------|---------|------|
| | Number | Percent | |
| Low (up to 5 years) | 28 | 25.2 | 8.1 |
| Medium (6-12 years) | 70 | 63.1 | |
| High (>12 years) | 13 | 11.7 | |
| Total | 111 | 100.0 | |

Consequently, it appears that majority of the respondents had the opportunity to cultivate ‘BARI Aam-3’ for medium duration. It was found that the adoption of ‘BARI Aam-3’ was increasing gradually, might be because of its high yield, higher income, high demand, taste, sweetness, etc. The growers were very much motivated to cultivate ‘BARI Aam-3’ and the popularity of ‘BARI Aam-3’ was increasing in the area rapidly.

Extent of adoption

The possible extent of adoption ranged from 0.0 to 100.0 percent, where zero percent (0) indicates no adoption and 100.0 percent indicates full adoption. The observed extent of adoption ranged from 1.6 percent to 100.0 percent, where 1.6 percent indicates very low adoption and 100.0 percent indicates full adoption. Results presented in the Table 4 show that more than half (55.9%) of the respondents adopted ‘BARI Aam-3’ to medium extent while more than one-fourths (27.9%) of them adopted it to high extent and only 16.2 percent of them adopted the technology to low extent. The large majority (83.8%) of them adopted BARI Aam-3 to medium to high extent. This could be attributed to the fact that ‘BARI Aam-3’ is a popular mango variety recognized for its many special attributes including its delightful taste and sweetness which allows growers to earn high profit from its cultivation.

Table 4. Distribution of the respondents based on their adoption of ‘BARI Aam-3’

| Categories | Respondents | | Mean |
|----------------------|-------------|---------|------|
| | Number | Percent | |
| Low (up to 41.33) | 18 | 16.2 | 67.8 |
| Medium (41.34-94.25) | 62 | 55.9 | |
| High (above 94.25) | 31 | 27.9 | |
| Total | 111 | 100.0 | |

Rahman and Khatun (2018) noted that ‘BARI Aam-3’ was the most adopted mango variety (57.0%) among all mango varieties. The highest 77.0 percent farmers adopted ‘BARI Aam-3’ 'due to its sweetness, flavor and high market demand followed by ‘BARI Aam-4’ and ‘BARI Aam-8’ (Uddin *et al.*, 2018).

Contribution of the selected characteristics of the respondents

Multiple regression analysis was conducted to test the hypothesis that there is no significant contribution of the selected characteristics of the respondents to their extent of adoption of BARI Aam-3. Results presented in Table 5 indicate that there were significant contributions of respondents’ level of education, farm size, annual income, extension contact, innovativeness and knowledge on mango cultivation to their extent of adoption of ‘BARI Aam-3’.

Table 5. Multiple regression coefficients showing the contribution of respondents' selected characteristics to the adoption of 'BARI Aam-3'

| Dependent variable | Independent variables | β | P value | SE | |
|------------------------------------|--------------------------------|---------|---------|-------|--|
| Extent of adoption of 'BARI Aam-3' | Age | 0.125 | 0.326 | 0.331 | |
| | Level of education | -0.210 | 0.018* | 0.439 | |
| | Family size | -0.063 | 0.436 | 1.088 | |
| | Farm size | 0.235 | 0.048* | 0.633 | |
| | Annual income | -0.319 | 0.007** | 0.004 | |
| | Training experience | -0.055 | 0.494 | 0.062 | |
| | Extension contact | 0.396 | 0.000** | 0.239 | |
| | Farming experience | -0.041 | 0.740 | 0.284 | |
| | Organizational membership | 0.039 | 0.676 | 0.080 | |
| | Cosmopolitaness | 0.062 | 0.486 | 0.763 | |
| | Innovativeness | -0.178 | 0.033* | 0.606 | |
| | Knowledge on mango cultivation | 0.191 | 0.043* | 0.794 | |
| | Constant | | -5.655 | | |
| | R ² | | 0.447 | | |
| | Adjusted R ² | | 0.379 | | |
| F value | | 6.600 | | | |
| P value | | 0.000** | | | |

* Significant at 0.05 level ** Significant at 0.01 level; SE = Standard Error.

Of these, their extension contact and annual income were the most important contributing factors (significant at 1.0% level) which profoundly influenced their extent of adoption of 'BARI Aam-3' and level of education, farm size, innovativeness and knowledge on mango cultivation were the second most important contributing factors (significant at 5.0% level). Respondents' farm size, extension contact and knowledge on mango cultivation had positive significant contribution to their extent of adoption of 'BARI Aam-3'. Farm size is related to their economic strength. It may be attributed to the fact that the growers with larger farms had greater opportunity to cultivate 'BARI Aam-3' across extensive land areas. They had the capability to adopt 'BARI Aam-3' to high extent due to having a larger area available for cultivation. Different finding was observed by Rahman and Khatun (2018) where growers' farm size had significant negative effect on their adoption of 'BARI Aam-3' mango variety. The predictor variables, such as extension contact and knowledge on mango cultivation might have influenced the respondents' awareness and positive attitude towards 'BARI Aam-3', motivating them to adopt this variety. The growers who had more extension contact may have had better communication with extension personnel and other agricultural

information sources, influencing them to adopt 'BARI Aam-3' on a large scale. Rahman and Khatun (2018) in their studies reported that the farmers' extension linkage had significant positive effect on their adoption of mango var. 'BARI Aam-3'. It is likely that the growers who had more knowledge on mango cultivation were interested in 'BARI Aam-3' due to its many special characteristics. Different finding was revealed by Uddin *et al.* (2018) where the mango growers' possession of modern knowledge on mango production had no significant contribution to their adoption of the BARI mango varieties. Respondents' level of education had negative significant contribution to their extent of adoption of 'BARI Aam-3'. Perhaps the educated growers were more involved with other sources of income like service, business, and self-entrepreneurship other than mango cultivation, which left them with less time to dedicate to mango cultivation. Therefore, they had poor adoption of 'BARI Aam-3'. Different finding was observed by Rahman and Khatun (2018) where the farmers' education level had no significant effect on their adoption of 'BARI Aam-3'. The annual income of the respondents had negative significant contribution to their extent of 'BARI Aam-3' adoption. The reason could be that the growers who had higher income were involved with business and other off-farm activities; consequently, they had limited time available for the large-scale cultivation of 'BARI Aam-3'. Different finding was found by Rahman and Khatun (2018) where farmers' farm income had no significant effect on their adoption of mango variety 'BARI Aam-3'. Respondents' innovativeness had negative significant contribution to their extent of adoption of 'BARI Aam-3'. The reason could be that the innovative growers were always engaged in trying new technologies; thus, they may not have dedicated themselves to the cultivation of a single technology and cultivated 'BARI Aam-3' along with other technologies.

It was observed that 44.7 percent ($R^2 = 0.447$) of the variation in the extent of adoption of 'BARI Aam-3' by the respondents can be attributed to their age, level of education, family size, farm size, annual income, training experience, extension contact, farming experience, organizational membership, cosmopolitaness, innovativeness and knowledge on mango cultivation. The F value 6.600 indicates that the model is significant ($p = 0.000$). Each predictor variable may contribute some of the variations in the extent of adoption of 'BARI Aam-3' by the respondents simply by chance. Adjusted R-square value penalizes the addition of extraneous predictors in the model, and the value of 0.379 still indicates that the variance in the extent of adoption of 'BARI Aam-3' by the respondents can be attributed to the predictor variables rather than by chance, and the model is suitable model.

Conclusion

BARI Aam-3 is a popular mango variety which is being cultivated widely in Bangladesh. The majority of the 'BARI Aam-3' respondents cultivated 'Langra' followed by 'Fazli' and 'Himsagar' ('Khirshapat'). The majority of the growers cultivated 'BARI Aam-3' for 6-12 years (medium cultivation period). The average level of adoption of 'BARI Aam-3' was 67.8 percent. In this study, the majority of the growers were found to adopt 'BARI Aam-3' to medium extent. The extent of adoption of 'BARI Aam-3' by the respondents was likely to be influenced by their level of education, farm size, annual income, extension contact, innovativeness and knowledge on mango cultivation. The research institutes may be strengthened to develop more appropriate technologies for a sustainable and competitive mango sector. It is evident from the study that hybrid mango varieties like 'BARI Aam-3' and 'BARI Aam-4' capable of producing higher yield, having better taste and other attributes, boosted the mango sector in Bangladesh. The promising mango sector may be further enriched through enhanced breeding programme utilizing the desirable traits of local popular varieties like 'Himsagar', 'Harivanga' and 'Gouramati' and exotic varieties like 'Katimon'. Coordinated programmes of BARI, DAE, BADC, HORTEX Foundation and NGOs under the leadership of BARC may be implemented for expanding and managing mango farming for increased domestic consumption and export. The government/concerned agricultural authorities may promote and disseminate more new agricultural technologies and provide those technologies to growers as incentive in large scale. The concerned authorities may take necessary steps to bring the fallow land under cultivation.

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AGRICULTURAL MECHANIZATION AND ECONOMIC DEVELOPMENT IN BANGLADESH: EVIDENCE FROM TIME-SERIES ANALYSIS

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Abstract

Bangladesh's economy benefited greatly from agricultural mechanization; however, it also faces challenges. The objective of this study was to examine the effects of mechanization on crucial economic indicators between 1991 and 2022. Advanced statistical and econometric techniques were applied to carry out the study. Despite the fact that the quantities of power tillers and irrigation equipment have a negative impact on crop production and gross domestic product, respectively, the study's findings indicate that agricultural mechanization has generally positive and significant effects on both. However, agricultural mechanization has a negative and significant impact on income inequality and employment in the agricultural sector; in contrast, energy consumption has a favorable effect on income inequality. The number of electricity users, irrigation equipment, and arable land area also has positive effect on employment creation. The study suggests that advanced farming techniques, timely cultivation, reduced input waste, more irrigation capacity, shorter harvest periods, and lower production costs are the main determinants of increased crop production and gross domestic product. Nevertheless, financial barriers to small-scale farmers, high-cost machinery, unfair distribution of machinery resources, and fragmented land contribute to increasing income inequality. Moreover, lack of skills, limited access to training facilities, and fewer job opportunities are responsible for declining employment, although the adoption of advanced technologies enhances employment opportunities. To overcome challenges in establishing agro-service centers, encouraging eco-friendly mechanization, reforming land policies, providing low-interest loan facilities, and establishing machinery rental service centers are necessary in Bangladesh.

Keywords: Agricultural mechanization; Crop productivity; Economic growth; Income inequality; Employment; Bangladesh

Introduction

Agricultural mechanization refers to the application of engineering principles and technologies in agricultural production, storage, and processing to increase productivity and efficiency, while reducing costs for farmers. It primarily involves replacing human and animal labor with machine power (Magdoff, 1982), making

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it a key factor in modern agricultural transformation. In Bangladesh 80-95% of such practices as tillage, irrigation, weeding, and pesticide application have been mechanized (DFPM, 2024). Before the agricultural mechanization project began in 2019, only 4% of rice was harvested using combine harvesters; this increased to 22% by the 2022-2023 fiscal year. Regional adoption has also risen significantly, with combine harvesters used in 71% of rice fields in Netrokona, 70% in Manikganj, 60% in Brahmanbaria, 52% each in Dinajpur, Thakurgaon, and Habiganj, 50% in Moulvibazar and Noakhali, 47% in Bhola, and 41% in Sunamganj and Patuakhali (Rai, 2023).

Agriculture is a vital sector in Bangladesh, with about 70-80% of the population directly or indirectly dependent on it. In the 2021-2022 fiscal year, the sector contributed 11.66% to country's gross domestic product (GDP) (Bangladesh Economic Review, 2024). Given the strong link between agriculture, the national economy, and people's livelihoods, transitioning from traditional farming to technology-based agricultural management is essential to ensure sustainable livelihood security.

Agricultural mechanization has both direct effects on production and indirect effects on agricultural value chains across the economy. By enabling farmers to cultivate larger areas in less time, mechanization increases production while reducing labor requirements. Technologies such as tractors with GPS-based guidance systems, allow precise fertilization and planting, reducing input waste and improving crop quality (Rahman, 2023)¹. Mechanization also contributes to higher crop productivity and national GDP by supporting key farming operations, including seedbed preparation, transplanting, sowing, harvesting, and the application of pesticides and fertilizers. Despite its benefits, agricultural mechanization faces several challenges in a developing country like Bangladesh. High initial costs of machinery, limited maintenance services, and inadequate technical skills make it difficult for small-scale farmers to adopt, potentially increasing income inequality. Rapid mechanization also raises concerns about rural employment, as it may displace seasonal agricultural workers. In addition, excessive use of modern machinery can contribute to soil fertility decline and soil erosion (Ovie, 2024; Magdoff, 1982). Other barriers include, poor infrastructure, low investment, unskilled workforce, knowledge gap, limited digital literacy, and policy constraints.

In Bangladesh, the use of modern agricultural technology began in the late 1960s and early 1970s. This occurred during the 'Green Revolution,' a time of agricultural change that used mechanization, better irrigation techniques, and high-yielding crop varieties to boost food production and lower poverty (Rahman,

¹GPS stands for Global Positioning System, a satellite-based navigation system used for determining precise location.

2023). The introduction of deep tube wells (DTWs) for irrigation in the early 1960s marked the beginning of agricultural mechanization in Bangladesh (Pingali, 2007). Bangladesh's irrigation policy changed dramatically following its independence in 1971, encouraging the use of low-lift pumps (LLPs) and shallow tube wells (STWs) (Biggs and Justice, 2015). Since its founding in 1973, the Bangladesh Agricultural Development Corporation (BADC) has been significant in advancing agricultural mechanization in Bangladesh. Only when considerable import barriers were eliminated for agricultural equipment in 1989, particularly for two-wheeled tractors (2WTs), a broader mechanized process begins. A spike in the import of small engines and machinery, mainly from China (Mottaleb et al., 2016), was caused by this policy shift. Local agro-machinery manufacturing workshops were established in the 1990s as a result of a steady increase in the demand for agricultural machinery (Islam, 2018). Now-a-days, tractors, power tillers, combine harvesters, rice transplanters, seeders and planters, sprayers, contemporary irrigation systems, threshers, chaff cutters, grain dryers, storage facilities, etc., are some of the prevalent modern agricultural machineries used in the country. The degree of agricultural mechanization in Bangladesh differs depending on the area and kind of farm. The overall degree of mechanization in the agricultural sector is still low when compared to many other developed nations, despite some modest improvements in the adoption of agricultural machinery.

Numerous studies have been carried out on agricultural mechanization both within Bangladesh and internationally. Hossen (2019) studied the agricultural mechanization and modernization strategies of Bangladesh. He concluded that for Bangladesh to have sustainable crop production, it needs to move from manual labor to a structured, regionalized mechanization strategy that focuses on developing skilled workers, fixing infrastructure, and providing good after-sales service. Emami et al. (2018) examined the fact that mechanization in agriculture is essential for food security in developing nations and proposed a strategy for Iran. Islam and Shirazul (2009) explored the importance of mechanization in sustainable agriculture in Bangladesh, highlighting its challenges and opportunities. Alam et al. (2017) analyzed agricultural machinery manufacturing in Bangladesh, including its potential and challenges. Rahman et al. (2020) investigated agricultural mechanization in Bangladesh and the barriers to meeting the Sustainable Development Goals (SDGs). Prior studies to examine the impacts of agricultural mechanization on key economic indicators of Bangladesh through rigorous statistical and econometric analyses are scarce. This study will discuss the effects of agricultural mechanization on the main economic indicators of Bangladesh, applying statistical and econometric methods, which will help policymakers to make policy on how we can overcome the challenges of mechanization and maintain sustainable economic development in our economy. The specific objectives of the study are: (i) To examine the impact of agricultural mechanization on crop and GDP (ii) To assess the effects of mechanization on

agricultural employment (iii) To analyze the relationship between mechanization and income inequality.

Materials and Methods

Data Collection

The study collected annual time series data from various authentic secondary sources and journal articles covering the years from 1991 to 2022. Fertilizer consumption (Kg per ha arable land) in the agriculture sector and arable land area ('000 acres) are sourced from the Food and Agriculture Organization (FAO, 2023 and 2024). Data on the number of tractors are gathered from FAO (2023), Alam et al. (2017), Gurung et al. (2017), and Alam and Khan (2017). The quantities of power tillers are also compiled based on secondary and authentic journal papers (Jabbar, 1980; Ahmmed, 2014; Mottaleb et al., 2017; International Development Enterprises, 2012). Data on the number of irrigation equipment (DTWs, STWs, and LLPs) and irrigated area ('000 ha) by irrigation equipment and the number of electricity consumers in agriculture are gathered from Bangladesh Agricultural Development Corporation (2020) and Bangladesh Power Development Board (2022-2023), respectively. Furthermore, energy consumption (TWh), which includes all energy uses, including electricity, is sourced from Ritchie *et al.* (2022)². Data on gross domestic product (current US\$) and Gini index (Gini, 1921) are gathered from the World Bank (2025c; 2025b). Here, the Gini index is a proxy variable for measuring income inequality in Bangladesh. It is most commonly used to quantify the disparity in income, although it may be used to measure inequality in any distribution, including wealth distribution as well as life expectancy. It determines inequality on a scale of 0 to 1, with higher numbers indicating more significant disparity. This is sometimes expressed as a percentage ranging from 0 to 100%, known as the Gini index (Joe, 2023). The crop production index, a proxy variable for overall crop production data, is obtained from the Food and Agriculture Organization (FAO, 2023). The base period for the crop production index is 2004-2006, and it covers all types of crops except fodder crops. Finally, the employment rates (%) in the agriculture sector are collected from the International Labor Organization (2019). Notably, specific data on the number of tractors and imported power tillers were missing for a few years and are extrapolated using trend analysis in time series analysis (Gupta and Gupta, 2007).

Model Specification

The present study measures the effect of farm mechanization on crop production, country's GDP, income inequality, and employment in the agricultural sector. Hence, a total of four multiple regression models were selected based on

²TWh stands for Terawatt-hour, a unit used to measure electricity.

preliminary diagnostic tests, including tests for normality, stationarity, and multicollinearity among the independent variables. The common independent variables of these models were the number of electricity consumers in the agricultural sector, number of irrigation equipment (deep tube wells, shallow tube wells, and low-lift pumps), irrigated area by irrigation equipment ('000 ha), the number of power tillers, the number of tractors, fertilizer consumption (Kg per ha), and energy consumption (Terawatt). These models include arable land area as a supporting independent variable. Conversely, the agriculture sector's employment rate, income inequality, crop production, and gross domestic product are the dependent variables since they are the leading economic indicators of Bangladesh. The analysis uses a log-log model, which applies natural logarithm (ln) to both independent and dependent variables. This technique aids in the management of nonlinearity, stabilizes heteroskedasticity, improves data interpretation, simplifies complex relationships, manages multiplicative effects, decreases skewness, and improves the residual distribution for regression. It also allows us to analyze percentage change in variables across many domains. The empirical models are given below:

$$\begin{aligned} \mathbf{Ln(Crop\ Production)_i} &= \alpha_0 + \alpha_1 \mathbf{Ln(No.\ of\ Electricity\ Consumers\ in\ Agriculture)_i} \\ &+ \alpha_2 \mathbf{Ln(Irrigation\ Equipment)_i} + \alpha_3 \mathbf{Ln(Irrigated\ Area\ by\ Irrigation\ Equipment)_i} \\ &+ \alpha_4 \mathbf{Ln(No.\ of\ Tractors)_i} + \alpha_5 \mathbf{Ln(No.\ of\ Power\ Tillers)_i} + \alpha_6 \mathbf{Ln(Fertilizer} \\ &\mathbf{Consumption)_i} + \alpha_7 \mathbf{Ln(Energy\ Consumption)_i} + \alpha_8 \mathbf{Ln(Arable\ Land\ Area)_i} + \\ &U_i \dots \dots \dots (i) \end{aligned}$$

$$\begin{aligned} \mathbf{Ln(Gross\ Domestic\ Product)_i} &= \beta_0 + \beta_1 \mathbf{Ln(No.\ of\ Electricity\ Consumers\ in} \\ &\mathbf{Agriculture)_i} + \beta_2 \mathbf{Ln(Irrigation\ Equipment)_i} + \beta_3 \mathbf{Ln(Irrigated\ Area\ by\ Irrigation} \\ &\mathbf{Equipment)_i} + \beta_4 \mathbf{Ln(No.\ of\ Tractors)_i} + \beta_5 \mathbf{Ln(No.\ of\ Power\ Tillers)_i} + \beta_6 \\ &\mathbf{Ln(Fertilizer\ Consumption)_i} + \beta_7 \mathbf{Ln(Energy\ Consumption)_i} + \beta_8 \mathbf{Ln(Arable\ Land} \\ &\mathbf{Area)_i} + V_i \dots \dots \dots (ii) \end{aligned}$$

$$\begin{aligned} \mathbf{Ln(Income\ Inequality)_i} &= \eta_0 + \eta_1 \mathbf{Ln(No.\ of\ Electricity\ Consumers\ in\ Agriculture)_i} \\ &+ \eta_2 \mathbf{Ln(Irrigation\ Equipment)_i} + \eta_3 \mathbf{Ln(Irrigated\ Area\ by\ Irrigation\ Equipment)_i} \\ &+ \eta_4 \mathbf{Ln(No.\ of\ Tractors)_i} + \eta_5 \mathbf{Ln(No.\ of\ Power\ Tillers)_i} + \eta_6 \mathbf{Ln(Fertilizer} \\ &\mathbf{Consumption)_i} + \eta_7 \mathbf{Ln(Energy\ Consumption)_i} + \eta_8 \mathbf{Ln(Arable\ Land\ Area)_i} + E_t \\ &\dots \dots \dots (iii) \end{aligned}$$

$$\begin{aligned} \mathbf{Ln(Employment\ in\ Agriculture)_i} &= Y_0 + Y_1 \mathbf{Ln(No.\ of\ Electricity\ Consumers\ in} \\ &\mathbf{Agriculture)_i} + Y_2 \mathbf{Ln(Irrigation\ Equipment)_i} + Y_3 \mathbf{Ln(Irrigated\ Area\ by\ Irrigation} \\ &\mathbf{Equipment)_i} + Y_4 \mathbf{Ln(No.\ of\ Tractors)_i} + Y_5 \mathbf{Ln(No.\ of\ Power\ Tillers)_i} + Y_6 \\ &\mathbf{Ln(Fertilizer\ Consumption)_i} + Y_7 \mathbf{Ln(Energy\ Consumption)_i} + Y_8 \mathbf{Ln(Arable\ Land} \\ &\mathbf{Area)_i} + \epsilon_t \dots \dots \dots (iv) \end{aligned}$$

Statistical and Econometric Methods

The descriptive statistics method is used to identify the distribution of the data. Checking the stationarity of the variables is essential when dealing with annual time series data. To assess the stationarity of the variables, we utilized the augmented Dickey and Fuller (1979) and Phillips and Perron (1988) tests using Eviews (version 10) software. The four models are then tested by applying the Johansen (1988) co-integration test to determine the long-run relationship among the variables. According to Engle and Granger (1987), when the variables are co-integrated (results are not provided here), the regression coefficients confirm the validity of the outcomes, and the regression results are not spurious. Further, the co-integrating regression technique-fully modified ordinary least squares (FMOLS) method-is used to demonstrate the positive and negative effects of agricultural mechanization on the Bangladeshi economy. Phillips and Hansen (1990) introduced the fully modified ordinary least squares (FMOLS) technique, which assumes a single co-integration vector. According to their findings, the FMOLS estimator has excellent consistency and asymptotic deviations. The FMOLS co-integrating regression technique offers numerous significant advantages. It is particularly effective at obtaining robust parameter estimations, even with small sample numbers. It also addresses complex concerns, including measurement errors, endogeneity, serial correlation, and omitted variable bias. This technique additionally handles variations in long-term parameters, as demonstrated by the research of Kalim and Shahbaz (2009) and Fereidouni et al. (2017).

Results and Discussion

Descriptive Statistics

Before analyzing data, verifying the variables' descriptive statistics (mean, median, maximum, minimum, skewness, and kurtosis) is an essential task. Descriptive statistics is a very valuable technique for checking data normality, selecting outliers, identifying trends and patterns, and determining data variability.

Table 1 shows the mean, median, maximum, and minimum values, skewness, and kurtosis for each variable from 1991 to 2022 with a natural logarithm (Ln) transformation. The average crop production index during this period is 4.30, while GDP has a mean of 25.27. Most of the variables illustrate distributions close to normal, as indicated by skewness values near zero and moderate kurtosis. However, income inequality stands out with a negative skew (-1.06) and high kurtosis (6.44), suggesting a distribution with a high left tail and sharper peak. Arable land area also shows a notable right skew (1.03). Variables like employment in agriculture, fertilizer use, and energy consumption are more symmetrically distributed. Each variable includes 32 observations. These descriptive statistics provide a reliable basis for further econometric analysis.

Table 1. Descriptive Statistics of Dependent and Independent Variables

| Variables | Mean | Median | Maximum | Minimum | Skewness | Kurtosis | Obs. |
|---|---------|---------|---------|---------|----------|----------|------|
| Crop Production (Index:2004-06=100) | 4.3048 | 4.3290 | 4.7799 | 3.8024 | -0.1536 | 1.5813 | 32 |
| Gross Domestic Product (Current US\$) | 25.2704 | 25.0489 | 26.8547 | 24.1558 | 0.4120 | 1.9702 | 32 |
| Income inequality (Gini Index, %) | 3.4915 | 3.4990 | 3.6136 | 3.3178 | -1.0599 | 6.4370 | 32 |
| Employment in Agriculture (%) | 3.9425 | 3.8704 | 4.2414 | 3.6071 | -0.0021 | 1.5707 | 32 |
| Electricity Consumers in Agriculture (Nos.) | 10.0958 | 9.9275 | 10.9142 | 9.3652 | 0.1928 | 1.7122 | 32 |
| Irrigation Equipment (DTWs, STWs, LLPs) (Nos.) | 13.9458 | 14.1558 | 14.3869 | 12.8612 | -0.9557 | 2.7063 | 32 |
| Irrigated Area by Irrigation Equipment (DTWs, STWs, LLPs) ('000 ha) | 8.3359 | 8.4781 | 8.6566 | 7.6815 | -0.8485 | 2.4910 | 32 |
| No. of Tractors (Nos.) | 7.6637 | 7.7366 | 8.6170 | 6.1092 | -0.4780 | 2.2423 | 32 |
| No. of Power Tillers (Nos.) | 13.0556 | 12.9968 | 13.5410 | 12.4343 | -0.0059 | 2.2658 | 32 |
| Fertilizer Consumption (Kg per ha) | 5.2847 | 5.2409 | 5.9802 | 4.6730 | 0.0914 | 1.9632 | 32 |
| Energy Consumption (Terawatt) | 5.3302 | 5.3422 | 6.2499 | 4.2626 | -0.0783 | 1.8676 | 32 |
| Arable Land Area ('000 acres) | 15.9057 | 15.8968 | 16.0546 | 15.8527 | 1.0287 | 4.3874 | 32 |

Source: Eviews software based on annual time series data (1991-2022).

Unit Root Test

For annual time series data, it is essential first to examine the stationarity of the variables, as the choice of an appropriate model depends on the presence of unit roots. Moreover, determining stationarity is fundamental for avoiding spurious regression, co-integration analysis, forecasting accuracy, and distinguishing between short-run and long-run analyses. However, the results of unit root tests in Tables 2 and 3 show that augmented Dickey and Fuller (1979) and Phillips and Perron (1988) tests are performed twice: first on the variables in their original form and then on their first differences with the intercept, and intercept and trend. Both tests demonstrate that all variables are non-stationary at their initial levels, but stationary at first differences, indicating a solid rationale for running co-integrating regression for further analysis.

Effect of Agricultural Mechanization on Crop Production

According to the results of FMOLS (Table 4), agricultural mechanization has a positive impact on crop production in Bangladesh. Except for the number of power tillers (significant at the 1% level), the number of electricity consumers (not significant), the number of irrigation equipment (significant at the 1% level), irrigated area by irrigation equipment (significant at the 1% level), the number of tractors (significant at the 5% level), fertilizer consumption (significant at the 1% level), energy consumption (significant at the 1% level), and the arable land area (not significant) have a positive influence on crop yield. Advanced technologies that encourage accuracy and precision in farming techniques are frequently included in modern agricultural machines. According to estimates, mechanization can ensure reduced waste of seed and fertilizer while also saving about 30% of time and labor. It is possible to raise overall productivity by about 15% (Hasib, 2021). Mechanization can boost crop yield per hectare, for instance, by breaking compact subsoil layers that limit root growth and water flow. On specific soil types, modern tools may also improve seedbed quality, leading to better germination and healthier plants. Moreover, timely farm operations-often made possible through mechanization-are essential for maximizing yields (Magdoff, 1982). Manual planting in Bangladesh is labor-intensive, taking 123 to 150 person-hours per hectare, whereas mechanical transplanting with a four-row transplanter cuts it to just 9 to 11 hours, enhancing efficiency and easing labor shortages (Robin, 2023). Farm mechanization, which replaces human labor with machines, enables the efficient cultivation of large areas and improves agricultural productivity. A farm machine can cover more land in a day than thirty laborers can in a month (Ovie, 2024).

Table 2. Augmented Dickey-Fuller (ADF) Unit Root Test of Dependent and Independent Variables

| Variables | Level | | First Difference | |
|---|-----------------|---------------------|------------------|---------------------|
| | Intercept | Intercept and Trend | Intercept | Intercept and Trend |
| | Crop Production | 0.93 | 0.37 | 0.00** |
| Gross Domestic Product | 1.00 | 0.97 | 0.00** | 0.00** |
| Income Inequality | 0.10 | 0.07 | 0.00** | 0.00** |
| Employment in Agriculture | 0.88 | 0.10 | 0.00** | 0.01* |
| Electricity Consumers in Agriculture | 0.62 | 0.74 | 0.00** | 0.00** |
| Irrigation Equipment (DTWs, STWs, LLPs) | 0.06 | 0.85 | 0.01* | 0.00** |
| Irrigated Area by Irrigation Equipment (DTWs, STWs, LLPs) | 0.19 | 0.98 | 0.00** | 0.00** |
| No. of Tractors | 0.40 | 0.33 | 0.00** | 0.00** |
| No. of Power Tillers | 1.00 | 0.74 | 0.00** | 0.00** |
| Fertilizer Consumption | 0.92 | 0.02* | 0.00** | 0.00** |
| Energy Consumption | 0.39 | 0.01* | 0.00** | 0.00** |
| Arable Land Area | 0.10 | 0.09 | 0.00** | 0.00** |

Source: Eviews software based on annual time series data (19991-2022). Notes: ** P<0.01, *P<0.05.

Table 3. Phillips-Perron (PP) Unit Root Test of Dependent and Independent Variables

| Variables | Level | | First Difference | |
|---|-----------|---------------------|------------------|---------------------|
| | Intercept | Intercept and Trend | Intercept | Intercept and Trend |
| Crop Production | 0.93 | 0.29 | 0.00** | 0.00** |
| Gross Domestic Product | 1.00 | 0.98 | 0.00** | 0.00** |
| Income Inequality | 0.11 | 0.06 | 0.00** | 0.00** |
| Employment in Agriculture | 0.95 | 0.47 | 0.00** | 0.01* |
| Electricity Consumer in Agriculture | 0.58 | 0.57 | 0.00** | 0.00** |
| Irrigation Equipment (DTWs, STWs, LLPs) | 0.07 | 0.87 | 0.00** | 0.00** |
| Irrigated Area by Irrigation Equipment (DTWs, STWs, LLPs) | 0.07 | 0.64 | 0.00** | 0.00** |
| No. of Tractors | 0.44 | 0.37 | 0.00** | 0.00** |
| No. of Power Tillers | 0.40 | 0.04* | 0.00** | 0.00** |
| Fertilizer Consumption | 0.97 | 0.03* | 0.00** | 0.00** |
| Energy Consumption | 0.38 | 0.01* | 0.00** | 0.00** |
| Arable Land Area | 0.11 | 0.09 | 0.00** | 0.00** |

Source: Eviews software based on annual time series data (19991-2022). Notes: **P<0.01, *P<0.05.

The use of machines in farming has helped Bangladesh increase the production of rice, wheat, maize, and some vegetables. It all started with water pumps for irrigation, and later, as high-yield rice became popular, the need for irrigation grew. According to the World Bank (2025a) report, 78.9% of the arable land area is irrigated, which has boosted food production. Machinery such as tractors and irrigation equipment increase crop production by working continuously, as opposed to humans, who feel tired. This continuous activity produces larger production though the cultivation of additional land. Producing and operating agricultural machines requires significant energy, mostly from fossil fuels, along with some human labor. Although mechanization reduces the need for human and animal effort, it increases reliance on energy for both manufacturing and operation. This links agriculture closely to the cost and availability of petroleum. While inputs like fertilizers and pesticides also demand high energy, their proper use often leads to higher crop yields (Magdoff, 1982). On the other side, the amount of power tillers (significant at the 1% level) has an undesirable effect on crop yields, which was not expected. Though power tillers boost crop yields, farmers in developing countries like Bangladesh lack proper training. Consequently, improper use of agricultural mechanization (power tillers, tractors, etc.) can result in poor water retention, decreased soil aeration, and compaction of the soil (Kansanga et al.

2020). Moreover, heavy machinery can compact soil, diminishing fertility and increasing erosion risk (Rahman, 2023). Heavy farm machines may harm soil structure, and lubricant can leak into the soil during servicing, resulting in soil pollution (Robin, 2024; Magdoff, 1982). Farm mechanization loosens soil structure, making it more vulnerable to erosion by wind and water. During heavy rainfall, oversaturation causes nutrient-rich soil to wash away, degrading soil quality (Ovie, 2024; Magdoff, 1982). Soil erosion depletes fertility and reduces crop yields. The loss of topsoil makes it difficult to sustain agricultural productivity, and in extreme cases, the land may become unsuitable for cultivation.

Effect of Agricultural Mechanization on GDP

Similar effects of agricultural mechanization can be observed on gross domestic product (GDP) in the country. Other than for the number of irrigation equipment, all independent variables have positive and significant (at 1% and 5% significance levels) effects on GDP in Bangladesh. As a result, higher agricultural mechanization contributes to an increase in GDP, although the impact of fertilizer use is not statistically significant. The usage of modern agrarian machinery has had a substantial impact on Bangladesh's agricultural sector. According to Solow's (1956) 'Growth Theory' technological progress in agriculture shifts the production function upward, leading to an increase in GDP per capita, although the capital and labor force are unchanged. By reducing seasonal variations, mechanization helps to significantly raise crop output, hence supporting food security in Bangladesh. Enhanced food security strengthens the trade position of the nation by lowering dependence on food imports. Moreover, as food becomes cheaper and more accessible, the standard of living and purchasing power of the people rise. Increased agricultural efficiency allows government spending on this sector to be cut, hence generating more budgetary space for investment in other sectors of the economy and finally helping gross domestic product to grow. Tractors and irrigation systems are examples of agricultural equipment that has increased agricultural output as well as effectiveness, allowing farmers for faster agricultural operations using fewer workers. This advancement has strengthened food security and contributed to economic growth (Rahman, 2023). Farm mechanization further drives economic development by improving agricultural efficiency, which, in turn, raises farmers' profits and supports broader economic growth (Agri Studoc, 2023). An estimated BDT 2,000 is required to prepare one Bigha (33 decimals) of land using an animal drawn plow³. The cost decreases to BDT 600 only if a tractor is used in Bangladesh (Hasib, 2021). Mechanized farming has played a transformative role in Bangladesh's economic advancement by streamlining agricultural processes, reducing dependence on manual labor, and increasing productivity (LightCastle Partners, 2022). The adoption of mechanized tools helps

³BDT=Bangladeshi Taka, the official currency of Bangladesh.

minimize post-harvest losses and lower production expenses, allowing farmers to enhance profitability and reinvest in innovative agricultural solutions (Cereal Systems Initiative for South Asia, 2022). The rising demand for farming technology has also driven investments in equipment manufacturing, fostering industrial growth and promoting advancements in the sector (LightCastle Partners, 2022). Mechanization contributes to increased agricultural output, which then, in essence, supports the expansion of numerous agro-based companies (Pran Group, ACI Limited, Kazi Farms Group, etc.) and raises the gross domestic product of the nation. Moreover, increasing agricultural production through mechanization boosts trade surplus, and that in effect increases GDP because it is a component of GDP. The overall growing use of mechanization strengthens the agricultural landscape of Bangladesh, fostering rural economic growth, and supports long-term economic resilience. Conversely, according to the regression results, irrigation equipment (significant at the 5% level) has an adverse effect on Bangladesh's gross domestic product (GDP). Over-dependence on irrigation equipment like deep tube wells, shallow tube wells, and low lift pumps can negatively impact GDP by depleting groundwater reserves and escalating energy expenditures, leading to unsustainable farming methods (Barbier, 2024). Additionally, excessive water application can harm soil health by washing out soil nutrients, diminishing long-term agricultural productivity, and, as a result, hindering economic growth. In developing countries like Bangladesh, over-irrigation, inefficient use of irrigation equipment, and poor maintenance impede output and growth.

Effect of Agricultural Mechanization on Income Inequality

According to findings, agricultural mechanization has an adverse impact on income inequality. Apart from consumption of energy (significant at the 1% level), every independent variable has a positive effect on income inequality. It means that increasing the number of electricity consumers (significant at the 5% level), the number of irrigation equipment (significant at the 5% level), the irrigated area by irrigation equipment (not significant), the number of tractors (not significant), power tillers (significant at the 10% level), fertilizer consumption (not significant), and arable land area (not significant) raises the Gini index, hence growing income inequality in Bangladesh. Small-scale farmers, who constitute a significant portion of the farm labor force, often struggle to afford modern technology, leading to disparities in mechanization levels. For small-scale farmers to successfully adopt and use mechanized technology, access to credit, training, and technical assistance can be essential. Income gaps may increase in areas without these support networks since wealthy farmers have greater access to resources and automation options. The high cost of purchasing and maintaining agrarian machinery creates financial barriers, limiting small farmers' ability to adopt advanced farming techniques. Although the government of Bangladesh distributed a significant number of farm machinery through subsidy programs, the needy farmers didn't receive the full

benefits because of third parties. Even many farmers are unaware of the allocation made in their name (Shahid, 2024). This, in turn, contributes to differences in productivity and income between large and small farms, potentially exacerbating economic inequality (Rahman, 2023). According to the International Food Policy Research Institute (IFPRI), smallholder and marginal farmers have comparatively limited access to labor-saving technologies like power tillers, which are used more frequently as farm sizes increase (Ahmed et al. 2021). The increased efficiency of automated farms can drive down prices, putting pressure on small farmers who lack the means to compete at the same scale. In Bangladesh, because land is often small and broken into scattered plots, it's tough for many small farmers to make cost-effective use of modern machinery. Meanwhile, better off landowners with larger farms find it easier to adopt these technologies, which boost their yields and income. Moreover, using machinery usually results in higher returns on investment, benefiting those who can afford such equipment. This shift reduces the share of income that goes to labor, which is the main source of income for poorer households. Mechanization, when focused primarily on already developed regions (for Bangladesh: Dhaka, Chattogram, Gazipur, parts of Rajshahi, and Sylhet), can unintentionally widen the gap between advanced and underdeveloped areas (Hill Tracts region, River Island region). This unequal distribution of machinery resources often leads to increased regional economic inequality. Such disparities make it more difficult to achieve social and economic equity across the country (Magdoff, 1982). Moreover, agricultural mechanization widens the income gap between skilled and unskilled workers because skilled workers who benefit from mechanization have greater opportunities to earn more than unskilled workers. On the contrary, energy consumption can help reduce income inequality in agriculture by facilitating the use of mechanized farming tools, improving productivity, and lowering operational costs. Access to energy enables small-scale farmers to enhance their yields and minimize labor requirements, ultimately increasing their income. This, in turn, narrows the income gap by allowing farmers to reinvest in their operations, leading to more excellent economic stability in rural areas (Ahlborg and Sjöstedt, 2015).

Effect of Agricultural Mechanization on Employment in the Agriculture Sector

Agricultural mechanization has had a mixed adverse and favorable effect on employment rates in Bangladesh's agricultural sector. Irrigated areas by irrigation equipment (significant at the 5% level), number of tractors used (significant at the 1% level), number of power tillers (significant at the 5% level), fertilizer consumption (not significant), and energy consumption (significant at the 1% level) all have a negative impact on agricultural employment rates. This means that these types of mechanization reduce jobs in the farming industry. However, the number of electricity consumers in the agricultural sector (significant at the 1%

level), the quantity of irrigation equipment (significant at the 1% level), and arable land area (not significant) have a favorable effect on employment rates. Therefore, these types of mechanization boost employment rates. Low-skilled workers make up the majority of the workforce in rural parts of developing nations like Bangladesh, and the majority cannot use modern agricultural equipment. They lose their jobs due to a dearth of training facilities in rural areas, which leads to structural unemployment in those places. Mechanization in agriculture shortens the harvesting period, which creates a seasonal unemployment problem. Technological advancements in agriculture can only help those who possess the necessary skills. Low-skilled or unskilled workers must change professions, which is challenging for them but causes frictional unemployment in countries like Bangladesh. Farm workers who rely on manual labor may be forced to seek alternative employment, often migrating to cities for work. Over the past three decades, many rural workers in Bangladesh have migrated to metropolitan areas, seeking opportunities in the growing service and RMG sectors. This shift has contributed to labor shortages in agriculture, particularly during crucial periods like planting and harvesting (Robin, 2023). This shortage of labor during crucial periods increases wage rates, and researchers found that participation in the agricultural labor force declined between 2005 and 2022, while real wages in agriculture steadily increased from 2010 to 2022 in Bangladesh. Additionally, farmers lacking the expertise to operate and maintain machinery may depend on external service providers, increasing production costs and reducing self-sufficiency (Rahman, 2023). As mechanization reduces the demand for farm labor, rural populations may decline, disrupting local economies and communities. In Bangladesh, significant number of (approximately 18.43 million in 2022) women are engaged in agricultural work. Mechanization displaces their jobs (Haggblade et al. 2010), and they have no alternatives to shift to other professions, which increases rural women's unemployment. The output per labor is significantly increased as a result of mechanization, which necessitates less labor in the agricultural sector (Magdoff, 1982), and it has a very adverse effect on employment in labor-intensive countries like Bangladesh. On the flip side, increasing electricity consumers in agriculture helps farmers adopt better technologies and irrigation facilities, leading to higher productivity and more jobs for skilled workers. More irrigation equipment enables year-round farming, creating additional employment opportunities in planting and maintenance. It is true that as machines take the place of animals, less animal feed is required, potentially freeing up more arable area for the production of human food (Magdoff, 1982). As the amount of arable land increases, more workers are needed for tasks like land preparation and harvesting, boosting employment in the agricultural sector of Bangladesh. Furthermore, modern farming machinery has raised domestic demand for machinery and spare parts, which has led to the creation of new job opportunities in the industrial sector of Bangladesh (ACI Motors Ltd., Alim Industries Ltd., and The Metal (Pvt.) Ltd., etc.).

Table 4. Results of Fully Modified OLS (FMOLS)

| Independent Variables | Crop Production | | Gross Domestic Product | | Income Inequality | | Employment in Agriculture | |
|---|-----------------|---------|------------------------|---------|-------------------|---------|---------------------------|---------|
| | Coefficients | Prob. | Coefficients | Prob. | Coefficients | Prob. | Coefficients | Prob. |
| Electricity Consumers in Agriculture | 0.004 | 0.86 | 0.152 | 0.00*** | 0.075 | 0.01** | 0.076 | 0.00*** |
| Irrigation Equipment (DTWs, STWs, LLPs) | 0.517 | 0.00*** | -0.415 | 0.01** | 0.079 | 0.03** | 0.201 | 0.00*** |
| Irrigated Area by Irrigation Equipment (DTWs, STWs, LLPs) | 0.828 | 0.00*** | 0.549 | 0.02** | 0.134 | 0.30 | -0.200 | 0.04** |
| No. of Tractors | 0.037 | 0.03** | 0.064 | 0.03** | 0.024 | 0.15 | -0.037 | 0.00*** |
| No. of Power Tillers | -0.888 | 0.00*** | 0.848 | 0.02** | 0.418 | 0.05* | -0.384 | 0.01** |
| Fertilizer Consumption | 0.220 | 0.00*** | 0.019 | 0.88 | 0.086 | 0.27 | -0.003 | 0.95 |
| Energy Consumption | 0.841 | 0.00*** | 1.024 | 0.00*** | -0.354 | 0.00*** | -0.575 | 0.00*** |
| Arable Land Area | 0.519 | 0.27 | 3.290 | 0.00*** | 0.011 | 0.97 | 0.530 | 0.12 |
| R ² | | 0.98 | | 0.99 | | 0.58 | | 0.98 |

Source: Eviews software on the basis of annual time series data (1991-2020). **Notes:** *** p<0.01, ** p<0.05, * p<0.10.

However, we have to take some important actions in order to overcome the obstacles of agricultural mechanization in Bangladesh. Promoting sustainable, eco-friendly machinery practices can help reduce the adverse effects and maintain a balanced approach to agricultural mechanization in Bangladesh (Rahman, 2023). Establishing agro-service centers, strengthening land policies, providing low-interest loans and long-term credit support from financial institutions, and allocating funds for machinery research and development are crucial for the sustainable development of the agricultural sector of Bangladesh (Islam and Shirazul, 2009; Hossen, 2019). The government and private sector should establish machinery rental centers for hiring agricultural machinery to enable small farmers to access modern equipment to increase crop production (West Africa Examination Councils, 2019).

Conclusion

Agricultural mechanization has produced both positive and negative effects on Bangladesh's national economy during the period 1991-2022. The empirical results indicate that mechanization contributes positively and significantly to overall crop production and gross domestic product (GDP), highlighting its important role in improving agricultural productivity and economic growth. However, the analysis also reveals some unfavorable outcomes. Specifically, the number of power tillers and irrigation equipment shows negative effects on crop production and GDP, respectively. Moreover, agricultural mechanization has a significant adverse impact on income inequality and employment in the agricultural sector, suggesting that increased mechanization may reduce labor demand and widen income disparities in rural areas. On the other hand, energy consumption has a favorable effect on income inequality, while the number of electricity consumers, irrigation equipment, and the area of arable land positively influence employment. Based on these findings, several policy measures are recommended to address the challenges associated with agricultural mechanization in Bangladesh. These include expanding agro-service centers, promoting environmentally sustainable mechanization, reforming land policies, providing low-interest credit facilities, establishing machinery rental service centers to ensure more inclusive and balanced agricultural development.

Limitations of the Study

Because of the unavailability of annual time series data from 1991 to 2022, this study could not include some important independent variables such as the number of transplanters, seeders, weeders, threshers, etc. Future research may find new dimensions by including these variables.

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EFFECT OF RHIZOBIUM INOCULATION AND CHEMICAL FERTILIZER ON GROWTH AND YIELD OF LENTIL GENOTYPES IN GANGES TIDAL FLOODPLAIN SOIL

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Abstract

A field experiment was conducted in Rahmatpur, Barishal, within the Ganges Tidal Floodplain, to evaluate the effect of *Rhizobium* inoculant and chemical fertilizer on lentil (*Lens culinaris* L.) growth and yield. The study employed a split-plot design with three replications, investigating three lentil genotypes: BARI Masur-1, BARI Masur-7 and BD-3818, and five fertilizer treatments: Control, *Rhizobium* inoculum, recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB, recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum and 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum. Results indicated that the growing year did not significantly influence lentil growth and yield. BARI Masur-7 consistently outperformed the other genotypes, demonstrating superior performance across various growth and yield parameters including plant population, plant height, days to flowering and maturity, primary branches, fresh and dry weight of leaves and roots, number of pods per plant, number of seeds per pod, thousand-seed weight, seed yield, stover yield, biological yield, and harvest index. Furthermore, BARI Masur-7 exhibited a lower incidence of foot rot and Stemphylium blight. The most effective treatment combination for BARI Masur-7 was found to be 50% of the recommended chemical fertilizer N₁₀P_{7.5}K_{12.5}S₅Zn₁B_{0.75} kg ha⁻¹ combined with *Rhizobium* inoculum (30g/kg seed). This combined approach resulted in the highest seed yield (1636 kg ha⁻¹), highest harvest index (46.9%), and a favorable benefit-cost ratio (3.84). Additionally, this treatment significantly reduced the incidence of Foot rot (1.16%) and Stemphylium blight (0.33 on a 0-5 scale) compared to other treatments. These findings highlight a promising and sustainable approach for enhanced lentil production in the Ganges Tidal Floodplain soil.

Keywords: Disease incidence, *Lens culinaris* L., growth, profitability, yield contributing characters.

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Introduction

Lentil (*Lens culinaris* L.) is a vital pulse crop in Bangladesh (Aktar *et al.*, 2019), accounting for 40% of the country's cultivated pulse area and serving as a preferred food and nutrition source (BBS, 2019). Lentils, popularly known as Poorman's meat, are used to prepare an inexpensive and nutritious split with rice (*Hotchpoch*) all over Bangladesh, which provide more complete protein. Globally, lentil plays a crucial role in food and nutritional security due to its high protein content, carbohydrate, vitamin B complex and minerals and ability to enrich soil through biological nitrogen fixation (Khazaei *et al.*, 2019). Despite its importance, the per capita pulse consumption in Bangladesh (12 g day^{-1}) is significantly lower than the WHO's recommended intake (45 g day^{-1}), highlighting a critical nutritional gap. Bridging this gap necessitates increasing pulse production through effective fertilizer management and the adoption of high-yielding varieties.

Lentil cultivation in Bangladesh is concentrated in the ecologically sensitive Ganges Tidal Floodplain area. This region presents unique agricultural challenges due to its distinct hydrological regime and dynamic soil properties. The soils, primarily silty clay loam to clay, exhibit varying degrees of alkalinity and salinity. These soils often suffer from nutrient imbalances and deficiencies, particularly in phosphorus, sulfur, zinc, and boron, which restrict crop growth and yield (Rahman *et al.*, 2023). Furthermore, the area is susceptible to waterlogging, flash floods, and increasing climate change impacts like sea-level rise and exacerbated salinity intrusion, all of which complicate sustainable agricultural practices (Gopalakrishnan *et al.*, 2019).

To address these challenges and boost lentil productivity, effective nutrient management is paramount. Traditional approaches often rely on imbalanced or excess chemical fertilizer use, leading to environmental concerns, increased production costs, and potential long-term soil degradation (Krasilnikov *et al.*, 2022). A more sustainable alternative involves leveraging the symbiotic relationship between lentil plants and nitrogen-fixing *Rhizobium* bacteria. *Rhizobium* inoculation can significantly reduce dependence on synthetic nitrogen fertilizers, improve soil health, and contribute to environmentally friendly agriculture (Quddus *et al.*, 2024). The effectiveness of *Rhizobium* inoculation can vary based on soil type, environmental conditions and lentil genotype. The unique characteristics of the Ganges Tidal Floodplain soil, including its fluctuating salinity and water regimes, may influence Rhizobial survival, nodulation, and nitrogen fixation efficiency. Currently, there is a lack of research on how *Rhizobium* inoculation interacts with chemical fertilizer application in this specific soil type. Understanding this interaction is crucial for optimizing nutrient management. Additionally, evaluating different lentil genotypes under these varying management regimes is essential to identify the best varieties for the region's challenging conditions. This study aims to investigate the effect of *Rhizobium*

inoculation and varying levels of chemical fertilizer application on the growth and yield of different lentil genotypes cultivated in the Ganges Tidal Floodplain soil. The findings will provide valuable insights into the sustainable intensification of lentil production in this ecologically sensitive and agriculturally important region, ultimately contributing to improved food and nutritional security and farmer livelihoods.

Materials and methods

A field experiment was conducted during Rabi season of two consecutive years 2014-15 and 2015-16 at the Agronomy research field of Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Rahmatpur, Barishal (22°48' N, 90°18' E). The study area is located within the Ganges Tidal Floodplain (AEZ-13). This well-drained, medium-high land features even topography and a clay loam texture. The soil is characterized by low organic matter content (0.94%), a neutral soil reaction (pH: 6.9), low total nitrogen content (0.043%), available P (10.6 $\mu\text{g g}^{-1}$), S (2.9 $\mu\text{g g}^{-1}$), B (0.16 $\mu\text{g g}^{-1}$), exchangeable K (0.16 meq. 100 g^{-1}) and is slightly saline (1.20 dS/m). The experimental area experiences a sub-tropical, dry or savanna climate. The average annual temperature is approximately 28.8°C, which is slightly higher than the average for Bangladesh. The region receives significant rainfall, averaging 46.9 mm annually over approximately 95.6 mm in rainy days.

The land was prepared using a tractor-driven chisel plough. This involved three rounds of ploughing and cross-ploughing, followed by laddering, to achieve the optimal soil tilth. The experimental treatments were structured with two factors: Factor A (main plot) five levels of fertilizer application viz., T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). Factor B (Sub-plot) three different genotypes viz. G_1 = BARI Masur-1, G_2 = BARI Masur-7 and G_3 = BD-3818. The seeds of different genotypes were collected from Pulse Research Centre, BARI, Ishordi, Pabna, and the *Rhizobium* inoculum was collected from the Division of Soil Science, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh.

The experiment was designed as a split-plot with three replications. The experimental area was firstly divided into three large blocks and then each block was further divided into five main plots. Subsequently, each main plot was subdivided into three smaller sub-plots. Fertilizer levels were randomly assigned to the main plots, while different genotypes were assigned to the sub-plots. Each individual plot measured 3 meters by 6 meters, with a 1-meter border separating plots and a 2-meter border between replications. In total, the experiment was

comprised of 45-unit plots. Nutrients N, P, K, S, Zn and B were applied treatment wise as urea, TSP, MoP, gypsum, zinc sulphate (heptahydrate) and boric acid; respectively during final plot preparation.

Before sowing, the seeds were first lightly coated with molasses. This sticky layer helped the bio-fertilizer adhere better to the seeds when it was subsequently mixed at a rate of 30 grams per kilogram of seeds. After thorough mixing, the inoculated seeds were stored in a cool, dry place to prevent them from clumping together. Before sowing, seeds were treated with Provex-200 at 2.5 g/kg seeds to control the seed-borne diseases. Treatment wise seeds were sown at 35 kg ha⁻¹ in rows by hand with the spacing of 30 cm × continuous placing in the second week of November in both years. Weeds were controlled, plants were thinned, irrigation was provided, and plant protection measures were taken as needed. The crop was harvested once 90% of the plants and pods had turned brown to black. After harvest, the crop bundles were sun-dried on a threshing floor. Seeds were then separated from the plants by beating the bundles with bamboo sticks. A winnower was used to separate the grain from the straw. Finally, the dry seeds and stover from each plot were weighed and the yields were converted to kilograms per hectare.

Data collection and recording were done properly: For plant population, a one-square-meter area was marked with rope in each plot. Plants within this area were counted 20 days after sowing (DAS) to determine the number of plants per square meter. Plant height was measured on ten randomly selected plants from outside the harvest area at 20, 40, 60, and 80 DAS. Measurements were taken from ground level to the tip of the plant and recorded in centimeters. The number of primary branches was counted at harvest on the same ten selected plants. Days to first flowering and 50% flowering were recorded by visual observation. Days to maturity was recorded when plant growth ceased and 90% of the plants and pods had turned from straw to black. At 50 DAS, ten plants were randomly selected from outside the harvest area in each unit plot, tagged, uprooted, and brought to the laboratory. Fresh leaves were separated from each branch, and their fresh weight was determined in grams using an electric balance. The collected fresh leaves were then oven-dried at 70°C for 72 hours. After cooling, their dry weight was also measured in grams with an electric balance. At 80 DAS, ten plants were randomly selected from outside the harvest area in each unit plot and tagged. The roots were cut, stored in paper bags, washed, and cleaned. Their fresh root weight was determined in grams. These root samples were then oven-dried at 70°C for 72 hours. After cooling, their dry root weight was measured in grams using an electric balance. At maturity, the number of pods per plant was counted on the same ten selected plants in each treatment. From these ten sampled plants, ten randomly selected pods were collected, and the number of

seeds per pod was counted. Finally, a composite sample from each treatment was used to determine thousand seed weight. One thousand seeds were counted and weighed using a digital electric balance. The weight was adjusted to 9% moisture content and recorded in grams.

The incidence of foot rot, caused by *Fusarium oxysporum* Schltdl., was recorded at 25, 50, and 75 DAS. This was determined by counting the number of foot rot infected plants per square meter area and the percentage of incidence was then calculated using the following formula:

$$\text{Incidence of foot rot (\%)} = \frac{\text{Number of foot rot infected plants /m}^2}{\text{Total number of plants /m}^2} \times 100$$

The incidence of Stemphylium blight, caused by *Stemphylium botryosum*, was assessed twice: once before flowering and again after pod formation. A 0-5 point scoring scale (Bakr and Ahmed, 1992) was used to evaluate the level of infection, where: 0 = highly resistant, 1 = resistant, 2 = moderately resistant, 3 = moderately susceptible, 4 = susceptible, and 5 = highly susceptible, whereas Biological yield and Harvest index were calculated using the following formula:

$$(i) \text{ Biological yield (kg ha}^{-1}\text{)} = \text{Grain yield} + \text{Stover yield}$$

$$(ii) \text{ HI (\%)} = \frac{\text{Seed yield}}{\text{Seed yield} + \text{Stover yield}} \times 100 = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \text{ (Donald, 1963).}$$

Cost and return analysis: For each treatment, the total variable cost (TVC) per hectare for lentil cultivation was determined, encompassing expenses for labor, plowing, fertilizers, seeds, and pesticides. Land rental costs were excluded from this analysis. Gross return per hectare was calculated by multiplying the seed yield (converted to kg ha⁻¹) by the current market price. Net return was then calculated by subtracting the TVC from the gross return. Finally, the benefit-cost ratio (BCR) was determined using the following formula: BCR = Gross Return ÷ Total Variable Cost.

Statistical analysis: The collected data were subjected to statistical analysis of variance (ANOVA) using the open-source software R (version 3.5.2; Vienna, Austria; <https://www.R-project.org/>). To compare the means of all data, the least significant difference (LSD) test was applied within the R statistical model at 5% level of probability.

Weather and climate

Some weather data were collected from the RARS, Bangladesh Agricultural Research Institute (BARI), Rahmatpur, Barishal for the experimentation (Fig. 1).

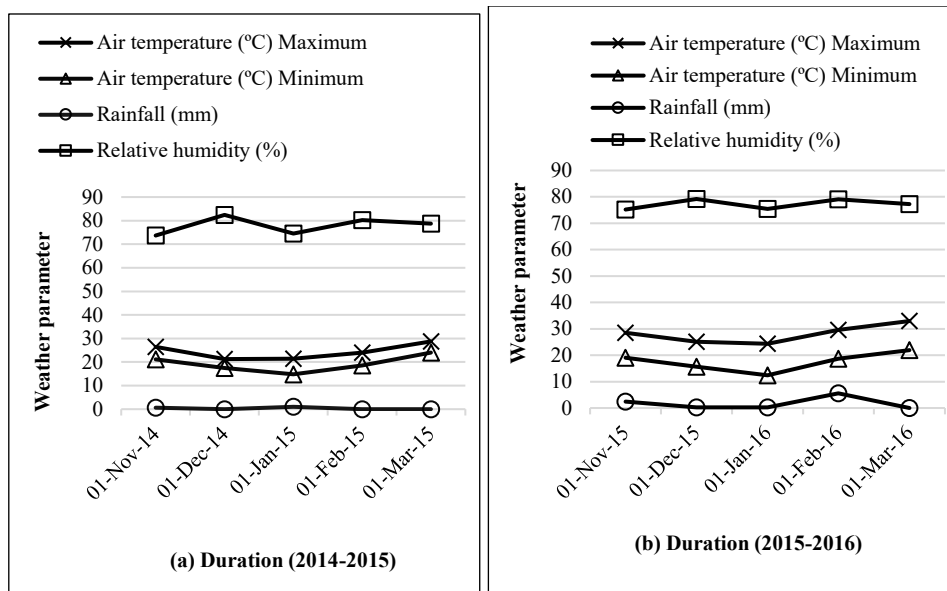


Fig. 1 (a, b). Monthly average of maximum, minimum air temperature, rainfall and relative humidity during the *Rabi* season in 2014-2015 and 2015-2016 at RARS, Barishal.

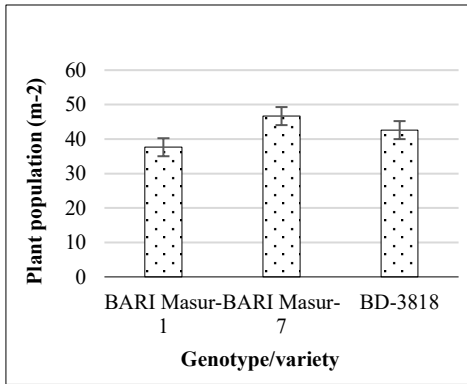
Results and Discussion

Effect of growing year on the growth and yield attributes of lentil

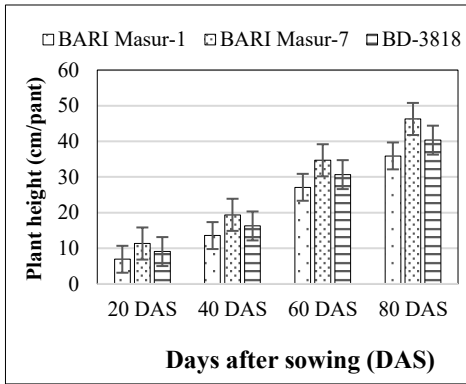
Lentil growth and yield attributes remained consistent, showing no significant difference between the growing seasons of 2014-15 and 2015-16 (Data not presented).

Effect of genotype/variety on the growth and yield attributes of lentil

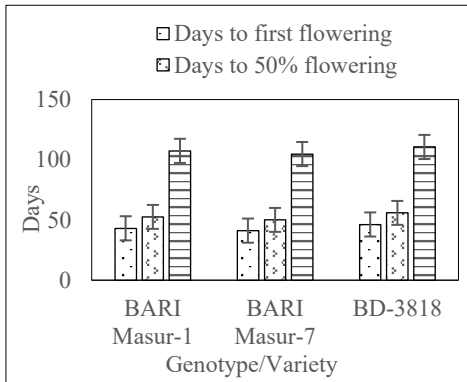
Fig. 2 shows that BARI Masur-7 exhibited significantly superior performance compared to BD-3818 and BARI Masur-1 in respect to plant population m^{-2} , plant height, primary branches $plant^{-1}$, fresh and dry weight of leaf and root, number of pods $plant^{-1}$, number of seeds pod^{-1} , thousand seed weight, yield and harvest index. Furthermore, BARI Masur-7 showed fewer days to flowering and maturity, and a lower incidence of Foot rot and Stemphylium blight.



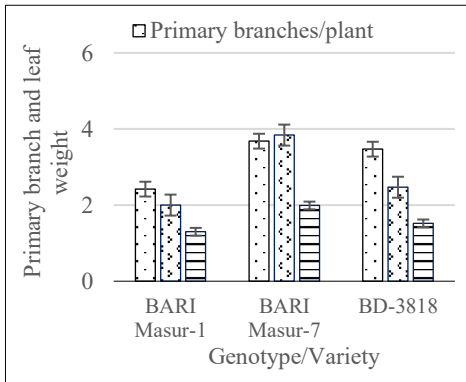
(a) Effect of genotype on plant population



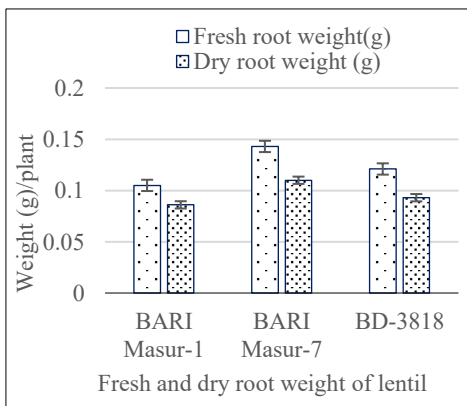
(b) Effect of genotype on plant height



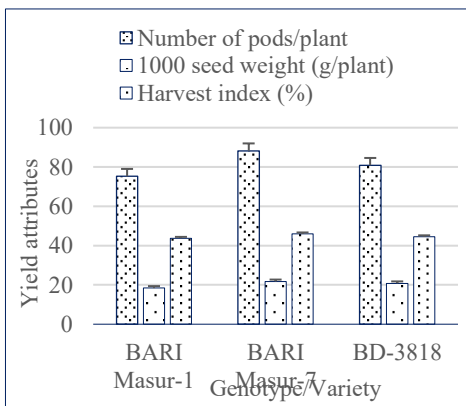
(c) Effect of genotype on flowering and maturity



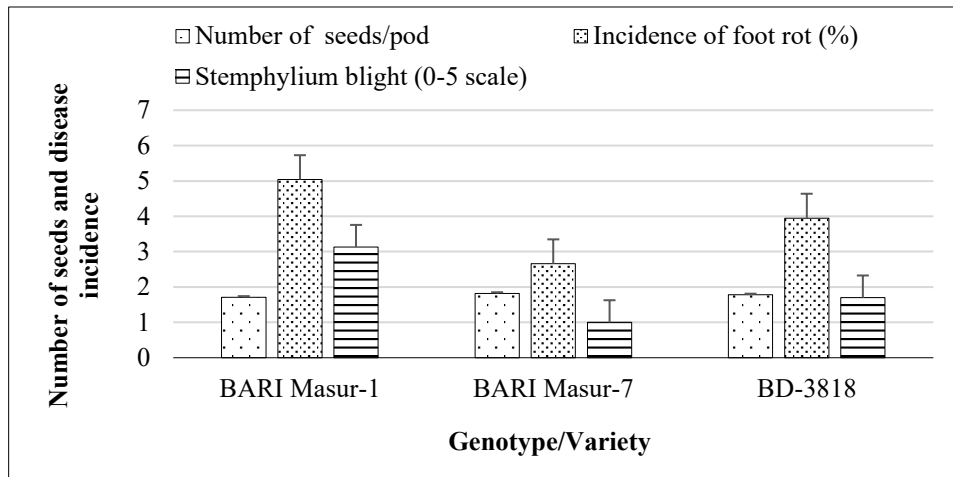
(d) Effect of genotype on 1st branch and leaf weight



(e) Effect of genotype on root weight of lentil



(f) Effect of genotype on yield attributes of lentil



(g) Effect of genotype on number of seeds/pod and disease incidence

Fig. 2 (a-g) Effect of genotype/variety on the growth, yield attributes and yields of lentil. Vertical bar indicates standard error of mean at 5% level of significance by LSD test.

Effect of Rhizobium inoculation and chemical fertilizers on growth and yield attributes of lentil

Lentil plant population and height were significantly affected by various fertilizer management practices (Table 1). The highest plant population (49.2) was observed in treatment T₅, which involved applying 50% of 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB kg ha⁻¹ along with *Rhizobium* inoculum (30 g/kg seed). The highest plant population observed with a combination of 50% inorganic fertilizer and *Rhizobium* inoculation is likely due to the bacteria's ability to enhance seed germination and seedling survival. *Rhizobium*, nitrogen-fixing bacteria, plays a crucial role in promoting healthy plant growth and population, by converting atmospheric nitrogen into a usable form for the plant. This symbiotic relationship between *Rhizobium* and legume can significantly increase plant vigor and population (Argaw, 2017). In contrast, the control treatment (T₁) had the lowest population (35.8). Lentil plant height significantly increased with plant age, showing a sharp rise up to 80 days after sowing (DAS) across all fertilizer treatments (Table 1). The tallest plants (47.6 cm) were observed in the T₅ treatment, while the control treatment had the shortest plants (34.8 cm) at 80 DAS.

Table 1. Effect of fertilizer management practices on plant population and plant height of lentil genotypes

| Treatment | Plant population/m ² at 20 DAS | Plant height (cm) | | | |
|----------------|---|-------------------|--------|--------|--------|
| | | 20 DAS | 40 DAS | 60 DAS | 80 DAS |
| T ₁ | 35.8 | 7.00 | 13.3 | 26.1 | 34.8 |
| T ₂ | 42.3 | 9.07 | 16.6 | 30.5 | 40.2 |
| T ₃ | 38.9 | 8.97 | 16.1 | 28.9 | 38.3 |
| T ₄ | 45.2 | 9.25 | 16.9 | 32.5 | 43.4 |
| T ₅ | 49.2 | 11.2 | 19.1 | 36.1 | 47.6 |
| LSD (0.05) | 3.01 | 0.35 | 0.61 | 1.53 | 1.09 |
| CV (%) | 10.08 | 5.38 | 5.28 | 7.04 | 3.79 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation, DAS= Days after sowing. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Many researchers have reported that *Rhizobium* inoculation and fertilizer application significantly boost all growth parameters in legume crops. For instance, Malik *et al.* (2014) found a maximum significant increase ($P \leq 0.05$) in mungbean plant height when compost, *Rhizobium*, and nitrogen were applied together. Plant height varies among different varieties. In line with the findings, BARI Masur-7 exhibited the tallest plants in our study.

As presented in Table 2, fertilizer management practices significantly impacted several lentil growth parameters, including days to flowering and maturity, primary branches plant⁻¹ and the fresh and dry weights of leaves and roots. The T₅ treatment significantly extended the time for lentil to reach its first flowering (46.9 days), 50% flowering (56.3 days), and full maturity (111 days). In contrast, the control treatment led to the quickest progression through

these developmental stages. While some literature indicates that higher nitrogen availability can prolong the vegetative phase and thus shorten the reproductive phase, it is also recognized that genotypic variations influence days to flowering. In this study, the T₅ treatment produced the maximum number of primary branches per plant (4.10), closely followed by the T₄ treatment. The control treatment, however, resulted in the fewest primary branches (2.42) (Table 2).

Table 2. Effect of fertilizer management practices on days to flowering, days to maturity, primary branches plant⁻¹, fresh and dry leaf weight, fresh and dry root weight of lentil genotypes

| Treatment | Days to flowering | | Days to maturity | Primary branches plant ⁻¹ at harvest | Fresh leaf weight (g) at 50 DAS | Dry leaf weight (g) at 50 DAS | Fresh root weight (g) at 80 DAS | Dry root weight (g) at 80 DAS |
|----------------|-------------------|------|------------------|---|---------------------------------|-------------------------------|---------------------------------|-------------------------------|
| | First | 50% | | | | | | |
| T ₁ | 40.3 | 49.7 | 105 | 2.42 | 1.96 | 1.29 | 0.10 | 0.08 |
| T ₂ | 43.1 | 52.2 | 108 | 2.85 | 2.70 | 1.63 | 0.11 | 0.09 |
| T ₃ | 42.4 | 51.9 | 107 | 2.66 | 2.54 | 1.48 | 0.11 | 0.09 |
| T ₄ | 44.8 | 54.2 | 108 | 3.92 | 2.89 | 1.73 | 0.12 | 0.10 |
| T ₅ | 46.9 | 56.3 | 111 | 4.10 | 3.43 | 1.90 | 0.13 | 0.11 |
| LSD (0.05) | 0.70 | 0.90 | 0.44 | 0.23 | 0.11 | 0.07 | 0.003 | 0.002 |
| CV (%) | 2.29 | 2.41 | 0.58 | 10.2 | 5.95 | 6.39 | 4.65 | 3.09 |

Means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

These findings align with existing research on branching in plants. Rahman *et al.* (2013) reported that branching is both a genetic characteristic and is influenced by environmental factors. Awal and Roy (2015) also confirmed that the number of branches can vary among different varieties. At 50 days after sowing (DAS), the T₅ treatment resulted in significantly the highest fresh leaf weight (3.43 g) and dry leaf weight (1.90 g), while the control treatment exhibited the lowest weights (Table 2). Significantly, the highest root fresh weight (0.13 g) and root dry weight (0.11 g) were observed in the T₅ treatment at 80 days after sowing (DAS) (Table 2). Conversely, the lowest root fresh and dry weights were recorded in the control treatment at 80 DAS. Our results indicate that lentil fresh and dry root weight largely depends on early root system development and nodule production. This also varies between varieties due to their genetic makeup. Notably, BARI Masur-7 exhibited higher individual root weight compared to BARI Masur-1 and BD-3818. The highest dry root weight was observed in BARI Masur-7 plots treated with 50% inorganic fertilizer + inoculants (T₅). This suggests that the combined application of inoculants and chemical fertilizers likely triggered an enhanced nodulation process, leading to a greater number of nodules and consequently, higher dry matter production.

Table 3 clearly demonstrates that the fertilizer management practices significantly influenced the yield attributes of lentil and the incidence of *Stemphylium* blight disease. However, these practices did not have a significant impact on the incidence of foot rot disease. In this study, significantly the maximum number of pods plant⁻¹ (92.5) was recorded in T₅, which involved applying 50% of inorganic 10-7.5-12.5-5-1-0.75 kg ha⁻¹ along with *Rhizobium* inoculum (30 g/kg seed) and the lowest (69.4) was in control treatment. Research consistently shows that the number of pods per plant is a significant factor in determining lentil yield.

Table 3. Effect of fertilizer management practices on the number of pods plant⁻¹, number of seeds pod⁻¹, thousand seed weight, Incidence of foot rot and *Stemphylium* blight of lentil genotypes

| Treatment | Number of pods plant ⁻¹ | Number of seeds pod ⁻¹ | Thousand seed weight (g) | Incidence of foot rot (%) | <i>Stemphylium</i> blight (0-5 scale) |
|----------------|------------------------------------|-----------------------------------|--------------------------|---------------------------|---------------------------------------|
| T ₁ | 69.4 | 1.67 | 19.9 | 5.63 | 2.83 |
| T ₂ | 81.9 | 1.78 | 20.4 | 3.78 | 1.88 |
| T ₃ | 76.0 | 1.74 | 20.0 | 4.41 | 2.33 |
| T ₄ | 87.3 | 1.81 | 20.5 | 3.35 | 1.55 |
| T ₅ | 92.5 | 1.85 | 20.7 | 2.26 | 1.11 |
| LSD (0.05) | 2.15 | 0.03 | 0.10 | NS | 0.32 |
| CV (%) | 3.74 | 2.55 | 0.76 | 27.7 | 23.5 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Our findings align with those of Sonkarlay *et al.* (2020), who observed the highest pod count (164 pods per plant) in lentils when chemical fertilizers were combined with biofertilizers and organic fertilizers. Further supporting this, studies by Datta *et al.* (2013) concluded that lentil seed yield is positively correlated with the number of pods per plant. This strong relationship underscores the importance of optimizing conditions for robust pod development. It is also worth noting that lentil genotypes themselves play a significant role in pod formation, with different varieties exhibiting varying capacities for pod production. Beyond lentils, the beneficial effects of bio-fertilizers on pod count are well-documented. In case of number of seeds pod⁻¹, significantly the highest number of seed (1.85) was found in T₅ treatment and the lowest (1.67) was in control (Table 3). Sonkarlay *et al.*, (2020) reported that the number of seeds pod⁻¹ (2.57) was the highest when applied 75% RDP+ farmyard manure @ 5 t/ha + biophos @ 20 ml/kg seed. Datta *et al.* (2013) found that the numbers of filled pods differ with varieties.

The weight of a thousand seeds, a key indicator of lentil quality and yield, was significantly impacted by different fertilizer management in our study. The highest thousand-seed weight (20.7 g) was observed in treatment T₅, while the lowest (19.9 g) came from the control treatment (Table 3). The application of inoculants alongside chemical fertilizers likely plays a crucial role by ensuring optimal nutrient availability, which in turn supports the development of heavier grains.

The effect of fertilizer management practice on the incidence of foot rot was insignificant and the incidence of foot rot ranged from 2.26 to 5.63% (Table 3). Hannan *et al.* (2012) reported that post-emergence deaths of plants due to foot rot disease were significantly reduced after combined seed treatment with BINA-bio-fertilizer and BAU-bio-fungicide. *Stemphylium* blight significantly impacted lentil health in our study. The control treatment exhibited the highest *Stemphylium* blight disease score (2.83), indicating severe susceptibility, while the T₅ treatment demonstrated the lowest score (1.11), suggesting a strong suppressive effect (Table 3). This highlights the crucial role of effective management practices in mitigating this disease. Our findings align with previous research on varietal resistance. Alam (2016) reported that certain lentil varieties show varying degrees of susceptibility to *Stemphylium* blight under field conditions. For instance, local varieties were highly susceptible, BARI Masur-3 and BARI Masur-4 showed moderate susceptibility, whereas BARI Masur-5, BARI Masur-6, and notably, BARI Masur-7 exhibited moderate resistance. This reinforces the importance of selecting resilient lentil genotypes, combined with appropriate fertilizer strategies, to minimize *Stemphylium* blight incidence.

Table 4 illustrates that lentil yields and harvest index were significantly influenced by the various fertilizer management practices. The T₅ treatment recorded the highest seed yield (1468 kg ha⁻¹), while the control treatment exhibited the lowest yield (1025 kg ha⁻¹). This finding was corroborated by Sonkarlay *et al.* (2020), who reported a superior seed yield (1550 kg ha⁻¹) in lentil when a combination of chemical, bio-fertilizer, and organic fertilizer was utilized. Similarly, Singh *et al.* (2013) documented significantly enhanced physiological parameters and grain yield (1236 kg ha⁻¹) in lentil treated with vermicompost (4 t ha⁻¹) in conjunction with *Rhizobium* and phosphate-solubilizing bacteria. Previous reports also indicated better growth with a combination of organic and inorganic fertilizers compared to inorganic fertilizers alone.

The T₅ treatment consistently outperformed the control in several yield parameters. Specially, T₅ yielded the highest stover (1721 kg ha⁻¹) compared to the control's 1341 kg ha⁻¹. This finding aligns with observations by Sonkarlay *et al.* (2020), where they reported even higher stover yields (1903 kg ha⁻¹) when a combination of chemical, bio-fertilizer and organic fertilizers was applied, suggesting a potential for further optimization beyond the T₅ treatment. Beyond stover yield, T₅ also demonstrated a significantly higher biological yield (3188 kg ha⁻¹) than the control (2366 kg ha⁻¹). This superior performance extended to the harvest index,

with T₅ achieving the highest (46.0%) compared to the control's lowest (43.3%) (Table 4). These results collectively indicate that the T₅ treatment positively influenced the overall biomass production and the efficiency of partitioning this biomass into harvestable yield.

Table 4. Effect of fertilizer management practice on seed yield, stover yield, biological yield, and harvest index of lentil genotypes

| Treatments | Seed yield (kg ha ⁻¹) | Stover yield (kg ha ⁻¹) | Biological yield (kg ha ⁻¹) | Harvest index (%) |
|----------------|-----------------------------------|-------------------------------------|---|-------------------|
| T ₁ | 1025 | 1341 | 2366 | 43.3 |
| T ₂ | 1319 | 1622 | 2944 | 44.7 |
| T ₃ | 1249 | 1562 | 2811 | 44.4 |
| T ₄ | 1396 | 1663 | 3059 | 45.6 |
| T ₅ | 1468 | 1721 | 3188 | 46.0 |
| LSD (0.05) | 15.5 | 19.6 | 34.9 | 0.09 |
| CV (%) | 1.70 | 1.75 | 1.72 | 0.30 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test. LSD = least significant difference, CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Interaction effect of genotype and fertilizer management on the growth and yield attributes of lentil

Table 5 indicates that plant population did not exhibit significant variations as a result of the interaction between fertilizer management practices and lentil genotypes. This suggests that the combination of different fertilizer approaches and lentil varieties did not lead to statistically different plant densities. A significant interaction effect of fertilizer management practices and lentil genotype was observed on plant height up to 40 days after sowing (DAS). Beyond this point, specifically up to 80 DAS, plant height was not significantly affected by these interactions. This highlights the importance of early-stage interactions in determining lentil plant height. The highest plant height measurements at both 20 DAS (13.3 cm) and 40 DAS (23.2 cm) were recorded in the T₅ × G₂ treatment combination (50% of inorganic N₁₀P_{7.5}K_{12.5}S₅Zn₁B_{0.75} kg ha⁻¹ + *Rhizobium* inoculum × BARI Masur-7). The lowest plant height was observed in the control × BARI Masur-1 treatment. The observed plant height data aligns with the previous findings, providing external validation for our results. The superior early growth (plant height) observed in the T₅ × G₂ treatment combination strongly suggests that the integrated use of bacterial inoculums (*Rhizobium*) alongside chemical fertilizers plays a crucial role in actively regulating the early development of lentil under optimum conditions. The interaction of fertilizer management practices and

genotype shows that the maximum number of days to reach first flowering, 50% flowering and maturity in lentil was observed in $T_5 \times G_3$ treatment combination (50% of inorganic 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum × BD-3818). On the other hand, the minimum days to first flowering, 50 percent flowering and maturity was in control × BARI Masur-7. These findings highlight that the $T_5 \times G_3$ treatment, which included *Rhizobium* inoculum alongside a partial dose of inorganic fertilizers, resulted in a longer vegetative phase and delayed reproductive development. While this might seem counterintuitive for early harvest, a prolonged growth period could potentially lead to greater biomass accumulation and, subsequently, higher yields, assuming favorable environmental conditions continue.

Table 5. Interaction effect of fertilizer management practices (T) × genotype (G) on lentil plant population, plant height, days to flowering and maturity

| Treatment (T) × Genotype (G) | Plant population/m ² | Plant height (cm) at | | | | Days to flowering | | Days to maturity |
|------------------------------------|------------------------------------|----------------------|-----------|-----------|-----------|----------------------|------|---------------------|
| | | 20 DAS | 40 DAS | 60 DAS | 80 DAS | First | 50% | |
| $T_1 \times G_1$ | 31.0 | 6.47 | 12.3 | 22.5 | 30.5 | 39.8 | 49.5 | 105 |
| $T_2 \times G_1$ | 38.0 | 6.73 | 13.7 | 26.8 | 34.9 | 43.2 | 52.3 | 107 |
| $T_3 \times G_1$ | 34.7 | 6.45 | 13.3 | 26.0 | 33.6 | 42.3 | 51.7 | 107 |
| $T_4 \times G_1$ | 40.5 | 6.93 | 13.8 | 28.7 | 39.1 | 44.3 | 53.8 | 108 |
| $T_5 \times G_1$ | 44.0 | 8.00 | 14.7 | 31.5 | 41.6 | 45.8 | 55.5 | 11 |
| $T_1 \times G_2$ | 40.0 | 7.82 | 14.5 | 29.9 | 39.5 | 38.3 | 47.8 | 103 |
| $T_2 \times G_2$ | 46.5 | 11.9 | 19.8 | 34.3 | 45.4 | 40.8 | 49.2 | 105 |
| $T_3 \times G_2$ | 42.7 | 11.7 | 19.4 | 31.9 | 43.9 | 40.2 | 49.7 | 104 |
| $T_4 \times G_2$ | 49.3 | 12.1 | 20.2 | 36.3 | 48.2 | 42.5 | 51.2 | 105 |
| $T_5 \times G_2$ | 54.8 | 13.3 | 23.2 | 41.1 | 54.5 | 44.0 | 52.5 | 107 |
| $T_1 \times G_3$ | 36.5 | 6.73 | 13.2 | 25.8 | 34.3 | 42.8 | 51.7 | 106 |
| $T_2 \times G_3$ | 42.5 | 8.6 | 16.2 | 30.5 | 40.2 | 45.3 | 55.0 | 111 |
| $T_3 \times G_3$ | 39.3 | 8.80 | 15.6 | 28.7 | 37.5 | 44.8 | 54.3 | 110 |
| $T_4 \times G_3$ | 45.8 | 8.73 | 16.8 | 32.6 | 43.0 | 47.5 | 57.5 | 112 |
| $T_5 \times G_3$ | 48.8 | 12.3 | 19.6 | 35.8 | 46.7 | 50.8 | 61.0 | 114 |
| LSD (0.05) | NS | 0.53 | 0.48 | NS | NS | 0.75 | 0.83 | 0.79 |
| CV (%) | 2.99 | 5.04 | 2.51 | 4.47 | 4.16 | 1.47 | 1.35 | 0.63 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G_1 = BARI Masur-1, G_2 = BARI Masur-7 and G_3 = BD-3818.

The *Rhizobium* inoculum might be contributed to a sustained nitrogen supply, raising vegetative growth before transitioning to flowering. In contrast, the rapid progression to flowering and maturity in the control \times BARI Masur-7 treatment suggests that under nutrient-limited conditions, the plants accelerated their reproductive cycle, possibly as a survival mechanism to ensure seed production. BARI Masur-7 appears to be a genotype that inherently matures earlier, and this characteristic is amplified when nutrient availability is low.

Table 6 illustrates the interactive effects of fertilizer management practices and genotype on various lentil plant parameters. In terms of primary branches per plant, the maximum number (4.75) was observed in the $T_5 \times G_2$ treatment combination (50% of inorganic $N_{10}P_{7.5}K_{12.5}S_5Zn_1B_{0.75}$ kg ha⁻¹ + *Rhizobium* inoculum \times BARI Masur-7). Conversely, the lowest number of primary branches (2.06) was recorded in the control \times BARI Masur-1 treatment. It is evident that treatments incorporating *Rhizobium* inoculums generally led to the production of more primary branches. Similar view corroborated by Basu *et al.* (2021). Significantly, the highest fresh and dry leaves weights were also registered in the $T_5 \times G_2$ treatment combination, measuring 4.45 g and 2.40 g, respectively. In contrast, the lowest fresh and dry leaf weights (1.49 g and 1.10 g) were found in the control \times BARI Masur-1 treatment. Regarding root characteristics, no significant interaction effect of fertilizer management practices and lentil genotype was found on fresh root weight, with values ranging from 0.09 g to 0.14 g (Table 6). However, for dry root weight, the highest weight (0.112 g) was recorded in the $T_5 \times G_2$ treatment combination, while the lowest (0.08 g) was in the control \times BARI Masur-1 treatment (Table 6). The results consistently highlight the beneficial impact of the $T_5 \times G_2$ treatment combination (50% inorganic fertilizer+ *Rhizobium* inoculum \times BARI Masur-7) on several key growth parameters of lentil. The increased above growth parameters of lentil observed in *Rhizobium*-added treatments is highly significant. This is likely attributable to the enhanced availability of nitrogen, stemming from both biological nitrogen fixation facilitated by the *Rhizobium* inoculum and the supplementary application of nitrogenous chemical fertilizers. Nitrogen is a crucial nutrient for vegetative growth like branching, leaf and root growth directly contributing to a more robust plant architecture (Basu *et al.*, 2021).

Table 6. Interaction effect of fertilizer management practices (T) × genotype (G) on the lentil primary branches plant⁻¹, fresh and dry leaf weight, fresh and dry root weight

| Treatment (T) × Genotype (G) | Primary branch plant ⁻¹ at harvest | Fresh leaf weight at 50 DAS (g) | Dry leaf weight at 50 DAS (g) | Fresh root weight at 80 DAS (g) | Dry root weight at 80 DAS (g) |
|---------------------------------|---|---------------------------------|-------------------------------|---------------------------------|-------------------------------|
| T ₁ × G ₁ | 2.06 | 1.49 | 1.10 | 0.09 | 0.077 |
| T ₂ × G ₁ | 2.13 | 2.02 | 1.30 | 0.11 | 0.086 |
| T ₃ × G ₁ | 2.11 | 1.80 | 1.19 | 0.11 | 0.081 |
| T ₄ × G ₁ | 2.75 | 2.15 | 1.36 | 0.11 | 0.092 |
| T ₅ × G ₁ | 3.03 | 2.57 | 1.55 | 0.12 | 0.094 |
| T ₁ × G ₂ | 2.68 | 2.77 | 1.56 | 0.11 | 0.093 |
| T ₂ × G ₂ | 3.36 | 3.87 | 1.99 | 0.12 | 0.098 |
| T ₃ × G ₂ | 3.01 | 3.56 | 1.85 | 0.11 | 0.095 |
| T ₄ × G ₂ | 4.60 | 4.06 | 2.16 | 0.13 | 0.104 |
| T ₅ × G ₂ | 4.75 | 4.45 | 2.40 | 0.14 | 0.112 |
| T ₁ × G ₃ | 2.51 | 1.63 | 1.22 | 0.09 | 0.083 |
| T ₂ × G ₃ | 3.05 | 2.22 | 1.59 | 0.11 | 0.091 |
| T ₃ × G ₃ | 2.86 | 2.26 | 1.40 | 0.11 | 0.087 |
| T ₄ × G ₃ | 4.43 | 2.47 | 1.67 | 0.12 | 0.096 |
| T ₅ × G ₃ | 4.51 | 3.27 | 1.75 | 0.12 | 0.107 |
| LSD (0.5) | 0.22 | 0.16 | 0.12 | NS | 0.003 |
| CV (%) | 5.86 | 5.22 | 6.52 | 5.11 | 2.77 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).; G₁ = BARI Masur-1, G₂ = BARI Masur-7 and G₃ = BD-3818

Table 7 shows that interaction effect of fertilizer management practices and genotype, the highest number of pods plant⁻¹ (98.6) was in T₅ × G₂ treatment combination and the lowest number of pods plant⁻¹ (62.5) was in control × BARI Masur-1. Number of seeds plant⁻¹ did not influence with interaction effect of fertilizer management practices and genotype. The highest thousand seed weight (22.0 g) was obtained from T₅ × G₂ treatment combination. Statistically identical results were also found in T₄ × G₂ treatment combination and inoculums × BARI Masur-7, whereas the lowest (18.2 g) was in control × BARI Masur-1 (Table 7). The interaction effect of fertilizer management and genotype on the incidence of foot rot and stemphylium blight was significant where the maximum incidence of foot rot (6.93%) and stemphylium blight (4.33) was in control × BARI Masur-1.

The minimum incidence of foot rot (1.16%) and stemphylium blight (0.33) was in $T_5 \times G_2$ treatment combination (Table 7).

Table 7. Interaction effect of fertilizer management practices (T) \times genotype (G) on the number of pods plant⁻¹, number of seeds pod⁻¹, thousand seed weight, and incidence of foot rot and *Stemphylium* blight of lentil

| Treatment (T) \times Genotype (G) | Number of pods plant ⁻¹ | Number of seeds pod ⁻¹ | Thousand seed weight (g) | Incidence foot rot (%) | <i>Stemphylium</i> blight (0-5 scale) |
|--|------------------------------------|-----------------------------------|--------------------------|------------------------|---------------------------------------|
| T ₁ \times G ₁ | 62.5 | 1.62 | 18.2 | 6.93 | 4.33 |
| T ₂ \times G ₁ | 76.5 | 1.71 | 18.4 | 4.26 | 3.16 |
| T ₃ \times G ₁ | 68.7 | 1.70 | 18.3 | 6.08 | 3.50 |
| T ₄ \times G ₁ | 82.3 | 1.74 | 18.5 | 4.83 | 2.66 |
| T ₅ \times G ₁ | 86.2 | 1.78 | 18.6 | 3.11 | 2.00 |
| T ₁ \times G ₂ | 78.7 | 1.71 | 21.3 | 3.82 | 1.66 |
| T ₂ \times G ₂ | 87.8 | 1.84 | 21.8 | 2.93 | 1.00 |
| T ₃ \times G ₂ | 84.0 | 1.79 | 21.6 | 3.01 | 1.16 |
| T ₄ \times G ₂ | 92.1 | 1.86 | 21.9 | 2.39 | 0.83 |
| T ₅ \times G ₂ | 98.6 | 1.92 | 22.0 | 1.16 | 0.33 |
| T ₁ \times G ₃ | 67.1 | 1.69 | 20.3 | 6.14 | 2.50 |
| T ₂ \times G ₃ | 81.5 | 1.79 | 20.9 | 4.16 | 1.50 |
| T ₃ \times G ₃ | 75.2 | 1.73 | 20.3 | 4.13 | 2.33 |
| T ₄ \times G ₃ | 87.6 | 1.84 | 21.1 | 2.83 | 1.16 |
| T ₅ \times G ₃ | 92.8 | 1.85 | 21.4 | 2.50 | 1.00 |
| LSD (0.05) | 1.69 | NS | 0.20 | 0.86 | 0.43 |
| CV (%) | 1.78 | 3.81 | 0.85 | 18.9 | 19.2 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G₁ = BARI Masur-1, G₂ = BARI Masur-7 and G₃ = BD-3818.

Table 8 clearly demonstrates the significant impact of the interaction between fertilizer management practices and genotype on the yields of lentil. The highest seed yield (1636 kg ha⁻¹) was achieved with the $T_5 \times G_2$ treatment combination and the lowest (909 kg ha⁻¹) was in control \times BARI Masur-1. Significantly the highest stover yield (1851 kg ha⁻¹) was in $T_5 \times G_2$ treatment combination, while the lowest (1258 kg ha⁻¹) from the control \times BARI Masur-1 (Table 8). On the other hand, the highest biological yield (3488 kg ha⁻¹) was found in $T_5 \times G_2$ treatment combination and the lowest (2166 kg ha⁻¹) was in control \times BARI Masur-1. The highest harvest index (46.9%) was in $T_5 \times G_2$ treatment combination and the lowest (42.0%) was

in control \times BARI Masur-1 (Table 8). The consistent superiority of the $T_5 \times G_2$ treatment combination across all yield parameters (seed yield, stover yield, biological yield, and harvest index) strongly indicates that integrating 50% of the recommended inorganic fertilizer with *Rhizobium* inoculum, specifically with the BARI Masur-7 genotype, creates an optimal environment for maximizing lentil productivity. This outcome is likely a culmination of the positive effects observed in earlier growth stages, such as increased primary branches and higher fresh and dry leaf weights, which collectively contribute to more robust plant development and ultimately, higher yields. The significant increase in harvest index in the $T_5 \times G_2$ treatment is particularly remarkable. A higher harvest index signifies a greater proportion of the total biomass being converted into economically valuable seed yield. This suggests that *Rhizobium* not only enhances overall biomass but also plays a role in optimizing the partitioning of resources towards seed development.

Table 8. Interaction effect of fertilizer management practices (T) \times genotype (G) on seed yield, stover yield, biological yield, and harvest index of lentil

| Treatment (T) \times Genotype (G) | Seed yield (kg ha ⁻¹) | Stover yield (kg ha ⁻¹) | Biological yield (kg ha ⁻¹) | Harvest index (%) |
|---|--------------------------------------|--|--|----------------------|
| T ₁ \times G ₁ | 909 | 1258 | 2166 | 42.0 |
| T ₂ \times G ₁ | 1152 | 1483 | 2640 | 43.6 |
| T ₃ \times G ₁ | 1072 | 1407 | 2479 | 43.2 |
| T ₄ \times G ₁ | 1249 | 1536 | 2785 | 44.8 |
| T ₅ \times G ₁ | 1325 | 1607 | 2931 | 45.2 |
| T ₁ \times G ₂ | 1157 | 1433 | 2586 | 44.8 |
| T ₂ \times G ₂ | 1451 | 1699 | 3153 | 46.0 |
| T ₃ \times G ₂ | 1404 | 1665 | 3069 | 45.7 |
| T ₄ \times G ₂ | 1537 | 1757 | 3294 | 46.7 |
| T ₅ \times G ₂ | 1636 | 1851 | 3488 | 46.9 |
| T ₁ \times G ₃ | 1009 | 1332 | 2345 | 43.0 |
| T ₂ \times G ₃ | 1354 | 1683 | 3039 | 44.5 |
| T ₃ \times G ₃ | 1272 | 1614 | 2886 | 44.1 |
| T ₄ \times G ₃ | 1403 | 1696 | 3099 | 45.3 |
| T ₅ \times G ₃ | 1442 | 1704 | 3146 | 45.8 |
| LSD (0.05) | 30.2 | 36.6 | 65.9 | 0.16 |
| CV (%) | 2.00 | 1.98 | 1.96 | 0.31 |

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G₁ = BARI Masur-1, G₂ = BARI Masur-7 and G₃ = BD-3818.

Cost and return analysis of lentil cultivation by application of combining bio-fertilizer with chemical fertilizers

Regarding the cost and return analysis, the maximum gross return of BDT 100041 ha⁻¹ was achieved with the T₅ × G₂ treatment combination. The minimum gross return of BDT 55768 ha⁻¹ was observed in the Control × BARI Masur-1 group. For net return, the T₅ × G₂ treatment combination again outperformed others, yielding the highest net return of BDT 73999 ha⁻¹ and an impressive benefit-cost ratio of 3.84. Conversely, the Control × BARI Masur-1 treatment combination resulted in the lowest net return of BDT 31568 ha⁻¹ and a benefit-cost ratio of 2.30 (Table 9) which is higher than that of Monira *et al.* (2025) where their BCR was 1.17.

Table 9. Cost and return analysis of lentil genotypes influenced by fertilizer management practices × genotypes

| Treatment (T) × Genotype | Seed yield (kg) | Stover yield (kg) | Gross return | Cultivation cost | Net return (BDT ha ⁻¹) | BCR |
|---------------------------------|-----------------|-------------------|--------------|------------------|------------------------------------|------|
| T ₁ × G ₁ | 909 | 1258 | 55768 | 23600 | 32168 | 2.36 |
| T ₂ × G ₁ | 1152 | 1483 | 70583 | 23757 | 46826 | 2.97 |
| T ₃ × G ₁ | 1072 | 1407 | 65727 | 27570 | 38157 | 2.38 |
| T ₄ × G ₁ | 1249 | 1536 | 76446 | 27727 | 48719 | 2.76 |
| T ₅ × G ₁ | 1325 | 1609 | 81087 | 26042 | 55045 | 3.11 |
| T ₁ × G ₂ | 1157 | 1433 | 70833 | 23600 | 47233 | 3.00 |
| T ₂ × G ₂ | 1451 | 1699 | 88769 | 23757 | 65012 | 3.73 |
| T ₃ × G ₂ | 1404 | 1665 | 85885 | 27570 | 58315 | 3.12 |
| T ₄ × G ₂ | 1537 | 1757 | 93947 | 27727 | 66220 | 3.39 |
| T ₅ × G ₂ | 1636 | 1851 | 100041 | 26042 | 73999 | 3.84 |
| T ₁ × G ₃ | 1009 | 1332 | 61862 | 23600 | 38262 | 2.62 |
| T ₂ × G ₃ | 1354 | 1683 | 82893 | 23757 | 59136 | 3.48 |
| T ₃ × G ₃ | 1272 | 1614 | 77914 | 27570 | 50344 | 2.83 |
| T ₄ × G ₃ | 1403 | 1696 | 85886 | 27727 | 58159 | 3.10 |
| T ₅ × G ₃ | 1442 | 1704 | 88204 | 26042 | 62162 | 3.39 |

T₁ = Control (no use of fertilizer), T₂ = *Rhizobium* inoculum (30 g/kg seed), T₃ = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB (FRG, 2012), T₄ = 20-15-25-10-2-1.5 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T₅ = 50% 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G₁= BARI Masur-1, G₂= BARI Masur-7 and G₃= BD-3818. **Output price:** Lentil seed= BDT 60 kg⁻¹, and stover = BDT 1.00 kg⁻¹. **Input prices:** Urea= BDT 20 kg⁻¹, Triple super phosphate= BDT 22 kg⁻¹, Muriate of potash= BDT 16 kg⁻¹, Gypsum= BDT 15 kg⁻¹, Zinc sulphate= BDT 1400 kg⁻¹, Boric acid= BDT 1200 kg⁻¹, *Rhizobium* inoculum= BDT 150 kg⁻¹, Wage rate= BDT 600 day⁻¹, Ploughing= BDT 1200 pass⁻¹acre⁻¹, Provex-200= BDT 300 100^{-g}, Imitaf 20 SL= BDT 265 100^{-ml}, Dithane M-45= BDT 150 100^{-g}, Lentil seed= BDT 100 kg⁻¹. The gross return was calculated on the farm gate price of Barishal district, Bangladesh. BDT is Bangladesh currency or Bangladeshi Taka; 1USD = 82 BDT. BCR: Benefit Cost Ratio.

Conclusion

Based on the comprehensive analysis of morphological and yield attributes, BARI Masur-7 consistently proved to be the superior lentil genotype, exhibiting enhanced growth, higher yield components, and it also displayed lower incidences of foot rot and *Stemphylium* blight across various fertilizer management practices. The most effective strategy for maximizing lentil yield involved inoculating seeds with *Rhizobium* bio-fertilizer (30 g kg⁻¹ seed) combined with 50% of the recommended inorganic 10-7.5-12.5-5-1-0.75 kg ha⁻¹ NPKSZnB + *Rhizobium* inoculum fertilizer. This approach not only optimized production but also achieved a significant 54.7% reduction in chemical fertilizer costs. Therefore, it can be conclusively stated that the integrated use of *Rhizobium* bio-fertilizer with a reduced amount of chemical fertilizer offers a highly effective, sustainable, and economically beneficial package for boosting lentil production in the Ganges Tidal Floodplain soil.

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INCLUSION OF SHORT DURATION MUSTARD INCREASES PRODUCTIVITY AND PROFITABILITY OF RICE BASED CROPPING PATTERN IN NORTH-EASTERN BANGLADESH

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Abstract

An on-farm trial was conducted at the farmers' field of Netrokona, a north-eastern district of Bangladesh during 2023-24 and 2024-25 to develop an improved cropping pattern *T. Aman* (var. BRRI dhan71)- mustard (var. BARI Sarisha-14)-*Boro* rice (var. BRRI dhan92) against farmers existing pattern *T. Aman* (var. BRRI dhan49)-Fallow-*Boro* rice (var. BRRI dhan29) for increasing the system productivity and profitability. The experiment was laid out in a randomized complete block design with five dispersed replications. Two cropping patterns *viz.*, improved (*T. Aman*- Mustard-*Boro*) and farmers' existing one (*T. Aman*-Fallow-*Boro*) were the treatment variables of the experiment. The unit plot size was 1000-1200 m². The result of the study revealed that three crops could be grown successfully in sequence in the tested site. Mean rice equivalent yield of improved cropping pattern was 16.45 t ha⁻¹ which was 32.88 % higher than the existing cropping pattern (12.38 t ha⁻¹). Besides, land utilization index, harvest index and profitability of improved pattern was higher than farmers' existing one. The mean gross return (Tk. 4,97,330 ha⁻¹) and gross margin (Tk. 2,48,673 ha⁻¹) were higher in improved pattern compared to farmers' pattern. The marginal benefit cost ratio (2.30) was also indicated the superiority of the improved pattern over the farmers' existing cropping pattern. Based on the findings, it is concluded that the improved cropping pattern, *T. Aman* (var. BRRI dhan71)-mustard (BARI Sarisha-14)-*Boro* rice (BRRI dhan92) could profitably be grown in the north-eastern part of Bangladesh.

Keywords: Cropping pattern, Mustard, Short duration, Productivity, Profitability, Netrokona

Introduction

Agricultural land is decreased by 0.73% each year due to infrastructural development of the country (BBS, 2024). The situation created a threat to food security in Bangladesh, which needs to address properly. With the advent of short-duration high yielding transplanted *T. Aman* rice varieties, opportunity has been created to include new crop in the cropping pattern, eg. mustard. It has been

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reported that mustard yield could be increased by 20-25% replacing traditional variety with high yielding short duration one, like BARI Sarisha-14 in the existing rice-based cropping system (OFRD, 2014).

Bangladesh is almost self-sufficient in rice production but other food production such as oil crops, pulses, wheat and vegetables etc. are still insufficient to a large extent. Mustard is one of the *rabi* crops in Bangladesh, while *T. Aman* rice is predominantly cultivated in monsoon season. Most of the *T. Aman* rice area is covered with long duration *T. Aman* varieties which cause a delay in mustard crop sowing, resulted reduce the yield. November 01 to 15 is the best time for mustard sowing, which can avoid drought and diseases at terminal growth stage of the crop. After harvest of *T. Aman* and before transplanting of *Boro* rice the land remains mostly fallow for around 80-86 days. Mustard (BARI Sarisha-14) is a high value cash crop which brings higher economic return. In Fallow-*Boro-T. Aman* rice cropping patterns mustard may be introduced as an alternative of farmers' pattern. Farmers' practices 'Fallow-*Boro-T. Aman*' cropping pattern is greatly influenced by the distribution pattern of annual rainfall.

There are 10 major cropping patterns in Netrakona district, among which Fallow-*Boro-T. Aman* rice covered 63 % of the net cropped area (DAE, 2024). Bangladesh Agricultural Research Institute (BARI) has developed short duration (75-80 days) high yielding mustard variety, namely BARI Sarisha-14 which has 30-40 % higher yield potential than the traditional variety of Tori-7. Inclusion of this new mustard variety after harvest of short duration *T. Aman* rice (115-120 days) can create an opportunity to fit in the Mustard-*Boro-T. Aman* rice cropping sequence. Therefore, the present study was conducted to evaluate the productivity and profitability of the new pattern 'Mustard-*Boro-T. Aman* rice' against the farmers' existing pattern in north-eastern Bangladesh.

Materials and Methods

The trial was conducted at the farmers' field of Netrokona MLT site under On-Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Mymensingh during 2022-23 and 2023-24 to increase cropping intensity, productivity and profitability of the farmers by inclusion of mustard (var. BARI Sarisha-14), *Boro* (var. BRRI dhan92) and *T. Aman* (var. BRRI dhan71) in the existing cropping system 'Fallow-*Boro* (var. BRRI dhan29)-*T. Aman* (var. BRRI dhan49)'. The experimental site belongs to Old Brahmaputra Flood plain Agro-ecological Zone (AEZ-9) of Netrokona. The approximate geographic coordinates for experimental site under Netrokona Sadar are at 24.88°N latitude and 90.73°E longitude with the altitude of 15 m above sea level. The land was medium high and the soil of the study area was clay loam to clay in texture with well drainage system. General soil types predominantly include Dark Grey Floodplain soil. The soil is

generally acidic having pH range of 4.3 to 5.8. Organic matter content is low to medium. Soils are mainly deficient in N, P, K, S, Zn and B. Maximum rainfall was received during the months of April to September. The highest temperature (33.9°C) was in August and the lowest was in December (10.1°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 (31.9 and 19.3°C), total rainfall (2018 mm) and relative humidity (82.7 %) were prevailing during the study period.

The experiment was laid out in a randomized complete block design with five dispersed replications. Two cropping patterns *viz.*, improved (*T. Aman*- Mustard-*Boro*) and farmers' existing one (*T. Aman*-Fallow-*Boro*) were the treatment variables of the experiment. The unit plot size was 800-1000 m². *T. Aman* rice was the first crop of the sequence. Seedlings of *T. Aman* rice var. BRRI dhan71 with 30 to 35 days old were transplanted with 20 cm × 15 cm spacing during 25 to 28 July 2023 and 22 to 27 July 2024 in two consecutive years. *T. Aman* rice was harvested during 20 to 27 October, 2023 and 20 to 28 October, 2024 in two successive years. Mustard was grown during *rabi* season and it was the second crop of the sequence. Fertilizer management was followed by Ahmmed *et al.* (2018) and intercultural operations like weeding, irrigation and pest management were done to support the normal growth and development of the crops. Mustard var. BARI Sarisha-14 was seeded as broadcast method @ 6 kg ha⁻¹. The crop was sown during 11 to 15 November, 2023 and 14 to 19 November 2024 and harvested during 25 to 31 January, 2024 and 01 to 08 February 2025, respectively. *Boro* rice was the third crop of the sequence. Seedlings of rice were grown in adjacent plot and transplanting was done with 30 to 35 days old seedlings of *Boro* rice var. BRRI dhan92 at a spacing of 20 cm × 15 cm during 20 to 25 February 2024 and 18 to 22 February 2025. *Boro* rice was harvested during 12 to 20 Jun. 2024 and 12 to 18 Jun. 2025 in two consecutive years. Rice plant was harvested at 30 cm height from soil surface and remaining parts of the plants was incorporated in soil. *T. Aman* rice plant was harvested at 15 cm from soil surface and remaining parts of the plants was incorporated in soil.

Data on the yield of various crops in sequences were recorded and converted to ton per hectare. The data of farmer's practice was recorded from adjacent farmers' plots. Agronomic performance like field duration, rice equivalent yield (REY), productivity and land utilization index of cropping patterns were calculated.

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

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

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

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

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

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

$$\text{Land Utilization Index (\%)} = \frac{d_1 + d_2 + d_3 + d_4}{365} \times 100$$

Where d_1, d_2, d_3 and d_4 the duration of 1st, 2nd, 3rd and 4th 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 farmer's prevalent pattern and any replacement for it can be computed as the marginal value product ((MVP) over the marginal value cost (MVC). The Marginal of prevalent pattern (F) and any potential replacement (E) which was computed as (CIMMYT, 1988).

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

Results and Discussion

Crop management: Crop management practices include date of sowing/transplanting, date of harvesting, fertilizer dose used, field duration and turnaround time etc. of improved and existing cropping pattern are shown in Table 1. Field duration of cropping pattern comprises on the individual crop duration. Farmers' cropping pattern *T. Aman-Fallow-Boro* has needed 219 and 215 days field duration in 1st and 2nd year. The newly introduced two crops in the farmers

Table 1. Agronomic parameters of farmers' existing cropping pattern and improved cropping pattern at MLT site Netrakona, during 2023-24 and 2024-25

| Parameters | Years | Farmers' Pattern (FP) | | | Alternate Pattern (AP) | | |
|--|---------|-----------------------|--------|-----------------|------------------------|-----------------|------------------|
| Crop | 2023-24 | T. Aman | Fallow | Boro | T. Aman | Mustard | Boro |
| | 2024-25 | T. Aman | Fallow | Boro | T. Aman | Mustard | Boro |
| Variety | 2023-24 | BRR1 dhan49 | Fallow | BRR1 dhan29 | BRR1 dhan71 | BARI Sarisha-14 | BRR1 dhan92 |
| | 2024-25 | BRR1 dhan49 | Fallow | BRR1 dhan29 | BRR1 dhan71 | BARI Sarisha-14 | BRR1 dhan92 |
| Sowing/ planting time | 2023-24 | 15-19 Jul.23 | Fallow | 15-19 Jan.24 | 25-28 Jul.23 | 11-15 Nov. 23 | 20-25 Feb.24 |
| | 2024-25 | 12-16 Jul.24 | Fallow | 10-15Jan.25 | 22-27 Jul.24 | 14-19 Nov. 24 | 18-22 Feb.25 |
| Seedling age (days) | 2023-24 | 30-40 | Fallow | 40-45 | 30-35 | - | 30-40 |
| | 2024-25 | 30-40 | Fallow | 40-45 | 30-35 | - | 30-40 |
| Spacing (cm) | 2023-24 | 20 × 15 | Fallow | 20 × 15 | 20 × 15 | Broadcast | 20 × 15 |
| | 2024-25 | 20 × 15 | Fallow | 20 × 15 | 20 × 15 | Broadcast | 20 × 15 |
| Fert. dose (NPKSZnB kg ha ⁻¹) | 2023-24 | 74-12-40-10-3-0 | Fallow | 140-15-30-0-3-0 | 70-15-35-10-4-0 | 90-35-42-26-2-2 | 140-15-60-15-3-0 |
| | 2024-25 | 74-12-40-10-3-0 | Fallow | 140-15-30-0-3-0 | 70-15-35-10-4-0 | 90-35-42-26-2-2 | 140-15-60-15-3-0 |
| Harvesting time | 2023-24 | 24-28 Oct.23 | Fallow | 12-16 May.24 | 20-27 Oct. 23 | 25-31Jan.24 | 12-20 Jun.24 |
| | 2024-25 | 23-27 Oct.24 | Fallow | 12-15 May 25 | 20-28 Oct.24 | 01-08 Feb.25 | 12-18 Jun.25 |
| Field duration (days) | 2023-24 | 101 | Fallow | 118 | 89 | 76 | 114 |
| | 2024-25 | 103 | Fallow | 122 | 92 | 79 | 115 |
| TAT (days) | 2023-24 | 60 | Fallow | 86 | 40 | 21 | 25 |
| | 2024-25 | 61 | Fallow | 79 | 39 | 24 | 16 |

existing pattern were mustard (BARI Sarisha-14) and *Boro* rice (BRRI dhan92). A short duration *T. Aman* rice variety BRRI dhan71 was also introduced to minimize the field duration of the crop. Total field duration of alternate cropping pattern *T. Aman*-Mustard-*Boro* rice has needed 279 and 286 days excluding seedling age of *T. Aman* and *Boro* rice to complete the cycle in 1st and 2nd year, respectively (Table 1). Thus, long turnaround time of 140-146 days in the farmers' existing pattern was utilized. Result indicated that mustard *T. Aman* and *Boro* rice could be easily fitted in Rice-Rice cropping pattern with average 23 days turnaround time in a year. The result is statistically similar with Khan *et al.* (2024) and Khatun *et al.* (2019). They reported that mustard could be easily fitted in the existing cropping pattern, *T. Aman*-Fallow-*Boro* rice.

Grain/Seed and by-product yield: Grain/Seed and by-product yield of the study have been presented in Table 2. It was revealed that the alternate cropping pattern, *T. Aman*- Mustard-*Boro* rice gave higher yield as well as by-product yield in two consecutive years. The yield of alternate pattern was higher due to inclusion of mustard with improved production technologies for the component crops. Similar results were also obtained by Nazrul *et al.* (2013), Anwar *et al.*, (2017) and Khatun *et al.*, (2019). Mustard var. BARI Sarisha-14 is a short duration high yielding mustard variety which can easily be grown during the fallow period (Mondal *et al.*, 2015). *T. Aman* rice grain yields were 4.88 and 4.80 t ha⁻¹ in 1st and 2nd years, respectively. Two years average grain and straw yields of *T. Aman* rice (var. BRRI dhan71) were 4.84 and 5.79 t ha⁻¹ in alternate cropping pattern showed 4.08 and 26 % higher than the existing pattern, *T. Aman* rice (var. BRRI dhan49) due to change of variety with improved production technologies. Seed yield of BARI Sarisha-14 was 1.76 and 1.60 tha⁻¹ and stover yields were 2.18 and 2.10 tha⁻¹ in two successive years. Two years average result showed that seed and stover yield of BARI Sarisha-14 in alternate cropping pattern was 1.68 and 2.14 t ha⁻¹. Grain yield of *Boro* rice (var. BRRI dhan92) was 7.13 t ha⁻¹ in 1st year and 7.21 t ha⁻¹ in 2nd year whereas mean grain and straw yields of *Boro* rice were 7.17 and 6.98 t ha⁻¹ respectively, which was 16 and 8.39 % higher than the existing pattern, *Boro* rice var. BRRI dhan29 with improved production technologies. Farmers' pattern gave lower yield probably due to imbalance use of fertilizers and poor management practices. It was revealed that the entire component crops of *T. Aman*-Mustard-*Boro* rice cropping pattern under improved practices gave higher yield as well as by-product yield in two consecutive years. Inclusion of mustard var. BARI Sarisha-14, rice var. BRRI dhan71 and BRRI dhan92 with improved production technologies increased the total yield over the farmers existing practice. Similar results were also obtained by Khatun *et al.* (2019), Kamrozzaman *et al.* (2015), Nazrul *et al.* (2013). Their findings also showed that inclusion of additional crop during the fallow period produced higher total yield than farmer's practice.

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

| Parameters | Years | Farmers' cropping pattern (FP) | | | Alternate cropping pattern (AP) | | |
|--|---------|--------------------------------|--------|-------------|---------------------------------|---------|-------------|
| | | <i>T. Aman</i> | Fallow | <i>Boro</i> | <i>T. Aman</i> | Mustard | <i>Boro</i> |
| Grain/Seed yield (t ha ⁻¹) | 2023-24 | 4.80 | - | 6.22 | 4.88 | 1.76 | 7.13 |
| | 2024-25 | 4.70 | - | 6.32 | 4.80 | 1.60 | 7.21 |
| | Average | 4.65 | - | 6.17 | 4.84 | 1.68 | 7.17 |
| By-Product yield (t ha ⁻¹) | 2023-24 | 5.60 | - | 6.72 | 5.79 | 2.18 | 6.89 |
| | 2024-25 | 5.40 | - | 6.75 | 5.25 | 2.10 | 7.07 |
| | Average | 5.50 | - | 6.74 | 5.52 | 2.14 | 6.98 |

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. The mean higher rice equivalent yield (16.45 t ha⁻¹) was recorded with the alternate cropping system with the increase of 32.88 % due to inclusion of BARI Sarisha-14 and recent high yielding varieties of rice with improved production technologies for the component crops. The lower rice equivalent yield (12.38 t ha⁻¹) was obtained in the farmer's pattern presumably due to inclusion of only two crops *Boro* and *T. Aman* rice with traditional management practices. REY increased 4.07 t ha⁻¹ by inclusion of mustard and rice varieties with improved production technologies for the component crops. It is evident from the above findings that alternate cropping pattern gave higher yield compared to the existing farmers' pattern. Similar results were also obtained by Khatun *et al.* (2019), Kamrozzaman *et al.* (2015), and Nazrul *et al.* (2013). Their findings also stated that inclusion of mustard crop during the fallow period produced higher REY than farmer's practice.

Production Efficiency (PE): Mean maximum production efficiency (49.65) in terms of kg ha⁻¹ day⁻¹ was obtained from farmer's existing cropping pattern which was 2.43 % higher over improved cropping pattern (Table 3). Production efficiency of improved cropping pattern was found 49.35 and 47.59 kg ha⁻¹ day⁻¹ in two consecutive years while in the existing cropping pattern it was found 50.32 and 48.98 kg ha⁻¹ day⁻¹, respectively (Table 3). The lower production efficiency in alternate cropping pattern was probably due to the inclusion of mustard variety, that took 61 days longer than the farmer's existing pattern. The results indicate that the crops remained in the field for longer time leading to lower production per day. Similar results were obtained by Khan *et al.* (2024). They reported that longer field duration leading lower production per day in Mustard-*Boro-T. Aman* cropping pattern.

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 77.40 % period of the year whereas farmer's pattern used the land for 60.82% period of the year (Table 3). Land utilization index was about 27.26 % higher in alternate cropping pattern than farmer's practice due to alternate pattern occupied the land for longer duration (283 days) and farmer's pattern (222 days) in a year. This higher land use efficiency in alternate cropping pattern is due to cultivation of three component crops in the pattern. Similar results were also obtained by Khatun *et al.* (2016).

Harvest Index: Improved cropping pattern *T.Aman* (var. BARI dhan71) –Mustard (var. BARI Sarisha-14)-*Boro* rice (var. BRRI dhan92) recorded the higher harvest index (48.33 %) than the farmers' existing cropping pattern, *T. Aman* rice (var. BRRI dhan49)-Fallow-*Boro* (var. BRRI dhan29) . The harvest index of alternate cropping pattern had higher value due to inclusion mustard and *Boro* rice varieties which contributed the higher economic and biological yield.

Table 3. Rice equivalent yield, production efficiency, land utilization index and harvest index of farmers' practice and improved pattern at MLT site Netrakona during 2023-24 and 2024-25.

| Year | Pattern | Rice equivalent yield (t ha ⁻¹) | Production efficiency (kg ha ⁻¹ day ⁻¹) | Land utilization index (%) | Harvest Index (%) |
|---------|---------|---|--|----------------------------|-------------------|
| 2023-24 | FP | 12.61 | 50.32 | 60.00 | 47.22 |
| | AP | 16.65 | 49.35 | 76.44 | 48.10 |
| 2024-25 | FP | 12.15 | 48.98 | 61.64 | 47.90 |
| | AP | 16.24 | 47.59 | 78.36 | 48.56 |
| Mean | FP | 12.38 | 49.65 | 60.82 | 47.56 |
| | AP | 16.45 | 48.47 | 77.40 | 48.33 |

Note: FP= Farmers' Pattern and AP= Alternate Pattern

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 means gross return of the alternate and farmers' pattern was Tk.4,97,330 and Tk. 3,37,490 ha⁻¹, respectively. The mean gross return of alternate cropping pattern was about 47 % higher than the farmers' existing pattern and it might be due to inclusion of high yielding mustard, *Boro* and *T. Aman* rice varieties. The mean total variable cost of the alternate and the farmers' existing cropping pattern was Tk. 2,48,657 and Tk. 1,79,045 ha⁻¹, respectively. It is noted that higher cost was involved in farmers' pattern due to addition of one crop. But about 57 % higher gross margin (Tk. 2,48,673 ha⁻¹) was calculated in alternate pattern over farmer's existing cropping pattern (Tk. 1,58,445 ha⁻¹). The mean

MBCR was found 2.30 which also indicated the superiority of alternate cropping pattern over the farmer's existing cropping pattern. Inclusion of new crops as well as improvement of agronomic management practices in the alternate cropping pattern increased the monetary benefit. This result is supported by Monim and Ahammad (2023). They also reported that inclusion of mustard in *T. Aman*-Fallow-Boro rice cropping pattern is profitable and acceptable to the farmers.

Table 4. Cost and return analysis of farmers' and improved cropping pattern cropping pattern at MLT site Netrakona 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 |
|---------|---------|---|--|---|------|
| 2022-23 | FP | 3,44,780 | 1,79,140 | 1,65,640 | 2.26 |
| | AP | 5,02,930 | 2,49,120 | 2,53,810 | |
| 2023-24 | FP | 3,30,200 | 1,78,950 | 1,51,250 | 2.33 |
| | AP | 4,91,730 | 2,48,194 | 2,43,536 | |
| Mean | FP | 3,37,490 | 1,79,045 | 1,58,445 | 2.30 |
| | AP | 4,97,330 | 2,48,657 | 2,48,673 | |

Note: Unit price (Tk. kg⁻¹): Mustard =70/-, Boro rice =25/-, T. Aman rice = 30/-, stover=2/-, and Rice straw=4/-

Farmers' opinion: Farmer's expressed their satisfaction for getting higher yield and economic return from the *T. Aman*-Mustard-Boro rice cropping pattern. They would like to follow the alternate pattern for efficient use of fallow land for getting more income as compared to *T. Aman* -Fallow-Boro rice cropping pattern. They are also happy with yield potentiality of BARI developed mustard variety.

Conclusion

The total crop productivity in terms of REY, production efficiency and profitability of alternate cropping pattern, *T. Aman* (var. BRRI dhan71) Mustard (var. BARI Sarisha-14) –Boro rice (var. BRRI dhan92) were much higher than that of the existing cropping pattern, *T. Aman* (var. BRRI dhan49) - Fallow- Boro rice (var. BRRI dhan29). Thus, the alternate cropping pattern could be piloting for large scale production in the high and medium high land of the north-eastern part of Bangladesh with the collaboration of DAE and BARI.

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EFFECT OF TILLAGE AND PLANTING METHODS ON MAIZE

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Abstract

Timely tilling and seeding are major challenges in crop production specially after harvesting of Aman rice. The problem can be solved using power tiller operated seeder (PTOS). Different tillage and planting methods were implied in farmers' fields for maize in Patuakahli and Rajshahi during *rabi* seasons of 2018-19 and 2019-20. The experiment was laid out with RCBD design with four treatments and three replications. The treatments were power tiller operated seeder with full tillage (PTOS), strip tillage (ST), zero tillage (ZT) and conventional tillage cum manual planting method (CT). Farmers unit plot area of about 0.40 ha (One *Bigha*) land was selected for this experiment considering uniform land type, soil type and cropping pattern. PTOS was found effective in tilling and planting of maize in all locations. Significantly the highest grain yield was found from PTOS than ST, ZT and CT. The BCR (benefit cost ratio) of PTOS and CT methods were found 1.54 and 1.08, respectively. The PTOS saved time preventing late sowing and also reduced labour curtailing crop production cost. So, the BARI developed PTOS can be recommended for reduced tillage practices for planting of maize in Bangladesh.

Keywords: BARI Seeder, PTOS, Maize, Seeding, Strip tillage, Zero tillage, BCR.

Introduction

Among all the agricultural operations, tillage is one of the most power intensive operations. The present cropping intensity could not have been achieved without mechanized tillage operation. At present, about 80% of the cultivated land of the country is tilled by power tiller while the remaining 15% land is covered by tractors (Rahman *et al.*, 2021). Only 5% upland crops are sown in line by seeder machine (Hossain, 2025). The government has a target to sow 10% upland crops by seeder within 2025 and 25% by the year 2030 (NAM, 2020). Power tiller is light duty agricultural equipment used for tilling operation in Bangladesh. The machine has been the part of farming system for many small and medium scale farmers in developing countries due to small farm and scattered field size combined with an affordable price compared with the tractors (Sarker *et al.*, 2012). It is portable and

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can be used or taken to the interior farmlands where there is no access road for big tractors. The affordability of this equipment in terms of low price for local farmers can make agricultural crop production to increase considerably. Conventional tillage is commonly practiced in the country, tilling 4-5 times followed by laddering by power tiller or tractor and hand broadcasting of seeds (Wohab *et al.*, 2007). Farmers usually adopt repeated or intensive tillage operations for crop cultivation for controlling weeds, minimizing the percolation rate of water, and preparing a soft bed for crop establishment. *Rabi* crops are cultivated after harvesting of Aman rice in most of the areas in Bangladesh. But, yield of crop is very low due to late planting. Generally, crop is planted after harvesting T. Aman in land prepared by 3-4 tillage operations followed by hand broadcasting seeds. This process is time consuming and costly operation and causes the delay in planting. As a result, yield loss of crops occurs in most of the cases. Farmers prepare the land by power tiller which takes more time, fuel, labour, as well as cost for crop production. On the other hand, land preparation, sowing of seeds in line and seed covering can be done by single pass using BARI seeder which is popularly known as PTOS (Hoque and Miah, 2015; Hoque *et al.*, 2021a; Hoque *et al.*, 2021b). Farmers can plant crops by seeder just after harvesting of Aman rice using residual soil moisture content. Seeder saves time, fuel and money for *rabi* crop production (Hoque and Gathala, 2018). There is abundant evidence that intensive tillage can cause the degradation of physical, chemical and biological soil properties, reduces soil organic carbon at double rate and decreases soil fertility (Grace, 2003), losses irrigation water and soils (Sayre and Hobbs, 2003). In addition, repetitive tillage requires significant amounts of fuel and energy and results in increased production cost and reduced profit (Gathala *et al.*, 2016). Therefore, adoption of reduced or minimum tillage practices that can potentially reduce environmental impacts and improve agricultural outputs (Buckwell *et al.*, 2014). BARI has developed power tiller operated seeder (PTOS) as resource conservation machine to address these problems. Resource conservation-based tillage technology permits direct seeding in untilled soil with moderate level of crop residue in different tillage techniques such as zero, strip, or reduced tillage, and raised and permanent beds (Gathala *et al.*, 2011; Hoque *et al.*, 2023). Research evidence illustrates that yields of wheat and maize from CA may be same or high, compared to conventional or traditional agriculture practices (Govaerts *et al.*, 2006). Mafongoya *et al.* (2016) reported that the increases in grain yield under conventional tillage over zero tillage practice of maize were 17.8% and 28.2% during 2000-2001 and 2001-2002 seasons, respectively at Msekera in Zambia. Wang *et al.* (2024) conducted seven field experiments in high terrain and low terrain sites in the black soil belt of Northeast China. The methods of tillage practices were selected as ridge tillage (RT), strip tillage (ST) and no tillage (NT) method. They found that maize yields in the RT method and ST method were 6.12 % and 5.04 % higher than that in the NT method at the high terrain site and 6.28

% and 5.19 % higher than that in the NT method at the low terrain site, respectively. An appropriate power tiller-based seeder machine may be introduced so that minimum tillage cum seeding and resource conservation tillage method can be practiced for maize as well as other crops. Therefore, this research has been undertaken to evaluate the tilling and seeding performance of BARI seeder for maize cultivation in different soil conditions.

Materials and Methods

Field experiments were conducted in Godagari Upazila of Rajshahi district and Dumki and Kalapara upazila of Patuakhali district during *rabi* season of 2018-19 and 2019-20. The Agro ecological zones (AEZs) and soil types in the project locations are given in Table 1. The soils and climates of two locations are quite different from each other. The existing common cropping patterns in the project locations were mainly based on two crops. T. Aman is the common crop in all locations. The improved seeder was used for land preparation and sowing of *Rabi* crops only.

Table 1. Agro ecological zones (AEZs) and soil types in the study locations

| District | Soil Condition |
|------------|--|
| Patuakhali | <ul style="list-style-type: none"> • AEZ: 13 (Ganges Tidal Floodplain) • Soil Type: Silty clay loam • Characteristics: Most of the top soils are acidic and subsoils are neutral to mildly alkaline. The soil remains wettywith poor drainage leading to late planting. The location experiences unusual rain fall and irrigation water scarcity. |
| Rajshahi | <ul style="list-style-type: none"> • AEZ: 26 (High Barind Tract) • Soil Type: Clay loam • Characteristics: The location is drought prone with low rainfall (annual 1200 mm). and it has terrace soil, high bulk density and declining groundwater table. |

The experiments of all locations were laid out in randomized block design. Four treatments were imposed in each of Rajshahi and Patuakhali locations for planting maize using BARI seeder with three replications. Three methods were followed for seed planting by BARI Seeder, such as, whole land shallow tilling (5-6 cm) i.e. single pass full tillage (PTOS), strip tillage and zero tillage. The conventional method of seed sowing was also used i.e. full tillage by power tiller using 3-4 passes and then line sowing of seeds followed by seed covering by laddering. So, the treatments were PTOS, strip tillage (ST), zero tillage (ZT) and conventional tillage (CT). Each plot size was unit plot of farmers with 0.03-0.05 ha of land. Uniform plots were selected for conducting the experiment. Herbicides (Atrazine

at 1.0 kg/ha and topramezone at 0.030 kg/ha in combination) were applied in the field with standing rice residue (25 cm) before strip and zero till seeding for controlling pre-emergence weeds. Locations, areas, crops and sowing methods under the experiments in Patuakhali and Rajshahi during *rabi* 2018-19 and 2019-20 are shown in Table 2. Fertilizer was applied as per FRG (2018). Seed rates of NK-40 hybrid maize in all locations were 20 kg/ha. Date of planting of maize in Rajshahi was 10-15 November and in Patuakhali it was 1-10 December both in the Rabi seasons of 2018-19 and 2019-20. Three irrigations were applied in Rajshahi at 20-30 days after sowing (DAS), 50-60 DAS (cob emergence) and at 80-89 DAS (grain formation) whereas two irrigations were applied in Patuakhali at 45-50 DAS (cob emergence), and at 80-89 DAS (grain formation).

Table 2. Experimental locations, crop areas and crops planted by BARI Seeder (PTOS) during *rabi* 2018-19 and 2019-20

| District | Location | Maize variety | Land area (decimal) | | | | |
|------------|-----------------------|---------------|---------------------|----|----|----|-----------------|
| | Upazila | | PTOS | ST | ZT | CT | Total area (ha) |
| Rajshahi | Godagari (Bijoynagar) | NK-40 | 25 | 35 | 27 | 33 | 120 (0.16) |
| | Tanore (Shampur) | NK-40 | 40 | 30 | 25 | 36 | 131(0.17) |
| Patuakhali | Kolapara (Tulatoli) | NK-40 | 40 | 34 | 26 | 10 | 110 (0.15) |
| | Dumki (Srirampur) | NK-40 | 45 | 26 | 25 | 33 | 129 (0.17) |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

The photographs of BARI seeder and its operation is shown in Fig. 1.



BARI Seeder (PTOS)

Operation of BARI seeder (PTOS) in farmer's field

Fig. 1. Pictorial views of BARI seeder (PTOS) and its operation in Rajshahi.

Economic analysis

A simple economic analysis was done based on total crop production. Production cost included input cost. The input cost was calculated by considering cost of land preparation, seed, fuel, fertilizers, herbicide, insecticide, irrigation and hiring charges of labour. The gross return and net return were calculated on the basis of local market price. The straight-line method was used for calculating of depreciation. The annual cost of operation of PTOS (BARI Seeder) was computed as the sum of fixed costs and variable costs Mottalib *et al.* (2019).

Data analysis

Data of different parameters of seeder was analyzed using Microsoft Excel worksheet. Yield and yield contributing parameters of crops under different tillage and sowing methods were analyzed using Statistix 10 software. Means differences among the treatments were compared least significant difference (LSD) ($P \leq 0.05$).

Results and Discussions

Yield comparison

Maize was sown by BARI seeder (PTOS) at Bijohnagar, Godagari, Rajshahi during 2018-19. Yield and yield contributing parameters of maize at Bijohnagar, Godagari and Shampur, Tanore Rajshahi for 2018-19 and 2019-20 are furnished in Tables 4 and 5, respectively. In both the years and locations, significantly the highest grain yield was found from PTOS and CT. There were no significant differences of plant height, grain per cob, straw yield and grain yield between PTOS and CT. Other parameters among the treatments were also found insignificant. Yield and yield parameters between ST and ZT were statistically alike but lower than those of PTOS and CT. Godagari, Rajshahi is located in high Barind Tract (AEZ-26). Here, *rabi* crops generally suffer in moisture stress. In strip and zero tillage system, maize roots could not penetrate the surrounding soils due to untilled hard soil. But, in PTOS and conventional tillage systems, the whole land was tilled and maize roots could easily penetrate the surrounding soils and received more moisture and nutrients than strip and zero tilled maize plants. Hence, yield parameters and grain yields of PTOS and conventional tillage became higher. These findings are supported by Islam *et al.* (2022).

Table 4. Yield and yield contributing characters of maize at Bijoynagar, Godagari, Rajshahi during 2018-19

| Treatments | Plant population/ m ² | Plant height (cm) | Cob/ plant | Grain/ cob | TGW (g) | Straw yield (t/ha) | Grain yield (t/ha) |
|------------|-------------------------------------|----------------------|---------------|---------------|------------|-----------------------|--------------------------|
| PTOS | 8.77 | 178.33 | 1.33 | 418.67 | 365.33 | 10.58 | 8.36 |
| ST | 8.70 | 162.33 | 1.00 | 385.33 | 349.58 | 8.84 | 6.89 |
| ZT | 8.60 | 156.33 | 1.00 | 375.33 | 324.53 | 8.38 | 6.53 |
| CT | 8.50 | 170.00 | 1.00 | 396.00 | 346.88 | 10.52 | 8.25 |
| LSD (0.05) | NS | 12.08 | NS | 42.25 | NS | 1.50 | 1.21 |
| CV (%) | 3.9 | 2.56 | 26.65 | 3.79 | 5.86 | 5.53 | 5.71 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

Table 5. Yield and yield contributing parameters of maize at Shampur, Tanore, Rajshahi during in 2019-20

| Treatments | Plant /m ² | Plant height (cm) | Grain/cob | 1000-grain wt. (g) | Grain yield (t/ha) |
|------------|--------------------------|-------------------|-----------|--------------------|--------------------|
| PTOS | 6.88 | 196.07 | 476.33 | 296.67 | 8.84 |
| ST | 6.28 | 186.40 | 445.67 | 273.60 | 6.89 |
| ZT | 5.90 | 179.00 | 409.33 | 265.33 | 6.53 |
| CT | 6.53 | 193.27 | 468.0 | 292.53 | 8.28 |
| LSD (0.05) | 0.78 | 7.12 | 50.82 | 20.45 | 0.98 |
| CV (%) | 6.09 | 1.89 | 5.66 | 3.63 | 6.92 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

Yield and yield contributing parameters of maize at Tulatoli, Kalapara, and Srirampur, Dumki, Patuakhali are shown in Table 6 and Table 7, respectively. It is revealed from the tables that significantly the highest plant height, grains per cob and straw yield and grains yield were found from PTOS and CT than ST and ZT treatments. Yield and yield contributing parameters of PTOS and CT were statistically similar. Significantly the lowest yields were obtained from ZT in all locations. ST gave the intermediate yield of maize than other treatments. Hence, maize cultivation by full tillage gave the significantly the highest yield. So, considering the time, fuel cost and yield, PTOS was found suitable for maize planting method in Patuakhali. Patuakhali also fresh water scared area due salinity (6-8 dS/m) during dry season. Clay soil becomes cracked due to water stress. Crop

growth stunted in untilled soil (Mottalib *et al.*, 2019). So, lower yields were found from strip tillage and zero tillage. Similar results were reported by Gathala *et al.* (2016) for maize.

Table 6. Yield and yield contributing characters of maize at Tulatali, Kolapara, Patuakhali during 2018-19

| Treatment | Plant population /m ² | Plant height (cm) | Cob length (cm) | Grain/cob | TGW (g) | Straw (t/ha) | Grain yield (t/ha) |
|-----------|----------------------------------|-------------------|-----------------|-----------|---------|--------------|--------------------|
| PTOS | 8.00 | 258.43 | 23.80 | 370.63 | 295.00 | 12.40 | 7.73 |
| ST | 7.67 | 223.97 | 18.13 | 350.13 | 286.67 | 11.51 | 6.47 |
| ZT | 7.00 | 189.50 | 14.60 | 296.47 | 273.33 | 9.55 | 6.20 |
| CT | 8.00 | 267.87 | 23.97 | 380.50 | 302.67 | 12.62 | 7.89 |
| LSD | NS | 26.19 | 5.06 | 51.48 | 23.68 | 1.59 | 1.05 |
| CV (%) | 7.53 | 3.94 | 8.90 | 5.21 | 2.89 | 4.87 | 4.73 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

Table 7. Yield and yield contributing characters of maize at Srirampur, Dumki, Patuakhali during 2018-19

| Treatment | Plant /m ² | Plant height (cm) | Cob length (cm) | Cob weight (g) | Grain/cob | TGW (g) | Straw yield (t/ha) | Grain yield (t/ha) |
|-----------|-----------------------|-------------------|-----------------|----------------|-----------|---------|--------------------|--------------------|
| PTOS | 8.77 | 265.53 | 28.33 | 243.00 | 513.33 | 285.57 | 11.55 | 7.51 |
| ST | 8.53 | 231.33 | 22.27 | 217.00 | 518.67 | 286.00 | 10.76 | 6.53 |
| ZT | 8.60 | 221.33 | 20.33 | 201.67 | 438.67 | 258.27 | 9.62 | 6.41 |
| CT | 8.53 | 248.87 | 22.00 | 225.00 | 516.67 | 292.93 | 11.24 | 7.38 |
| LSD | NS | 32.50 | 7.48 | 22.07 | 72.59 | 31.61 | 1.79 | 1.64 |
| CV (%) | 4.53 | 4.89 | 11.38 | 3.52 | 5.17 | 3.98 | 5.88 | 6.90 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

Yield and yield contributing parameters of maize at Srirampur, Dumki, Patuakhali are shown in Table 8. Significantly the highest grain yield was obtained from PTOS followed by CT and ST. Significantly the lowest grain yield and yield attributes were found from ZT. The reason might be that during dry season sufficient irrigation could not be applied in the maize field due to fresh water scarcity and soil became very hard and root could not be penetrated in the soil for moisture stress and hence crop growth became slower and yield became lower. Among CA practices PTOS performed the best followed by ST. ZT performed the

lowest. It may be due to shortage of soil moisture in the field during sowing period. Usually, maize sowing started at Dumki in mid-February. In this period land become harder rapidly due to high evaporation losses of soil moisture that reduced germination of seed in ST and ZT.

Table 8. Yield and yield contributing characters of maize at Srirampur, Dumki, Patuakhali during 2019-20

| Treatment | Plant/m ² | Plant height (cm) | Cob length (cm) | Grain/ cob | 1000-grain wt. (g) | Grain yield (t/ha) |
|-----------|----------------------|-------------------|-----------------|------------|--------------------|--------------------|
| PTOS | 8.80 | 262.07 | 23.00 | 528.00 | 235.00 | 7.31 |
| ST | 8.40 | 253.67 | 20.33 | 479.00 | 227.67 | 6.13 |
| ZT | 7.77 | 247.67 | 20.00 | 390 | 210.67 | 5.56 |
| CT | 9.47 | 258.67 | 21.67 | 505.67 | 231.67 | 6.48 |
| LSD | 1.19 | NS | 1.49 | 89.37 | 20.01 | 1.7 |
| CV (%) | 6.96 | 4.17 | 3.51 | 9.4 | 4.43 | 13.38 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

Yield and yield contributing parameters of maize at Tulatoli, Kalapara, Patuakhali are shown in Table 9. In case of maize, significantly the highest plant height, grains per cob and straw yield and grains yield were found from PTOS that was statistically similar with CT. Among the CA practices PTOS and ST produced the statistically similar and higher yield than ZT. In sufficient moisture during sowing hamper germination and plant stand in ZT field that reduced the crop yield. Hence, significantly the lowest yields were obtained from ZT. So, considering the time, fuel cost and yield, PTOS was found suitable for maize planting method in Patuakhali.

Table 9. Yield and yield contributing characters of maize at Tulatali, Kalapara, Patuakhali during 2019-20

| Treatment | plant/m ² | Plant height (cm) | Cob length (cm) | Grain/cob | 1000-grain wt. (g) | Grain yield (t/ha) |
|-----------|----------------------|-------------------|-----------------|-----------|--------------------|--------------------|
| PTOS | 8.20 | 271.48 | 17.74 | 479.46 | 242.60 | 7.71 |
| ST | 7.60 | 229.30 | 14.46 | 399.40 | 227.80 | 5.91 |
| ZT | 7.00 | 196.82 | 12.16 | 314.40 | 219.00 | 4.84 |
| CT | 8.00 | 270.18 | 16.66 | 483.40 | 244.40 | 7.35 |
| LSD | 0.96 | 12.24 | 1.04 | 25.44 | 10.04 | 0.80 |
| CV (%) | 9.03 | 3.67 | 4.97 | 4.4 | 3.12 | 8.69 |

Note: PTOS: Power tiller operated seeder, ST: Strip tillage, ZT: Zero tillage, CT = Conventional tillage

In both Rajshahi and Patuakhali locations similar grains yields were found between two Upazilas of each district during 2019-20. But, between two different agro-ecological zones (Rajshahi: 23 and Patuakhali: 13) different yield patterns were found in both the years, 2018-19 and 2019-20. Comparatively low grain yield was found in Patuakhali than Rajshahi. Patuakhali had soil salinity (8-10 DS/m) and late planting season (December), therefore, lower yields were obtained than Rajshahi. Similar results were reported by Gathala *et al.* (2016).

Economic analysis

The economic analysis was done from the viewpoint of machine owner as well as custom hire basis. Fixed cost and variable cost for seeder operation were estimated as Taka 2460 per hectare and Taka 1976 per hectare, whereas, those for power tiller were Taka 1886 per hectare and Taka 3254 per hectare, respectively (Table 10). The economic life of the machine was assumed five years. The area under land preparation by both PTOS and CT the machine operations per year was 26 and 13 ha, respectively. Again, the custom hiring charge for both the machines was estimated as Taka 7000 per hectare based on the field data. The revenue can be received by the owner of the seeder Taka 66664 per year and power tiller owner Taka 24180. Therefore, a LSP (local service provider) or a seeder machine, the owner can earn additional Taka 42484 per year than that of a only power tiller owner. The result also shows that BCR of a seeder was found 1.54 which is a profitable venture for an entrepreneur than that (1.08) of CT.

Table 10. Economic analysis of BARI seeder and power tiller

| A. Items | PTOS (Power tiller with BARI Seeder) | CT (Power tiller without seeder) |
|---------------------------------------|--------------------------------------|----------------------------------|
| A. Fixed cost | | |
| Purchase price (Taka) | 190000 | 120000 |
| Salvage value (Taka) | 19000 | 12000 |
| Depreciation (Taka/year) | 34200 | 21600 |
| Replacement cost (Taka/year) | 29520 | 16318 |
| Interest (Taka/year) | 10578 | 7298 |
| Total fixed cost (Taka/ha) | 2460 | 1886 |
| B. Variable cost | | |
| Fuel and oil cost (Taka/ha) | 709 | 1602 |
| Repair and maintenance cost (Taka/ha) | 252 | 313 |
| Labour cost (Taka/ha) | 909 | 1339 |
| Total variable cost | 1976 | 3254 |
| Total annual operating cost (Taka/ha) | 4436 | 5140 |
| Annual use in area (ha/year) | 26 | 13 |
| Net return (Taka/year) | 66664 | 24180 |
| Benefit cost ratio (BCR) | 1.54 | 1.08 |

Conclusion

The highest grain yields were found from the reduced tillage (PTOS) followed by conventional tillage, strip tillage (ST), and zero tillage (ZT) in both Rajshahi and Patuakhali. PTOS was found an effective tillage and maize planting method in moisture stressed condition. Significantly the highest crop yields were found from reduced tillage (PTOS) than ST, ZT and CT methods. The BCR of PTOS and CT method were found 1.54 and 1.08, respectively. The PTOS saved time to prevent late sowing and also reduced labour to curtail crop production cost. The PTOS is recommended for reduced tillage practices in Bangladesh. Future research may be undertaken on determination of seed rate, weed and fertilizer management for seeder for different soils and crops.

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ANALYSING FARMERS' BARGAINING POWER AND INTERMEDIARY CONTROL IN THE POTATO MARKET OF BANGLADESH

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Abstract

This study examines how farmgate potato prices are formed and how intermediaries influence farmers' price outcomes in Bangladesh. Using qualitative interviews, thematic analysis, and value chain mapping based on a structured farmer survey across major potato-growing regions, the study finds that price formation is largely governed by an *order-driven procurement system*—a process where terminal-market Aratdars predefine purchase quantities and prices for their local agents (Beparis), leaving little room for open negotiation at the farm level. Farmgate prices are thus shaped not only by supply and demand but also by institutional and informal mechanisms such as commission charges, cold storage receipt trading, and non-standard weighing practices. These factors enable intermediaries to control market information and timing, resulting in asymmetric price transmission where farmers bear most of the downside risk. Limited market information and dependence on storage further weaken farmers' bargaining capacity. The study recommends strengthening cooperative-based storage systems and digital price information platforms to improve farmers' collective bargaining power and ensure fairer value distribution along the potato chain

Keywords: Potato market, farmgate price, intermediaries, cold storage, bargaining power.

1. Introduction

Price volatility in agricultural commodities has long been a concern for policymakers and development economists (Gilbert & Morgan, 2010; Miranda & Helberger, 1988; Kalkuhl *et al.*, 2016). Market instability in perishable crops such as potatoes often arises from complex interactions among demand fluctuations, production variability, and storage or stock availability (Russo & Goodhue, 2018; Wright, 2011). Retail pricing mechanisms - including markup, uniform pricing, or scheduled discount systems - significantly affect how volatility is transmitted to

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producers (Li & Sexton, 2013). When retail prices are insulated from changes at the producer level, farmgate prices tend to fluctuate more sharply to restore market equilibrium, often constrained by minimum harvesting and handling costs (Russo & Goodhue, 2018).

Potato (*Solanum tuberosum* L.) is among the most important horticultural crops in Bangladesh, serving as both a staple food and a major source of rural income and employment (Shaheb *et al.*, 2015; Alamgir *et al.*, 2020). Although Bangladesh ranks among the world's top ten potato-producing countries, farmers often receive only a small fraction of the final retail price, reflecting inefficiencies and power asymmetries within the marketing system (Vivekanandhan *et al.*, 2025). Understanding how farmgate prices are formed and who exerts control over this process is essential for improving farmers' welfare and overall market efficiency.

Potato marketing in Bangladesh is multi-layered and dominated by intermediaries such as *Aratdars* (commission agents), *Beparis* (wholesalers), *Farias* (collectors), and retailers. These actors play decisive roles in setting farm-level prices and managing transactions. Farmers typically depend on price information from local intermediaries or nearby markets, with limited access to real-time prices in terminal markets. Consequently, farmgate prices are determined through asymmetric negotiations in which intermediaries - especially *Aratdars* operating via commission systems and cold storage receipts - hold disproportionate influence.

Institutional and informal arrangements further reinforce this asymmetry. Commission charges, cold storage receipt trading, credit linkages, and non-standard weighing practices often disadvantage smallholders (Huq *et al.*, 2004). Farmers' dependence on immediate cash after harvest, lack of adequate storage, and fragmented production structures compound their weak bargaining position (Abokyi *et al.*, 2020; Yeshiwas *et al.*, 2023). While several studies in Bangladesh have analyzed potato production, economics, profitability, and marketing margins (Sujan *et al.*, 2017; Islam *et al.*, 2018; Haque *et al.*, 2011; Akter *et al.*, 2016; Akter *et al.*, 2023; Mila *et al.*, 2022; Hossain *et al.*, 2025; Moazzem *et al.*, 2004), a few studies have explored the qualitative mechanisms and power relations that shape farmgate price control in practice.

This study fills this critical gap by examining how intermediaries influence potato price determination, how market information and price signals are transmitted, and how institutional and informal practices shape farmers' bargaining power. Specifically, it investigates the extent of open negotiation versus order-based pricing, the role of *Aratdars* and cold storage operators in setting farmgate prices, and the barriers to equitable farmer participation. This study contributes to the literature by uncovering the institutional and relational

mechanisms underpinning farmgate price formation and offering policy insights for improving market transparency and farmer empowerment within Bangladesh's potato value chain.

2. Methodology

2.1 Study Area

The study was conducted in major potato-producing regions of Bangladesh to capture a range of production systems and market conditions. The selected districts were Bagura (Bagura Sadar, Kahaloo), Nilphamari (Kishoreganj), Rangpur (Gangachora, Pirganj), Panchagarh (Debiganj, Boda), and Munshiganj (Sirajdikhan, Tongibari) - all recognized for their significant contribution to national potato output.

2.2 Sampling and Respondent Selection

A multistage stratified sampling method was used. First, key districts were chosen based on production importance and market connectivity. Second, upazilas were selected through consultation with Department of Agricultural Extension (DAE) officials to ensure coverage of high-production zones. Finally, 320 potato farmers and 80 market actors (including *Aratdars*, *Beparis*, *Farias*, retailers, and cold storage operators) were randomly selected to represent both producers and intermediaries.

2.3 Data Collection

Primary data were collected through structured and semi-structured interviews. The questionnaire and interview guide were designed to capture detailed information on:

- Production, storage, and marketing practices;
- Price-setting mechanisms and negotiation experiences and
- Institutional and informal market practices influencing price outcomes.

Key informant interviews were also conducted with *Aratdars*, *Beparis*, and cold storage operators to understand price formation and commission-based trading practices. Interviews were pre-tested for clarity and conducted by the lead researcher with trained local enumerators.

2.4 Analytical Approach

The analysis followed a qualitative thematic framework as stated below:

- Thematic coding identified recurring themes around intermediary influence, price transmission, and farmer bargaining power.

- Value chain mapping was used to illustrate the flow of produce and prices across market actors.
- Triangulation with market reports and interviews enhanced the credibility of insights.

This approach allowed for a deep understanding of the structural, institutional, and behavioral mechanisms shaping farmgate price formation in Bangladesh's potato markets.

3. Results and Discussion

3.1 Potato value chain network

The potato value chain in Bangladesh is characterized by multiple marketing routes that reflect varying levels of intermediary involvement (Fig. 1). Based on the survey findings, five major pathways were identified:

1. Farmer → *Beparis/Faria* → Wholesaler → Retailer (7%)
2. Farmer → *Beparis/Faria* → *Aratdar* → Wholesaler → Retailer (4%)
3. Farmer → *Beparis/Faria* → *Aratdar* → Cold Storage → *Aratdar* → Wholesaler → Retailer (11%)
4. Farmer → Cold Storage → *Aratdar* → Wholesaler → Retailer (77%)
5. Farmer → *Aratdar* → Wholesaler → Retailer (1%)

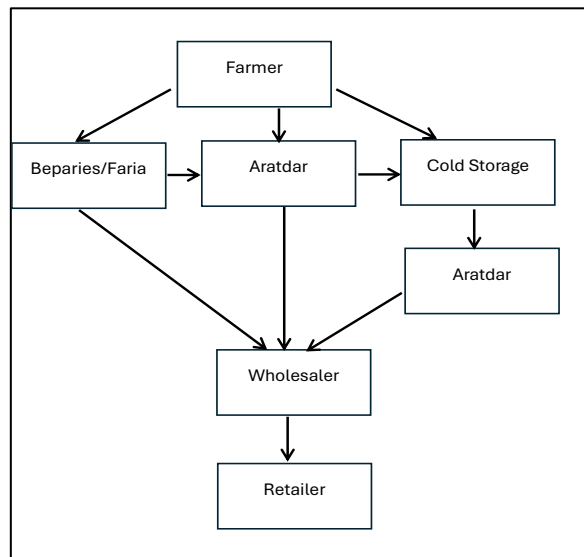


Fig. 1. Potato value chain.²

² Source: Study field survey 2024-25.

The potato value chain in Bangladesh is characterized by layered and intermediary-dominated marketing routes, with storage access serving as the key determinant of farmers' bargaining position. The most dominant pathway—*Farmer* → *Cold Storage* → *Aratdar* → *Wholesaler* → *Retailer*—accounts for 77% of total transactions, underscoring that cold storage is not merely a preservation facility but a strategic financial leverage point. Farmers who can afford to store their potatoes delay sales and engage directly with *Aratdars*, often securing relatively better prices. In contrast, 11% of potatoes move through a more extended chain involving *Beparis/Farias* → *Aratdar* → *Cold Storage* → *Aratdar* → *Wholesaler* → *Retailer*, where collectors store on behalf of traders and reintroduce the produce later at higher margins. Another 7% follow the shorter *Farmer* → *Bepari/Faria* → *Wholesaler* → *Retailer* route, and 4% travel via *Farmer* → *Bepari/Faria* → *Aratdar* → *Wholesaler* → *Retailer*, reflecting the pathways generally taken by farmers requiring quick cash after harvest. Only 1% of farmers bypass collectors entirely and sell directly to *Aratdars*, confirming that direct farmer-to-market transactions are infrequent.

These percentage-based patterns clearly illustrate that potatoes seldom move directly from producers to retailers or consumers. Instead, market participation is mediated by *Beparis* and *Farias* acting as primary collectors and liquidity providers, *Aratdars* acting as financial anchors and price-setters at the wholesale level, and *Wholesalers* and *Retailers* driving final distribution. The presence or absence of cold storage access largely determines whether farmers enter the value chain as distressed sellers or strategic price holders. More importantly, control over storage and capital allows intermediaries—particularly *Aratdars*—to shape supply timing, influence prices, and capture a disproportionate share of value. Thus, rather than a linear flow of goods, the potato supply system functions as a relational power network, where access to capital, storage rights, and commission-based transactions define who gains and who concedes within the chain.

3.2 Potato Market: Hierarchical Price Control and Limited Farmer Negotiation

The formation of farmgate potato prices in Bangladesh is primarily driven by a hierarchical structure of intermediaries rather than open market negotiation. *Aratdars*, who operate at terminal markets such as Dhaka, Bogura, or Chattogram, exercise decisive control over price determination. They issue procurement orders to their contracted *Beparis*, specifying both quantity and price, effectively anchoring farm-level offers to distant market dynamics rather than local supply or production conditions (Figure 2).

Beparis act mainly as price enforcers, transmitting the price dictated by *Aratdars* rather than independently negotiating with farmers. When visiting villages to collect produce, they typically present a fixed offer, “this is what the market is

paying today,” leaving farmers with minimal room to negotiate, usually within a margin of Tk. 0.5–1.0 per kg.

At the lower level, Farias and small-scale traders (often operating within or near cold storage facilities) handle smaller transactions but exert little influence on price-setting. Their activities primarily serve farmers who lack access to Beparis, often at even lower prices. Retailers enter the chain only after farmgate prices are established, extracting margins from an already unequal structure.

This hierarchical and top-down pricing mechanism makes farmers passive recipients of prices rather than active participants in the market. As a result, the concentration of power among Aratdars and Beparis perpetuates asymmetric value capture, limiting farmers’ ability to benefit from favorable market movements.

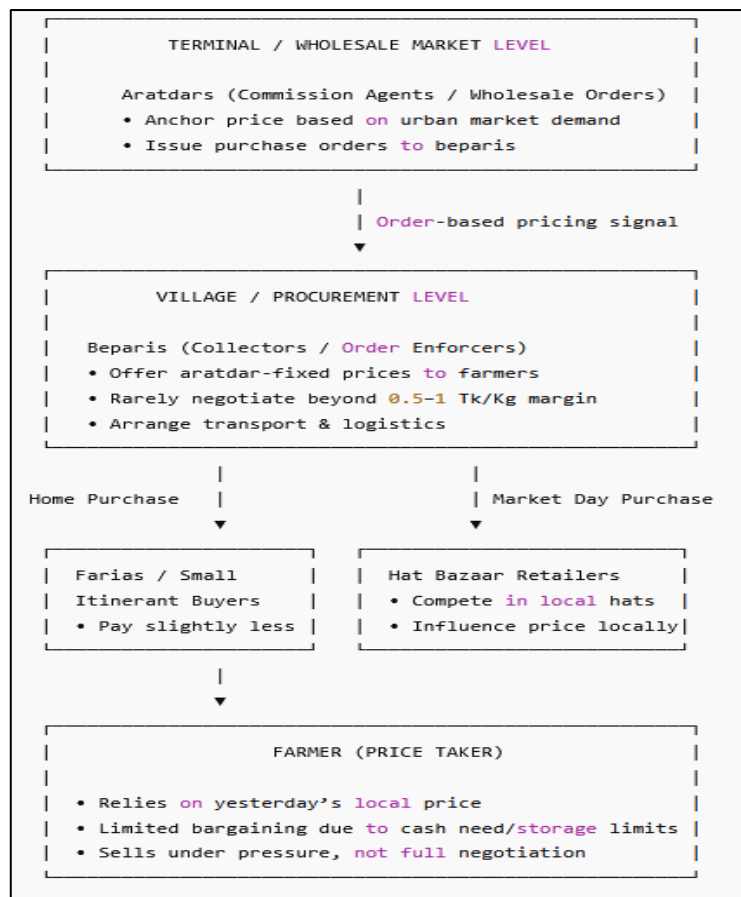


Fig. 2. Actor flow diagram: farm gate price-setting mechanism.³

³ Source: Author's own investigation from the field survey.

3.3 Potato Market: Nominal Negotiation within a Pre-Set Price Band

In the potato market, price formation at the farmgate level is largely influenced by order-based directives rather than free market negotiation (Fig. 3). Farmers usually sell their produce to Beparis or Farias, who act as intermediaries on behalf of Aratdars operating in major wholesale hubs such as Bogura, Munshiganj, or Rangpur. Prior to village-level collection or market (hat) days, these intermediaries receive specific orders from Aratdars that include desired quantities and a ceiling purchase price—commonly known among traders as the “yesterday price.” This reference price effectively anchors all local transactions and leaves minimal room for independent bargaining.

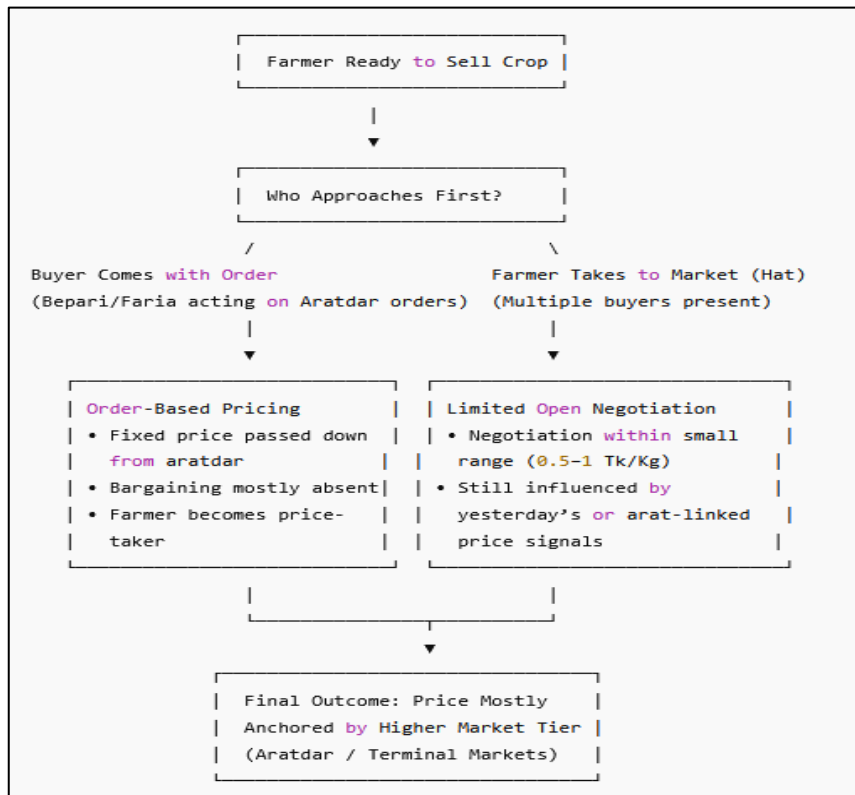


Fig. 3. Decision flow diagram: open negotiations vs. order-based pricing.⁴

Although farmers may attempt to negotiate slight premiums based on quality differentials, such as moisture content, tuber size, or potato type (seed vs. table potato), these variations rarely exceed Tk. 0.50–1.00 per kilogram from the price dictated by Aratdars (Fig. 3). In most cases, farmers are compelled to accept these

⁴ Source: Author's own investigation from the field survey.

offers due to liquidity constraints or the absence of storage facilities, especially during peak harvesting periods when prices are lowest. Consequently, what superficially appears as negotiation is largely symbolic bargaining within a pre-determined range. The actual price-setting power rests with distant market actors at higher levels of the supply chain, reinforcing the structural dependency of farmers on intermediary networks.

3.4 Potato Market: Slow Upward Transmission and Rapid Downward Adjustment

It is evident from Figure 4 that, in the potato market, price transmission between terminal markets and farmgate levels demonstrates clear asymmetry. Ideally, farm-level prices should respond proportionally and promptly to wholesale market movements. However, evidence shows that positive price signals from major wholesale hubs such as Dhaka or Chattogram are often delayed or diluted before reaching producers. When terminal prices rise, Aratdars and Beparis typically continue to procure potatoes from farmers at earlier, lower prices, even when market information about higher rates is already circulating at the upper levels of the chain. Farmers often hear explanations such as “the local price has not yet adjusted,” indicating that intermediaries consciously delay upward price transmission to capture the additional margin.

In contrast, negative price changes are transmitted immediately and forcefully. When terminal-market prices fall, collectors promptly inform farmers — often using phrases like “Arat-dara price kom,” leaving little room for bargaining. This elastic downward but rigid upward transmission pattern reveals strategic manipulation rather than market-driven efficiency. Intermediaries exploit information asymmetry to appropriate surplus gains during rising markets while shifting losses onto producers during downturns.

Farmers with cold storage access occasionally mitigate this imbalance by delaying sales until prices stabilize, benefiting from their ability to hold stocks. However, the high cost of storage and the immediate need for cash among smallholders limit this option to a minority of producers. Consequently, the majority of farmers remain price-takers, unable to respond effectively to terminal-market dynamics. This systematic asymmetry in price transmission underscores the market power imbalance that favors intermediaries over primary producers in the potato value chain.

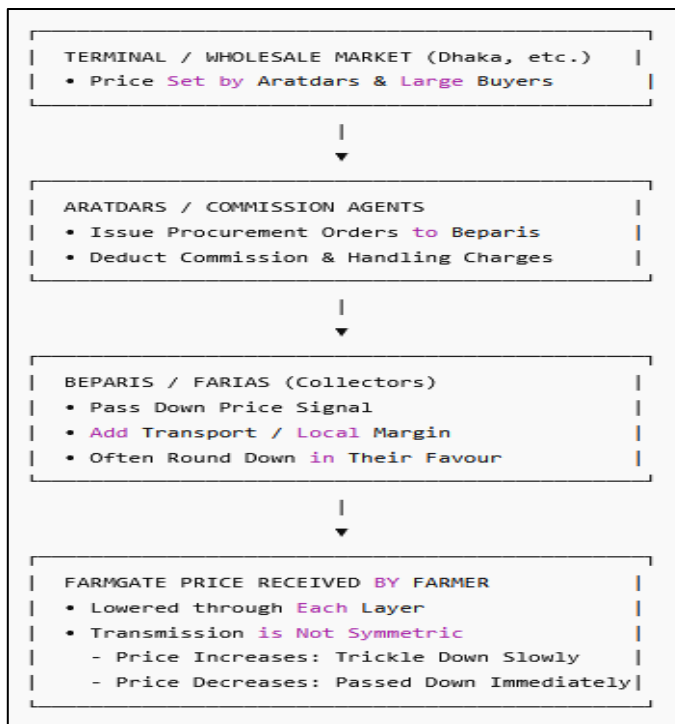


Fig. 4. Price transmission funnel.⁵

3.5 Potato Farmers: Highly Localized and Reactive Information Access

In the potato market, farmers' access to market information remains highly localized, fragmented, and reactive, creating a persistent disadvantage in farmgate negotiations. Survey data indicate that over 80% of potato farmers depend primarily on verbal communication with neighbouring farmers or local traders (Beparis or Farias) as their main source of price updates. Such information usually reflects the previous day's prices at nearby village hats (markets) rather than real-time movements in major wholesale centers such as Dhaka, Bogura, or Chattogram.

Although national television and radio occasionally broadcast wholesale price data, farmers often disregard these figures as irrelevant or unreliable, believing that they do not correspond to actual local offers. Consequently, price awareness at the production end of the chain remains both delayed and distorted. Farmers who sell under cash pressure—especially those without access to cold storage—are forced to accept whatever prices local traders offer, with minimal capacity to verify their fairness.

⁵ Source: Author's own investigation from the field survey.

In contrast, Beparis and Aratdars operate within dense, real-time communication networks spanning multiple districts. Through mobile phones and coordinated buyer groups, they continuously monitor price shifts in terminal markets and adjust procurement strategies accordingly. This information asymmetry allows intermediaries to exploit timing advantages: price increases at wholesale levels are transmitted slowly to farmers, while price declines are communicated almost instantly. Farmers thus face a consistent lag in benefiting from upward market trends but bear the full brunt of downturns immediately.

This pattern represents a structural asymmetry in market intelligence — where intermediaries use superior information access not only to guide procurement decisions but also to shape farmers' price expectations. The result is a system where price formation reflects buyer coordination rather than open information flow, reinforcing farmers' role as passive price takers in the potato market.

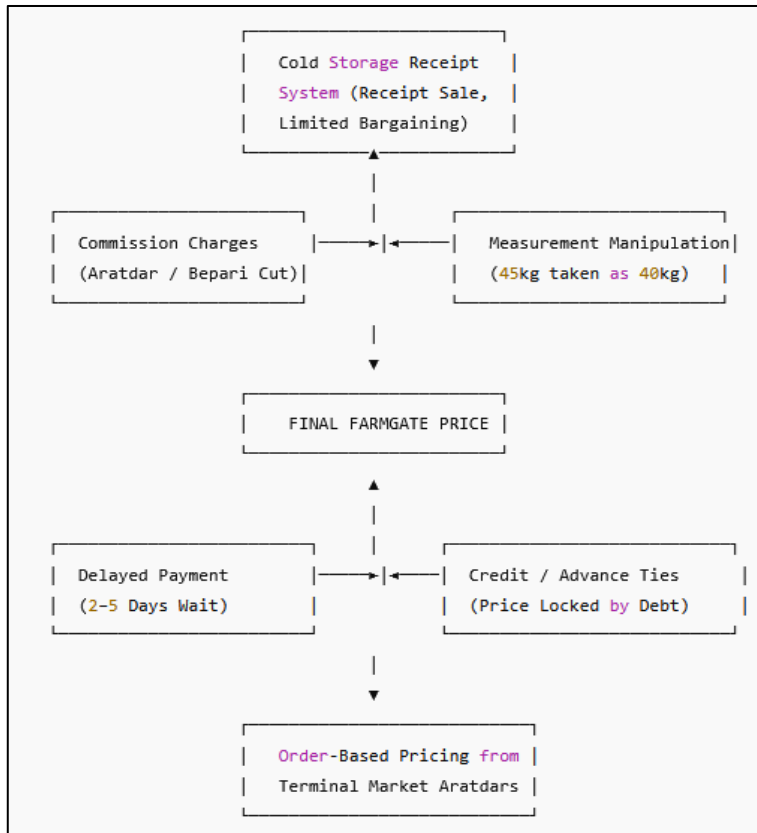


Fig. 5. Mechanism web diagram – determinants of final farmgate price.⁶

⁶ Source: Author's own investigation from the field survey.

3.6 Bargaining Power and Information Asymmetry in Potato Marketing

The findings from the field survey and focus group discussions reveal that potato farmers in Bangladesh operate under highly unequal bargaining conditions, where information asymmetry and dependency relations overwhelmingly favor intermediaries. Farmers typically face immediate liquidity needs following harvest, while Beparis and Aratdars control critical market functions such as access to buyers, storage facilities, price information, and credit. This imbalance transforms farmers into passive price receivers rather than active negotiators.

Over 90 percent of potato farmers rely on cold storage facilities; however, rather than using storage receipts to secure better prices later in the season, most farmers are forced to sell early to repay debts or finance cultivation costs. In many cases, Beparis purchase potatoes directly from cold storage receipts at a pre-determined low rate, thereby gaining control over the produce even before market price discovery takes place. As a result, the potential benefits of delayed sales are largely captured by intermediaries instead of producers.

In price negotiations, the margin of discussion for farmers usually remains limited to Tk. 0.50–1.00 per kilogram, reflecting a severely constrained negotiation bandwidth. Conversely, intermediaries operate within much wider margins through vertical bargaining with Aratdars and wholesalers, extracting higher profits through price arbitrage. The absence of real-time market information exacerbates farmers' vulnerability, as they have little means to verify the prices being quoted by buyers. Thus, instead of genuine negotiation, farmers often accept prices anchored by intermediaries' informational advantage.

Furthermore, the commission-based trading system allows Beparis to claim that they merely “pass on” prices fixed by Aratdars, thereby deflecting responsibility and minimizing farmers' bargaining leverage. Hidden extraction mechanisms such as manipulated weighing practices—treating 40 kg as 45 kg per mon—further reduce farmers' effective returns without open confrontation (Fig. 5). Collectively, these conditions create a structure where intermediaries dominate price formation, and farmers remain locked in a cycle of dependency and information disadvantage.

4. Conclusion and Recommendation

4.1 Conclusion

This study shows that farmgate potato price formation in Bangladesh is governed by a structurally asymmetric marketing system in which intermediaries—particularly Aratdars and Beparis—exercise substantial market power, leaving farmers with limited bargaining capacity. Although cold storage facilities are widely used, they often intensify farmers' dependence through loan obligations, commission-based transactions, and receipt-linked sales, rather than enabling

strategic market participation. The findings reveal pronounced price transmission asymmetry, whereby declines in wholesale prices are quickly passed on to farmers, while price increases are delayed or diluted. Informal yet institutionalized practices such as non-standard weighing, advance payments, and order-driven procurement further entrench intermediary dominance. Overall, the results indicate that institutional embeddedness and intermediary control, rather than competitive supply–demand forces alone, play a decisive role in shaping farmgate price outcomes in Bangladesh’s potato market.

4.2 Recommendations

- Promote farmer cooperatives and storage-based producer organizations to strengthen collective bargaining power and reduce farmers’ reliance on individual intermediaries.
- Introduce digital price information systems that provide farmers with real-time price updates from terminal and wholesale markets.
- Regulate *Aratdar* commissions and trading practices through transparent fee structures and formal transaction documentation.
- Enforce standardized weighing and transaction procedures to prevent systematic under-measurement and hidden price reductions.
- Encourage future research combining qualitative and econometric approaches, particularly price pass-through and volatility transmission analysis, to support evidence-based market reforms.

Acknowledgement

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EVALUATION OF SELECTED GARLIC GENOTYPES FOR SALINITY TOLERANCE UNDER DIFFERENT MULCHING PRACTICES IN COASTAL SALINE SOIL*

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AND A. N. S. U. A. SIDDIQUI⁵

Abstract

An experiment was carried out at the farmer's field of Tildanga, Dacope, Khulna from November 2020 to April 2021, to identify high-yielding genotypes of garlic under different mulching practices in saline-prone areas of Bangladesh. In the present study, six selected genotypes, namely KSA-009, DRA-012, SAM-016, KJH-001, SGA-021, and GNA-032, were evaluated under four mulching treatments *viz.*, Control (no mulch) (M_0), rice straw mulch (M_1), black polythene mulch (M_2), and transparent polythene mulch (M_3). The experiment was laid out in a randomized complete block design (factorial) with three replications. Results revealed that mulching significantly influenced growth and yield traits, including plant height, leaf number plant⁻¹, fresh and dry weights of leaves and bulb, clove length and breadth, number of cloves bulb⁻¹, bulb length and breadth and bulb yield. Under mulching practices, genotype KSA-009 combined with rice straw mulch produced the highest bulb yield (8.21 t ha⁻¹), which was statistically similar to the yields of genotypes DRA-012 and SAM-016 under the same mulching treatment. While under non-mulched conditions genotypes KSA-009, DRA-012, and SAM-016 performed better in respect to growth, yield attributes, and bulb yield, indicating that these three garlic genotypes were relatively tolerant to salinity. The lowest bulb yield (4.56 t ha⁻¹) was recorded in GNA-032 under non-mulch condition. Results indicated that genotype KSA-009 is suitable for coastal saline soil when grown with straw mulch.

Keywords: Garlic, Genotypes, Salinity, Mulches, Growth and bulb yield.

Introduction

Coastal agriculture in Bangladesh is severely threatened by soil salinity, a problem that worsens as the soil dries and is exacerbated by climate-induced sea-level rise, cyclones, and salinity intrusion. This crisis affects a significant portion of the country's cultivable land, with salt-affected areas having increased from 83.3 million hectares in 1973 to 105.6 million hectares in 2009 (SRDI, 2019). Around

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*A part of PhD dissertation of the first author.

2.85 million hectares of coastal areas exist, of which 0.83 million hectares are cultivable, but salinity intrusion reduces soil fertility and irrigation water quality, hampering agricultural production and threatening the livelihoods of millions living in the coastal region. In this region, the dominant cropping pattern is 'Fallow-Fallow-*T. aman* rice', which leads to very poor agricultural land use intensity. A key issue within this system is the cycle of late rice harvests, which delays the planting of subsequent *rabi* crops and further diminishes their yields.

Salinity stress disrupts plant metabolism through ionic toxicity, osmotic stress, and nutritional disorders, which can stunt crops, reduce yields, or cause total failure (Zorb *et al.*, 2019). Addressing this crisis is critical for national food security and aligns with global commitments like Sustainable Development Goal (SDG) 13 i.e. "Taking urgent action to combat climate change and its impacts" (FAO, 2021). Garlic (*Allium sativum* L.) is a strategically important *rabi* crop in Bangladesh, ranking second in production among bulb spice and is valued for its nutritional and medicinal properties. In our country this crop is also known as 'rashun'. Despite a steady increase in national production of garlic, 4.85, 5.02 and 5.27 lakh metric tons in 2019-20, 2020-21 and 2021-22, respectively (Anon., 2023), yields remain particularly limited in coastal saline regions, forcing heavy imports from countries like China, India, and Myanmar (Volza, 2024). A potential solution for low yield of this spice lies in an innovative management practice like mulching that conserves soil moisture during the critical dry period (Demo and Asefa, 2024). Mulching has emerged as an effective method not only to conserve soil moisture but also to reduce root-zone salinity and suppress weeds, thereby promoting healthier root systems and making cultivation more viable in saline soil (Cuevas *et al.*, 2019). Usage of salt tolerant garlic genotype/cultivar is also a good option for increasing garlic production in coastal saline soil. The experiment was, therefore, carried out to evaluate the performance of selected garlic genotypes under different mulching practices to identify the best combinations for enhancing garlic production and sustainability in this saline-prone environment.

Materials and methods

The experiment was conducted at a farmer's field in Tildanga, Dacope, Khulna (22°37'55"N, 89°30'10"E) during the 2020-2021 *rabi* season. After two consecutive years' screening of thirty-two genotypes under both non-saline and saline condition at three locations *viz.*, BARI, Gazipur; Amtali, Borguna and Dacope, Khulna six garlic genotypes, namely KSA-009, DRA-012, SAM-016, KJH-001, SGA-021 and GNA-032 were selected based on their yield performance to develop a suitable package of cultivation using different mulching practices. The experimental site was situated in the southern coastal belt of Bangladesh characterized by its vulnerability to salinity and other climatic stresses. Dacope, Khulna has a subtropical monsoonal climate with high humidity and ~1800 mm of annual rainfall (Fig. 1). The region is highly vulnerable to climate impacts, including cyclones, salinity intrusion, and rising

temperatures, which threaten to significantly reduce crop production. Before commencement of the experiment, cropping history of the experimental field was studied and the 'Fallow-Fallow-*T. aman*' cropping pattern were found there. The experimental treatments consisted of six selected garlic genotypes viz. KSA-009, DRA-012, SAM-016, KJH-001, SGA-021 and GNA-032 and four types of mulches viz. Control (no mulch), Rice straw mulch (5 - 7 cm), Black polythene mulch (0.01 mm) and Transparent polythene mulch (0.01 mm). The study was laid out in a factorial Randomized Complete Block Design with three replications. The combination of genotypes and mulch materials resulted in a total of twenty-four treatment combinations. The land was prepared by ploughing and harrowing to achieve a fine tilth. Subsequently, raised beds were constructed to facilitate essential drainage in the coastal environment. The soil was a silty clay loam, pre-planting analysis of which indicated low organic carbon, N, and K. Cloves were planted on 27 November at a spacing of 15 cm by 10 cm. Total 30 plants of garlic were planted in each plot and thus the unit plot area was 0.45 m². Rice straw mulch was applied to the soil at a dose of 10 t ha⁻¹. Straw mulch and polythene mulches were applied to the soil before planting of cloves or 15 days after clove emergence. A basal dose of fertilizers was applied at the time of planting, incorporating both organic and inorganic sources. Necessary intercultural operations, including irrigation and pest management, were performed uniformly. Initial soil data of the experimental site presented in the (Table 1). Final harvest of garlic cloves was done in the first week of April when the plants reached physiological maturity. Data on plant height, number of leaves plant⁻¹, fresh weight of leaves plant⁻¹, dry weight of leaves plant⁻¹, clove length and breadth, bulb length and breadth, bulb fresh weight and dry weight, number of cloves bulb⁻¹ and bulb yield plot⁻¹ were recorded from the inner rows of each plot.

Table 1. Initial soil data of the experimental site

| Soil parameters | Tildanga, Dacope |
|-----------------------------------|---|
| Mechanical composition | Sand (5%), Silt (55%), Clay (40%) |
| Soil texture | Silty clay loam |
| Bulk density (Mg/m ³) | 1.56 |
| pH | 7.8 (Slightly alkaline) |
| OC (%) | 0.93 |
| Total N | 0.08 |
| K (meq/100g) | 0.68 |
| P (ppm) | 92.4 |
| S (ppm) | 28.7 |
| B (ppm) | 0.8 |
| Zn (ppm) | 0.92 |
| CEC (meq/100g dry soil) | 7.95 |
| EC 1:5 (dS/m) | 11.29 |

Weather data of the experimental site is presented in the Figure 1.

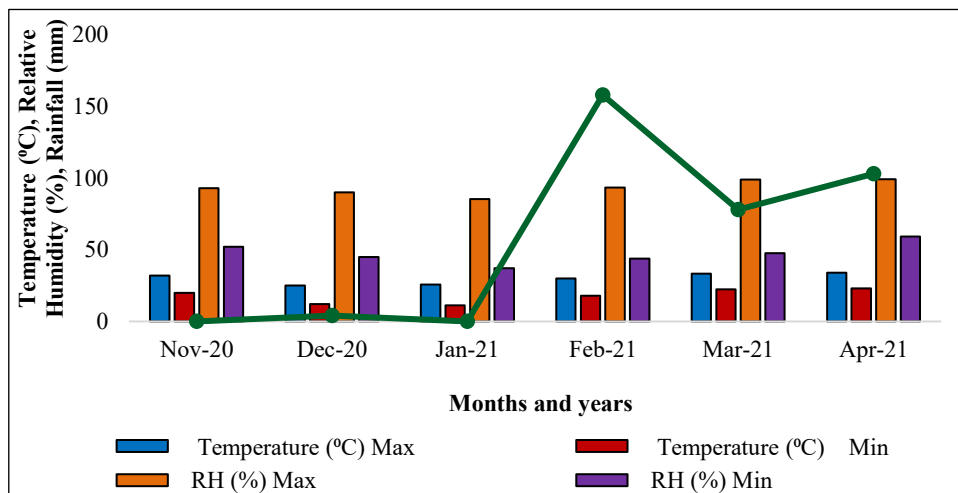


Fig. 1. Maximum and minimum (Temperature, Relative Humidity) and total rainfall during 2020-21 at Dacope, Khulna location.

Soil moisture content data (Table 2) at 0-45 cm depth were also taken at 15 days interval after spreading mulch in the plot during the cropping season according to the treatments.

Table 2. Soil moisture content at different depth of soil (cm) during 2020-21 at Tildanga Dacope, Khulna.

| Depth of soil (cm) | Days After Planting (DAP) | Soil moisture content (% w/w, dry basis) |
|--------------------|---------------------------|--|
| 0-15 | Planting time | 34 |
| 0-15 | 30 | 29 |
| 0-15 | 45 | 26 |
| 0-15 | 60 | 24 |
| 0-15 | 75 | 40 |
| 16-30 | Planting time | 56 |
| 16-30 | 30 | 47 |
| 16-30 | 45 | 39 |
| 16-30 | 60 | 44 |
| 16-30 | 75 | 49 |
| 31-45 | Planting time | 65 |
| 31-45 | 30 | 58 |
| 31-45 | 45 | 43 |
| 31-45 | 60 | 57 |
| 31-45 | 75 | 45 |

Soil and canal water (used for irrigation purpose) salinity data (Figure 2) were also taken at 7 days interval from the time of land preparation to 15 days before harvesting the crop.

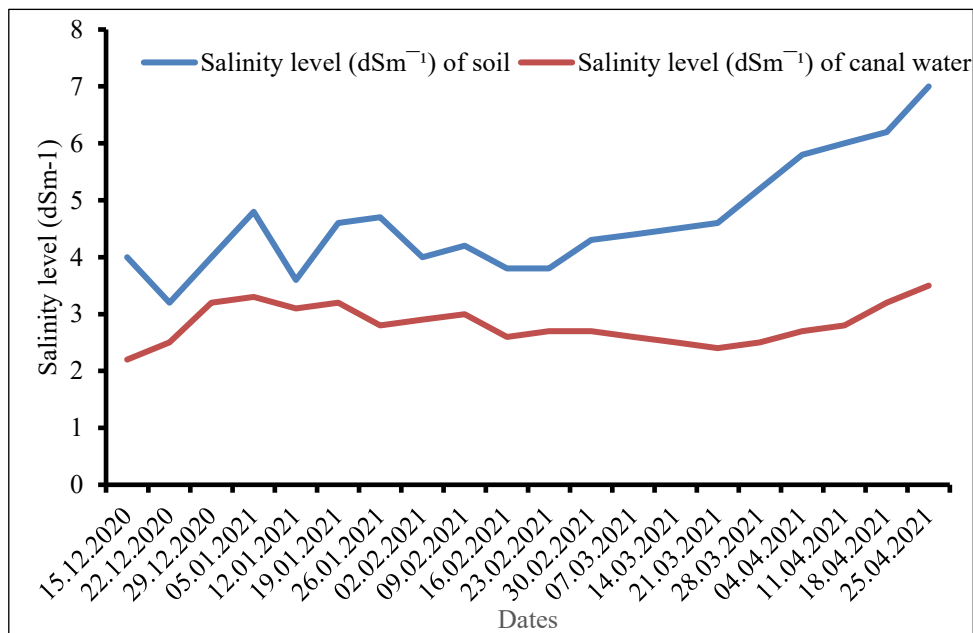


Fig. 2. Soil and canal water salinity level (dS m^{-1}) at different dates during 2020-21 in Tildanga.

The collected data were subjected to Analysis of Variance using R statistical software. Treatment means were compared using the Least Significant Difference (LSD) test at 1% or 5% level of significance according to necessity.

Results and discussion

Plant height at 110 days after planting

Genotype and mulch type significantly influenced garlic plant height at 110 days after planting (DAP). Genotypes KSA-009 and DRA-012 produced the tallest plants in combination with rice straw mulch (55.58 cm and 53.75 cm, respectively), while GNA-032 gave the shortest plants (43.00 cm) when no mulch was used (Table 3). Rice straw mulch (M_1) significantly increased plant height (53.61 cm) compared to the unmulched control (49.17 cm) (Table 3). The tallest plants were recorded in KSA-009 with M_1 mulch, whereas GNA-032 performed poorest in the unmulched control (M_0) (Table 3). These results highlight the importance of selecting salt-tolerant genotypes along with effective mulching practices to maximize growth and yield in saline conditions. The superior height of KSA-009

and DRA-012 reflects their genetic potential and adaptability, consistent with Sultana *et al.* (2022). Straw mulch has been reported to moderate soil temperature and improve growth parameters, supporting its role in enhancing garlic performance (Rafiuddin *et al.* 2023).

Number of leaves plant⁻¹

The number of leaves plant⁻¹ was significantly affected by the interaction of genotype and mulching (Table 3). The highest leaf number plant⁻¹ was found in the combination KSA-009 × M₁ (8.33) which was statistically similar with KJH-001 × M₁ (8.00), DRA-012 × M₁ (8.00), SGA-021 × M₁ (8.00), GNA-032 × M₁ (8.00), KSA-009 × M₁, KJH-001 × M₃, KSA × M₃, DRA × M₃, SAM-016 × M₃ and SGA-021 × M₃ and the lowest leaf number was noticed in GNA-032 × M₀ combination identical with other five genotypes with non-mulch. It is evident that all genotypes with rice straw mulch gave statistically similar and maximum leaf number and all genotypes except GNA-032 with transparent polythene mulch recorded identical and second highest leaf number, whereas all genotypes under no-mulch condition produced similar and minimum leaf number plant⁻¹. These findings demonstrate the combined role of genotype and mulching in enhancing leaf development, photosynthesis, and yield. Similar results were reported by Rashid and Islam (2019) i.e. rice straw mulch can act as a temperature regulator and protect the plants from extreme level of heat or cold. This favorable microclimate can support leaf development and overall, the number of plants. Kaur and Bains (2023) also reported that vermicompost and rice straw mulch produced the highest number of leaves (6.13 and 6.50), while the control treatments with no manure and no mulch yielded the lowest (3.71 and 3.61). This superior performance is due to vermicompost providing essential nutrients and rice straw mulch regulating soil temperature, creating optimal conditions for leaf development.

Fresh weight of leaves plant⁻¹

Fresh leaf weight plant⁻¹ was significantly influenced by the combination of genotype and mulching (Table 3). The interaction effect between genotype and mulching was found most pronounced in KSA-009 × M₁ (16.83 g) closely followed by KJH-001 × M₁ (16.26 g), DRA-012 × M₁ (15.95 g), SAM-009 × M₁ (15.53 g), SGA-021 × M₁ (15.53 g), GNA-032 × M₁ (15.26 g), KJH-001 × M₂, KJH-001 × M₂, KJH-001 × M₃, KJH-001 × M₀, KSA-009 × M₂, DRA-012 × M₂ and GNA-032 × M₂, whereas GNA-032 × M₀ produced the lowest (10.03 g), underscoring the synergistic role of genotype and mulching in vegetative growth. Previous studies support these findings such as Rahman *et al.* (2020) reported varietal differences in leaf weight, Yimer *et al.* (2020) demonstrated that mulching particularly rice straw and black polyethylene sheet enhances yield through improved moisture retention and stress mitigation. Rafiuddin *et al.* (2023) further emphasized the role of organic mulches in optimizing soil

conditions and yield. These results collectively affirm that integrating high-performing genotypes with effective mulching strategies is vital for maximizing garlic productivity.

Table 3. Interaction effect of genotypes and mulches on plant height at 110 DAP, number of leaves plant⁻¹, fresh weight of leaves plant⁻¹ and dry weight of leaves plant⁻¹

| Genotypes × Mulches | Plant height at 110 DAP (cm) | Number of leaves plant ⁻¹ | Fresh weight of leaves plant ⁻¹ (g) | Dry weight of leaves plant ⁻¹ (g) |
|--------------------------|------------------------------|--------------------------------------|--|--|
| KJH-001 X M ₀ | 47.00 | 7.00 | 12.03 | 1.67 |
| KJH-001 X M ₁ | 55.00 | 8.00 | 16.26 | 2.33 |
| KJH-001 X M ₂ | 50.33 | 7.33 | 14.90 | 1.91 |
| KJH-001 X M ₃ | 54.00 | 7.66 | 15.20 | 2.15 |
| KSA-009 X M ₀ | 48.33 | 7.33 | 14.36 | 1.66 |
| KSA-009 X M ₁ | 58.33 | 8.33 | 16.83 | 2.43 |
| KSA-009 X M ₂ | 52.66 | 7.33 | 15.16 | 1.90 |
| KSA-009 X M ₃ | 54.66 | 7.66 | 14.86 | 2.09 |
| DRA-012 X M ₀ | 48.00 | 7.33 | 14.06 | 1.63 |
| DRA-012 X M ₁ | 57.33 | 8.00 | 15.95 | 2.25 |
| DRA-012 X M ₂ | 51.66 | 7.33 | 14.83 | 1.82 |
| DRA-012 X M ₃ | 54.66 | 7.66 | 13.10 | 2.02 |
| SAM-016 X M ₀ | 47.00 | 7.00 | 13.13 | 1.58 |
| SAM-016 X M ₁ | 56.66 | 8.00 | 15.53 | 2.22 |
| SAM-016 X M ₂ | 50.66 | 7.33 | 14.76 | 1.79 |
| SAM-016 X M ₃ | 54.00 | 7.66 | 12.03 | 2.01 |
| SGA-021 X M ₀ | 46.00 | 7.00 | 12.56 | 1.58 |
| SGA-021 X M ₁ | 54.66 | 8.00 | 15.53 | 2.19 |
| SGA-021 X M ₂ | 50.00 | 7.33 | 14.06 | 1.73 |
| SGA-021 X M ₃ | 53.00 | 7.66 | 13.33 | 2.00 |
| GNA-032 X M ₀ | 43.00 | 7.00 | 10.03 | 1.44 |
| GNA-032 X M ₁ | 54.66 | 8.00 | 15.26 | 2.16 |
| GNA-032 X M ₂ | 48.66 | 7.33 | 14.26 | 1.68 |
| GNA-032 X M ₃ | 53.00 | 7.33 | 13.90 | 1.92 |
| LSD (0.05) | 8.61 | 0.88 | 3.45 | 0.57 |
| Level of sig. | * | * | ** | ** |
| CV (%) | 10.11 | 7.18 | 12.19 | 13.39 |

* indicates significant at 5% and ** indicates significant at 1% levels of probability; NS = Not significant;

DAP: Days after planting, M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ – Transparent polythene mulch; Sig: significance.

Dry weight of leaves plant⁻¹

Dry weight of leaves plant⁻¹ was significantly influenced by the interaction effect of genotype and mulching (Table 3). The highest dry weight of leaves plant⁻¹ was observed in KSA-009 × M₁ (2.43 g) combination closely followed by KJH-001 × M₁ (2.33 g), DRA-012 × M₁ (2.25 g), SAM-016 × M₁ (2.22 g), SGA-021 × M₁ (2.19 g), GNA-032 × M₁ (2.16 g), KJH-001 × M₂ (1.91 g), KJH-001 × M₃ (2.15 g), KSA-009 × M₂ (1.90 g), KSA-009 × M₃ (2.09 g), DRA-012 × M₃ (2.02 g), SAM-016 × M₃ (2.01 g), SGA-021 × M₃ (2.00 g) and GNA-032 × M₃ (1.92 g), whereas GNA-032 × M₀ combination gave the lowest dry weight plant⁻¹ (1.44 g). It revealed that all the genotypes under rice straw mulch condition performed better with regard to dry weight plant⁻¹ followed by the same genotypes under transparent polythene mulch and all 6 genotypes under non-mulched condition gave the inferior result in respect of dry biomass plant⁻¹. The above results highlighted the synergistic role of genotype and mulch in biomass accumulation. Rafiuddin *et al.* (2023) emphasized varietal differences in mulch response, while Atif *et al.* (2019) demonstrated genotype-specific biomass enhancement under uniform ecological conditions. Collectively, the results underscore the importance of genotype selection and mulch application in optimizing garlic growth under saline environments.

Clove length

Clove length in garlic was significantly influenced by genotype and mulch interaction (Table 4). The KSA-009 × M₁ combination gave the maximum clove length (2.48 cm) which was identical with DRA-012 × M₁ (2.45 cm), SAM-016 × M₁ (2.39 cm), SGA-021 × M₁ (2.33 cm), GNA-032 × M₁ (2.32 cm), KJH-001 × M₁ (2.33 cm), KSA-009 × M₃ (2.31 cm) and DRA-012 × M₃ (2.31 cm) whereas GNA-032 × M₀ recorded the minimum (1.88 cm) closely followed by all other genotypes under no mulch. It was observed that all the genotypes under non-mulched and rice straw mulched condition, respectively performed worse and better in respect of clove length. These findings align with previous studies (Galgaye, 2023; Abreham, 2017; Rai and Negi, 2021) that highlight the role of mulching and genotype in enhancing clove size.

Clove breadth

Clove breadth in garlic was significantly influenced by the interaction of genotype and mulch (Table 4), The KSA-009 × M₁ combination recorded the maximum clove breadth (1.41 cm) which was identical with DRA-012 × M₁ (1.38 cm), SAM-016 × M₁ (1.35 cm), SGA-021 × M₁ (1.32 cm), GNA-032 × M₁ (1.32 cm), KJH-001 × M₁ (1.34 cm), KJH-001 × M₃ (1.28 cm), KSA-009 × M₃ (1.31 cm), DRA-012 × M₃ (1.31 cm) and SAM-016 × M₃ (1.28 cm), and GNA-032 × M₀ recorded the minimum (0.95 cm) closely followed by all other genotypes under no mulch.

It was observed that all the genotypes under non-mulched and rice straw mulched condition performed better in respect of clove length. It is evident that all the genotypes under rice straw mulch gave the best result with regard to clove breadth and when no mulch was applied, all genotypes gave inferior results. These results underscore the importance of genotype selection and mulching in improving clove development under saline stress. The findings align with Rai and Negi (2021), who reported significant improvements in clove dimensions due to mulching and genetic factors.

Table 4. Interaction effect of genotypes and mulches on clove length, clove breadth, bulb length and bulb breadth of garlic genotypes

| Genotypes × Mulches | Clove length (cm) | Clove breadth (cm) | Bulb length (cm) | Bulb breadth (cm) |
|--------------------------|----------------------|-----------------------|---------------------|----------------------|
| KJH-001 X M ₀ | 2.03 | 1.00 | 2.36 | 2.13 |
| KJH-001 X M ₁ | 2.33 | 1.34 | 2.93 | 2.76 |
| KJH-001 X M ₂ | 2.08 | 1.10 | 2.60 | 2.43 |
| KJH-001 X M ₃ | 2.19 | 1.28 | 2.73 | 2.60 |
| KSA-009 X M ₀ | 2.05 | 1.00 | 2.50 | 2.30 |
| KSA-009 X M ₁ | 2.48 | 1.41 | 3.06 | 2.93 |
| KSA-009 X M ₂ | 2.16 | 1.25 | 2.63 | 2.46 |
| KSA-009 X M ₃ | 2.31 | 1.31 | 2.80 | 2.76 |
| DRA-012 X M ₀ | 2.04 | 1.00 | 2.46 | 2.30 |
| DRA-012 X M ₁ | 2.45 | 1.38 | 3.06 | 2.83 |
| DRA-012 X M ₂ | 2.15 | 1.20 | 2.60 | 2.43 |
| DRA-012 X M ₃ | 2.31 | 1.31 | 2.80 | 2.73 |
| SAM-016 X M ₀ | 2.03 | 1.00 | 2.43 | 2.20 |
| SAM-016 X M ₁ | 2.39 | 1.35 | 3.00 | 2.80 |
| SAM-016 X M ₂ | 2.12 | 1.18 | 2.60 | 2.43 |
| SAM-016 X M ₃ | 2.23 | 1.28 | 2.73 | 2.60 |
| SGA-021 X M ₀ | 2.00 | 0.99 | 2.20 | 2.13 |
| SGA-021 X M ₁ | 2.33 | 1.32 | 2.93 | 2.76 |
| SGA-021 X M ₂ | 2.07 | 1.10 | 2.56 | 2.33 |
| SGA-021 X M ₃ | 2.16 | 1.25 | 2.73 | 2.60 |
| GNA-032 X M ₀ | 1.88 | 0.95 | 2.13 | 2.10 |
| GNA-032 X M ₁ | 2.32 | 1.32 | 2.86 | 2.76 |
| GNA-032 X M ₂ | 2.06 | 1.08 | 2.53 | 2.33 |
| GNA-032 X M ₃ | 2.16 | 1.25 | 2.63 | 2.53 |
| LSD _(0.05) | 0.17 | 0.15 | 0.28 | 0.21 |
| Level of sig. | ** | ** | ** | ** |
| CV (%) | 4.94 | 7.66 | 6.51 | 5.30 |

* indicates significant at 1% levels of probability.

M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ - White polythene mulch. Sig.: Significance.

Bulb length

Bulb length in garlic was significantly affected by genotype and mulch interaction (Table 4). The highest bulb length (3.06 cm) was recorded in two combinations KSA-009 × M₁ DRA-012 × M₁ closely followed by DRA-012 × M₁ (3.00 cm), KJH-001 × M₁ (2.93 cm), SGA-021 × M₁ (2.93 cm), GNA × M₁ (2.86 cm), KSA-0009 × M₃ (2.86 cm) and DRA-012 × M₁ (2.86 cm). Whereas GNA-032 × M₀ yielded the lowest (2.13 cm). Under no mulch condition, genotypes KSA-009, DRA-012 and SAM-006 gave statistically similar but lower result compared to mulch treatments. These findings align with Mulu *et al.* (2021), Galgaye and Deresa (2023) and Rai and Negi (2021), who reported significant varietal and mulch effects on bulb traits in. Under rice straw mulch those genotypes gave higher bulb length because rice straw mulched helped conserve soil moisture (%) more (Table 2) and also reduce soil salinity (dS m⁻¹) (Fig. 2).

Bulb breadth

Bulb breadth in garlic was significantly influenced by interaction effect of genotype and mulch (Table 4). The maximum bulb breadth was recorded in KSA-009 × M₁ (2.93 cm) which was statistically similar to the combinations DRA-012 × M₁ (2.83 cm), SAM-016 × M₁ (2.80 cm), KJH-01 × M₁ (2.76 cm), SGA-021 × M₁ (2.76 cm), GNA-032 × M₁ (2.76 cm), KSA-009 × M₃ (2.76 cm) and DRA-012 × M₃ (2.73 cm) indicating strong genotype-specific responses to rice straw mulching. Under no mulch condition, all genotypes gave inferior results with regard to bulb breadth. These findings align with Rahman *et al.* (2020), Rai and Negi (2021), who reported significant varietal and mulch effects on bulb diameter. Enhanced clove size and favorable soil conditions under mulching contribute to improved bulb breadth, reinforcing the importance of integrating genetic selection with effective mulching strategies for optimal garlic production.

Fresh weight of bulb

Fresh bulb weight in garlic was significantly affected by the interaction of genotype and mulch (Fig. 3). Rice straw mulch (M₁) in combination with KSA-009 (KSA-009 × M₁) produced maximum bulb weight (17.43 g) closely followed by DRA-012 × M₁ (16.5 g) and the lowest was obtained from GNA-032 × M₀ (11.66 g). It was seen that genotypes in combination with rice straw mulch performed best and the genotypes under unmulched condition gave the inferior result with regard to clove breadth highlighting the synergistic effect of genetic potential and mulching. These findings are consistent with Rahman *et al.* (2020) who reported significant varietal and mulch effects on bulb weight. Enhanced moisture retention, reduced nutrient loss, and improved soil conditions under rice straw mulch contribute to increased bulb biomass. The results underscore the

importance of integrating genotype selection with effective mulching and tillage practices to optimize garlic yield under stress conditions.

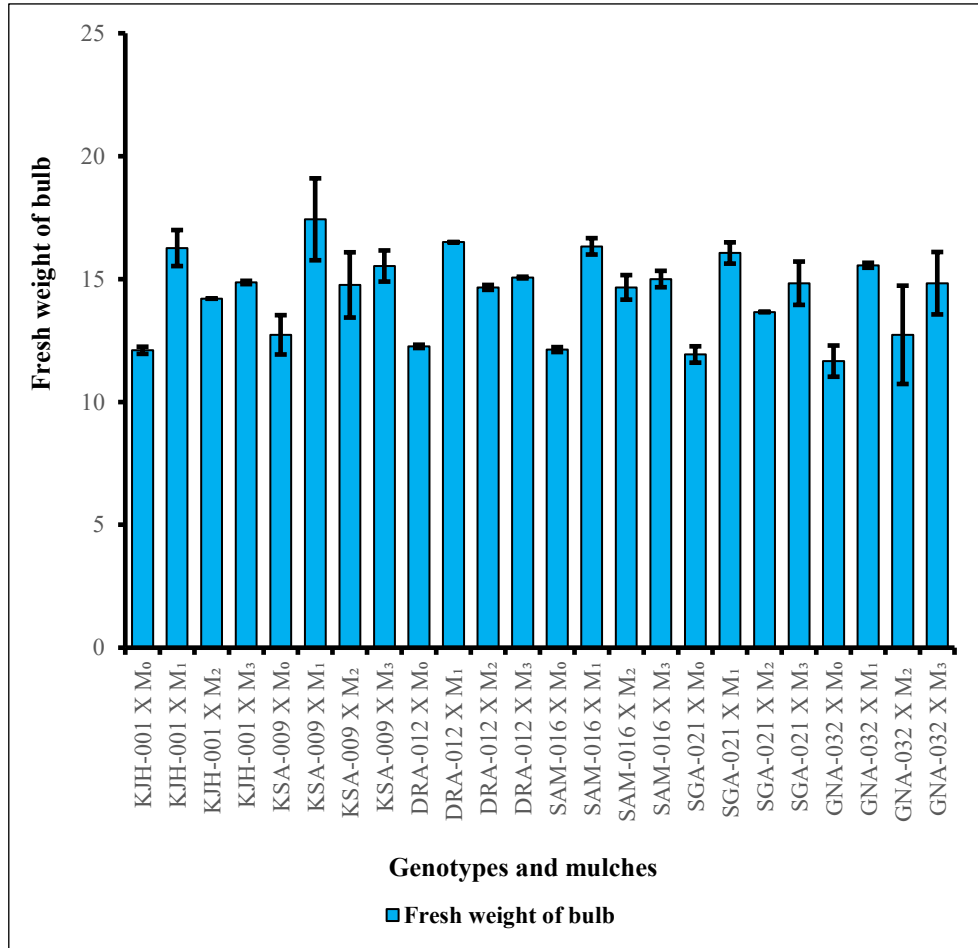


Fig. 3. Interaction effect of different genotypes and mulches on the Fresh weight of bulb. The vertical line (error bar) represents the Standard Error (SE) of the mean for specific genotypes × mulch combination.

M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ - White polythene mulch.

Dry weight of bulb

Dry bulb weight in garlic was significantly influenced by the genotype and mulch interaction (Figure 4). The most favorable combination was KSA-009 × M₁ (6.05 g) which was followed by DRA-012 × M₁ (4.90 g), SAM-016 × M₁ (4.83 g),

whereas GNA-032 × M₀ yielded the minimum dry weight of bulb (3.93 g), highlighting the synergistic effect of genotype and mulching. These findings are in consonance with Rahman *et al.* (2020) who reported significant varietal and mulch effects on dry bulb weight. Improved soil moisture retention, reduced temperature stress, and weed suppression under rice straw mulch contributed to enhanced root development and nutrient uptake, ultimately boosting garlic yield.

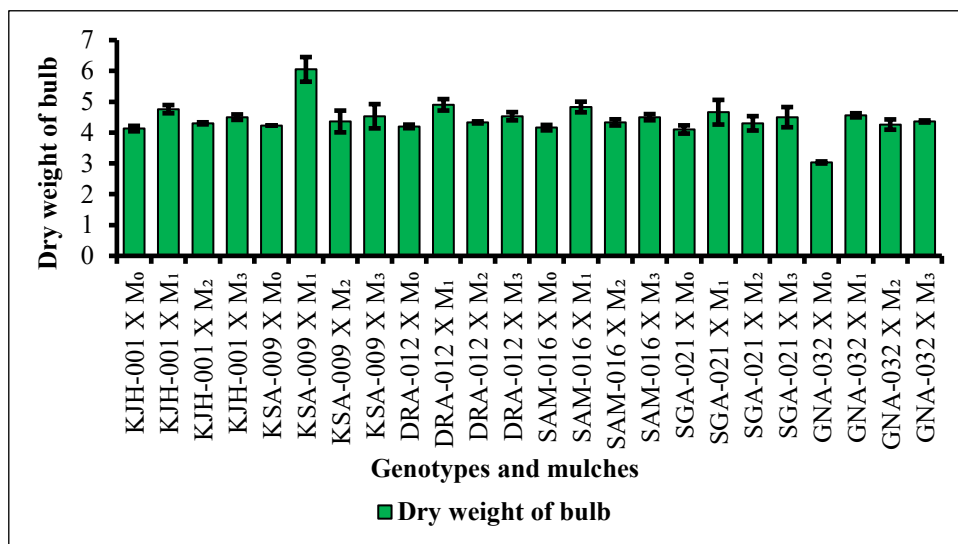


Fig. 4. Interaction effect of different genotypes and mulches on the dry weight of bulb. The vertical line (error bar) represents the Standard Error (SE) of the mean for specific genotypes × mulch combination.

M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ - White polythene mulch.

Number of cloves bulb⁻¹

The number of cloves bulb⁻¹ was also significantly affected interaction of genotype and mulch type. The combination of KSA-009 and M₁ mulch maximized number of cloves bulb⁻¹ (17.33) closely followed by DRA-012 × M₁, SAM-016 × M₁, KJH-001 × M₁, SGA-021 × M₁, GNA-032 × M₁ (Fig. 5), contrasting with the lowest count observed in GNA-032 under no mulch condition (12.00). These results underscore the importance of selecting compatible genotypes and mulching strategies to optimize garlic yield under saline conditions. Supporting studies by Rahman *et al.* (2020) similarly reported significant varietal and mulch effects on clove number with mulch treatments enhancing productivity, particularly when combined with specific cultivation practices such as zero tillage.

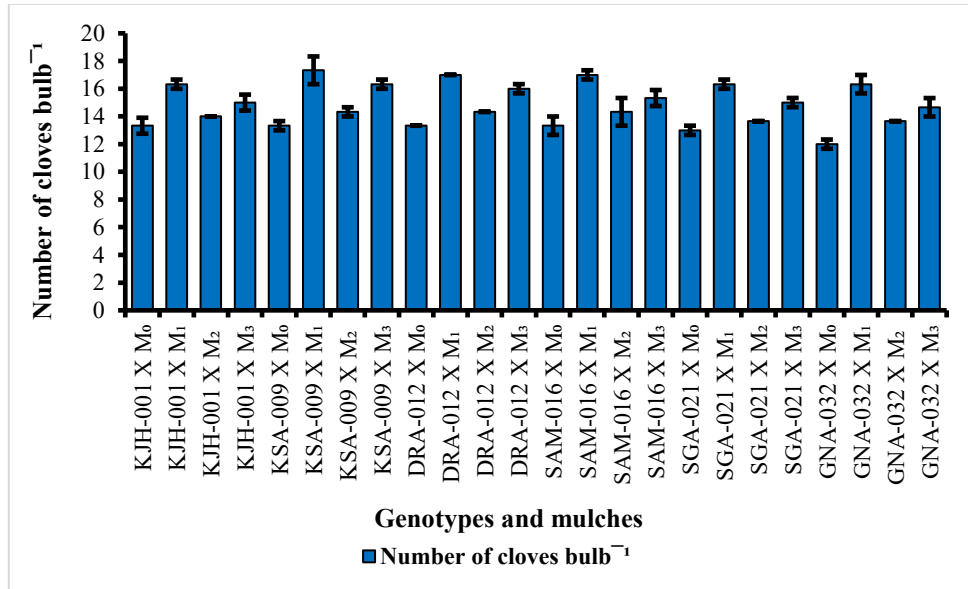


Fig. 5. Interaction effect of different genotypes and mulches on number of cloves bulb⁻¹. The vertical line (error bar) represents the Standard Error (SE) of the mean for specific genotypes × mulch combination

M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ - White polythene mulch.

Bulb yield

Both genotype and mulch type significantly influenced garlic bulb yield, exhibiting a strong synergistic interaction (Fig. 6). Notably, the combination of KSA-009 with rice straw mulch achieved the highest bulb yield of 8.21 t ha⁻¹ followed by DRA-012 with rice straw mulch (6.99 t ha⁻¹), while the lowest yield (4.56 t/ha) was observed in GNA-032 without mulch. When no mulch was applied, other genotypes did not perform better than KSA-009, DRA-012, and SAM-016 in respect of bulb yield. The genotype KSA-009 in combination with rice straw mulch gave the maximum yield because this combination recorded highest clove length and breadth, bulb length and breadth, clove number bulb⁻¹, fresh and dry weight of bulb. Besides, under rice straw mulch soil moisture was conserved more and soil salinity was reduced in a considerable amount. These results emphasize that integrating high-yielding genotypes with effective mulching strategies optimizes garlic production under saline conditions. Supporting studies by Rahman *et al.* (2020) demonstrated significant varietal differences in yield, with BAU Garlic-3 outperforming other varieties. Furthermore, Rahman *et al.* (2020) confirmed that combined planting systems and variety choices critically affected yield, with zero-tillage plus BAU Garlic-3 delivering the greatest production (9.14 t ha⁻¹).

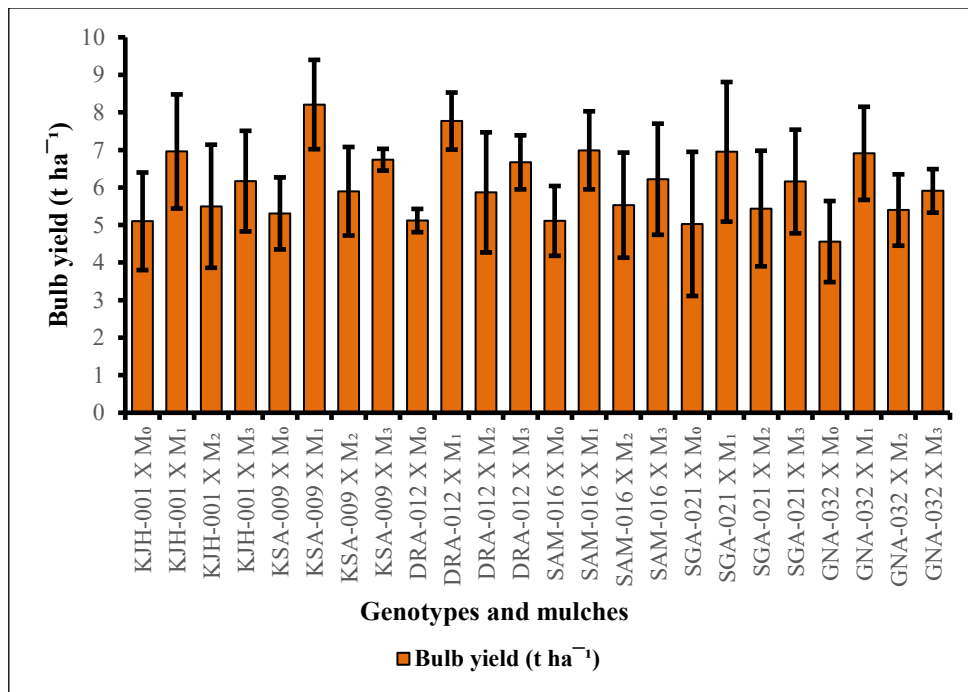


Fig. 6. Interaction effect of different genotypes and mulches on the yield of bulb (t ha⁻¹). The vertical line (error bar) represents the Standard Error (SE) of the mean for specific genotype × mulch combination

M₀ – No mulch (Control), M₁ - Straw mulch, M₂ - Black polythene mulch, M₃ - White polythene mulch.

Conclusion

The experiment results revealed that the garlic genotypes KSA-009, DRA-012, and SAM-016 performed better with regard to growth, yield attributes and yield indicating promising salt-tolerant lines. These three genotypes under rice straw mulch significantly enhanced growth and bulb formation and thus produced higher yields by mitigating soil salinity. The combination of tolerant garlic genotypes and mulching practices with rice straw offers a strong strategy for improving garlic yield in salt-prone areas, though further validation trials are recommended.

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GENETIC VARIABILITY AND CHARACTER ASSOCIATION FOR QUANTITATIVE TRAITS IN CAULIFLOWER (*Brassica Oleracea* Var. *Bsotrytis*) GENOTYPES

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Abstract

The present study was conducted to evaluate sixteen cauliflower (*Brassica oleracea* var. *botrytis* L.) genotypes under the agro-climatic conditions of Gazipur, Bangladesh during 07 November 2024 to 24 February 2025, to find out their variability, character association and path coefficient of curd yield and its related traits at the Research Field of Olericulture Division of Horticulture Research Center, Bangladesh Agriculture Research Institute. The experiment was laid out in a randomized complete block design with three replications. Significant variation ($p \leq 0.001$) was observed among genotypes for all traits, indicating ample genetic diversity suitable for selection and improvement of cauliflower. Early maturing genotypes such as CL-1, CL-2, and CL-4 showed the shortest duration for curd initiation and harvest but produced smaller curds and lower yields. In contrast, CL-5, CL-7, CL-9, CL-12 and CL-13 recorded superior vegetative growth, larger curd size and the highest curd yield per hectare (58.56-67.07 t/ha). High heritability coupled with high genetic advance as percent of mean for traits such as whole plant weight, marketable curd weight, days to first curd initiation, days to fifty percent curd initiation and net curd weight indicated that additive gene effects play a major role and simple selection methods would be successful. However, the less deviations between phenotypic coefficient of variation and genotypic coefficient of variation suggested low influence of growing environment for all traits and these traits are mostly controlled by gene. Correlation and path coefficient analyses revealed that days to first curd initiation, whole plant weight, marketable curd weight, curd breadth, and leaf length had strong positive associations and direct effects on curd yield, identifying them as major selection indices, suggesting these traits as key selection criteria for curd yield improvement in cauliflower genotypes.

Keywords: Genetic variability, heritability, path coefficient, correlation, cauliflower, *Brassica oleracea* var. *botrytis*.

Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L., $2n = 2x = 18$), an important nutritious vegetable crop of the Brassicaceae family, is popularly known as

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'Fulcopi' in Bangladesh. It is a vital member of cole crops, which is cultivated worldwide including Bangladesh. It protects heart health, lowers cholesterol, establishes immune system, prevents bone loss, reduces cancer risk, protects skin from UV rays and aids in digestion; nutrition quality of its 100 g head is-2.6 g protein, 30 mg carotene, 33 mg Ca, 4 Kcal energy, 57 mg P, 1.2 mg iron and 56 mg vitamin (Udaysinh *et al.*, 2024). Cauliflower is generally used as cooked vegetable either singly or mixed with potato, carrot, and peas. In Bangladesh, annually cauliflower occupies an area of 23,534 ha with a production of 429,670 MT and productivity of 18.25 t/ha (Anon., 2025). In Bangladesh, cauliflower plays a significant role in improving nutritional security and farmers livelihoods. Generally, this crop is grown only in winter season due to its temperate origin; however, with the development of tropical heat-tolerant varieties, its cultivation window has significantly expanded (Rahman *et al.*, 2020; Hussien *et al.*, 2021). Bangladesh's diverse agro-climatic conditions, ranging from humid sub-tropical summers to cool, dry winters, provide opportunities for year-round cultivation of cauliflower. This has encouraged the introduction of both tropical and temperate genotypes with varying adaptability and productivity. Tropical types are generally early maturing and heat-tolerant, while temperate types tend to exhibit better curd quality and higher yields under cooler conditions (Singh *et al.*, 2023). However, the adaptability, curd yield, and quality, as well as seed production capacity, are critical traits that require assessment for breeding purposes. Temperate genotypes often require specific vernalization conditions for seed production, while tropical genotypes may offer more flexibility in seed set under warmer environments (Thakur and Sharma, 2023).

In cauliflower high genetic variation exists for yield and yield contributing traits and exploitation of genetic potential for enhancing the productivity of this crop helps develop varieties using breeding method. An estimation of variability parameters viz. genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance as per cent of mean of the yield contributing traits suggests the strategy to be adopted for its utilization in genetic improvement (Ullah *et al.*, 2012). The magnitude of variability and its quantitative estimation for each character would indicate the potential of each plant and scope for improving the desirable and economic characters through selection. Knowledge regarding association i.e., correlation and path coefficient analysis between yield and its component traits are important in determining the component characters that could be used as selection parameters for effective improvement of the crop. The study was, therefore, carried out to investigate the genetic variability, correlation and path analysis in sixteen cauliflower genotypes with a view to

identifying promising genotypes for future breeding program under the agroclimatic conditions of Gazipur, Bangladesh.

Materials and Methods

The experiment was conducted at the research field of Olericulture Division, Horticulture Research Center (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh during the period from 07 November 2024 to 24 February 2025 to evaluate sixteen cauliflower genotypes using a randomized block design with three replications. The study area is situated in 23.9917° N longitude and 90.4137° E latitude at an altitude of 9 meter above the sea level. Seedlings were sown in seed bed on 07 November 2024 and then the seedlings were transferred to the 2nd seed bed 14 days after emergence (double transplanting). Thirty-day-old healthy seedlings (4-leaf stage) were transplanted in the main field on 07 December 2024. The unit plot size and plant spacing were maintained at 10.0 × 1.0 m and 50 cm × 50 cm, respectively. A total of 40 seedlings were planted in each unit plot. Fertilization was done at @ 70-50-75-18-4.2-2 kg ha⁻¹ NPKSZnB along with 10 tons cow dung per hectare. Half of the cow dung and half of the phosphorus, along with the entire sulfur and boron, were applied during final land preparation. The remaining cow dung and phosphorus were applied during pit preparation one week before planting. Nitrogen and potassium were applied in three equal installments at 20, 35, and 50 days after transplanting. Irrigation was provided as needed. Other cultural practices and plant protection measures were followed during the cultivation of the crop. Data were recorded on days to first curd initiation, days to 50% curd initiation, days to first harvest, whole plant weight, plant height, number of leaves per plant, individual marketable curd weight, net curd weight, curd length, curd breadth, leaf length, leaf breadth and curd yield per plant. Per plot yield was then converted to yield per hectare. All the recorded data were analyzed statistically using R software. Mean separation was done by least significant difference (LSD) test at 5% level of probability. From the recorded data, range (maximum and minimum), grand mean, Standard Error of Mean ((SEm), Environmental Coefficient of Variation (ECV), Genotypic Coefficient of Variation (GCV), Phenotypic Coefficient of Variation (PCV), Heritability (broad sense), Genetic advance and Genetic advance as percentage of mean were analyzed using R software. Pearson Correlation Coefficient and Path Coefficient Analysis were also done by R software.

Results and Discussion

Analysis of variance for various growth and yield related traits

Analysis of variance (ANOVA) revealed highly significant differences ($p \leq 0.001$) among the 16 cauliflower genotypes for all vegetative growth and yield-related characters investigated (Table 1). Significant treatment mean squares for days to first curd initiation (MS = 1678.84), days to 50% curd initiation (MS = 1783.77), days to harvest (MS = 1631.96), whole plant weight (MS = 1,705,002), marketable curd weight (MS = 536,656), net curd weight (MS = 370,370) and yield per hectare (MS = 214.662) indicate that the observed variation for both earliness and yield components was mainly attributable to genotypic differences rather than experimental error (Kotha Keerthana *et al.*, 2025). The presence of significant variation for earliness traits (days to curd initiation and days to harvest) suggests that the evaluated germplasm contains early and late types, providing scope to select genotypes adapted to specific planting windows and to target multiple markets. Similar reports of significant genotypic variation for earliness in cauliflower have been documented in variability studies (Lav Kumar *et al.*, 2019). Vegetative traits including whole plant weight, plant height, number of leaves, leaf length and breadth also showed highly significant treatment effects. Large treatment mean squares for whole plant weight and curd weight components indicate these are promising selection targets for improving marketable yield. Other authors have likewise found that curd weight and whole plant biomass are among the most variable and heritable traits contributing to yield, and therefore useful targets in selection and hybridization programs (Subhrajyoti Chatterjee *et al.*, 2018). The relatively small error mean squares for many characters (Table 1) indicate good experimental precision and reliability of the observed differences. Because treatment variance substantially exceeded error variance for key yield components, the estimates of genotypic differences are likely robust, supporting confident selection decisions (Kotha Keerthana *et al.*, 2025). Overall, the highly significant genotypic differences recorded for both earliness and yield-related traits point to a considerable scope for genetic improvement of cauliflower through selection and hybridization. The results support continued evaluation of the identified superior genotypes in multi-location trials and incorporation of high-performing lines into crossing programs to combine earliness and yield-related favorable traits—an approach recommended in prior cauliflower breeding and genetic variability studies (Hussein *et al.*, 2021).

Table 1. Analysis of variance (ANOVA) for various vegetative growth and yield related traits in 16 cauliflower genotypes

| Characters | Mean Sum Square | | |
|---------------------------------------|-----------------------|----------------------|------------------|
| | Replication Df (2) | Treatment Df (15) | Error Df (30) |
| Days to first curd initiation | 1.94 | 1678.84** | 0.96 |
| Days to fifty percent curd initiation | 2.15 | 1783.77** | 0.83 |
| Days to harvest | 21.82 | 1631.96** | 7.34 |
| Whole plant weight | 14160 | 1705002** | 319173 |
| Plant height | 9.69 | 283.60** | 5.61 |
| Number of leaves per plant | 1.04 | 54.01** | 1.53 |
| Marketable curd weight | 31584 | 536656** | 7368 |
| Curd length | 0.74 | 98.22** | 0.62 |
| Curd breadth | 0.32 | 57.63** | 1.02 |
| Leaf length | 2.59 | 194.37** | 6.66 |
| Leaf breadth | 2.17 | 50.47** | 1.63 |
| Net curd weight | 6795 | 370370** | 3943 |
| Yield ton per hectare | 12.63 | 214.66** | 2.94 |

* & **, indicate significant at 5% and 1% probability levels, respectively.

Mean performance of cauliflower genotypes

Mean performance of sixteen cauliflower genotypes was evaluated based on their growth duration, morphological characteristics, and yield related traits under Gazipur condition (Table 2). Significant variation ($P < 0.01$) was observed among 16 genotypes for all studied traits, indicating ample genetic variability suitable for selection and improvement (Rahman *et al.*, 2020; Hussien *et al.*, 2021). The lowest days to first curd initiation (DFCI), days to fifty percent curd initiation (DFPCI) and days to harvest (DH) were recorded in genotype CL-2 (23, 26, 41.10 days, respectively) followed by genotypes CL-4 (26, 29 and 42.67 days, respectively), CL-1 (37, 42 and 55 days, respectively), CL-6 (42, 44.67 and 58.33 days, respectively) and CL-3 (42.33, 46 and 72.67 days, respectively). The maximum days to first curd initiation (DFCI) was found in CL-9 (90.33 days) closely followed by CL-12 (90 days) and then followed by CL-13 (88.33 days) and CL-14

(87.67 days). The highest days to fifty percent curd initiation (DFPCI) and days to harvest (DH) were observed in CL-10 (97 and 106 days, respectively) followed by CL-9 (96.33 and 104 days, respectively), CL-12 (94 and 103 days, respectively) and CL-13 (92 and 102.67 days, respectively). From these results it is revealed that the earliest genotypes in terms of DFCI, DFPCI and DH were CL-2, CL-1, CL-4 and CL-6. In contrast, it showed that the latest genotypes were CL-9, CL-10, CL-13, and CL-14 with regard to DFCI, DFPCI and DH. Such variation in maturity duration (41–107 days) offers flexibility for staggered harvesting. Earliness is a desirable trait for early market advantage and extended harvesting periods, as supported by Thakur and Sharma (2023) and Nehra (2023). Marked differences were also noted in plant morphological traits such as whole plant weight (WPW), plant height (PH) and number of leaves per plant (NLPP). The maximum whole plant weights (heaviest plants) (WHP) were recorded in CL-7 (3161 g) followed by CL-13 (2628.67 g), CL-5 (2627.67 g), CL-3 (2575 g), CL-9 (2483.33 g) and CL-12 (2373.33 g), indicating strong vegetative vigor, while CL-2 (716.67 g) and CL-4 (783.33 g) exhibited the lowest plant biomass. The tallest plant was noted in CL-16 (76.67 cm) followed by CL-7 (72.33 cm), CL-15 (69.33 cm), CL-5 (62.27 cm) CL-13 (63.00 cm) and the shortest plant was observed in CL-2 (42.10 cm) and CL-4 (44.90 cm). The highest number of leaves/plant (NLPP) (26.00) was observed in CL-13 (26) followed by CL-7 (24.33), CL-9 (22.67), CL-5 (22.39) and CL-12 (21.33), whereas the lowest NLPP was recorded in CL-2 (11.30) followed by CL-4 (12.07). The genotypes having higher leaves/plant suggest their potential for higher photosynthetic capacity and biomass accumulation (Singh *et al.*, 2023; Hussien *et al.*, 2021), and the genotypes with lower number of leaves/plants gave lower whole plant weight i.e. lower biomass due to their low photosynthetic capacity because of lower number of leaves in the present investigation. Significant variation was also observed in marketable curd weight (MCW). The Genotype CL-9 produced the maximum marketable curd weight (MCW) (1676.67 g), which was statistically similar with CL-13 (1597.67 g) and CL-12 (1540.00 g) and then followed by CL-5 (1463.69 g) and CL-7 (1415.77 g), while genotypes CL-2 (351.33 g) recorded the smallest MCW (351.33 g) on par with CL-4 (379.67 g). These findings indicate that early maturing genotypes tend to have smaller curds, reflecting a trade-off between earliness and curd size, as reported in previous studies (Rahman *et al.*, 2020; Nehra, 2023). Curd and leaf morphology also showed substantial variation among genotypes. The longest curd (21.43 cm) was observed in CL-5 which was on par with CL-12 (19.67 cm) and the maximum breadth (25.33 cm) was noticed in CL-5 closely followed by CL-9 (24.67 cm), CL-12 (24.67 cm), CL-13 (24.33 cm) and CL-7 (23.67 cm), indicating superior curd development. Conversely, CL-2 and CL-4 exhibited the smallest curd dimensions (L x B: 5.50 cm x 10.93 cm and L x B: 5.70 cm x 11.90 cm. Leaf traits such as leaf length (LL)

and breadth (LB) were found highest in CL-7 (63 cm, 31.33 cm) followed by CL-13 (54.67 cm, 25.33 cm) and CL-9 (53 cm, 26.33 cm), suggesting a positive relationship between leaf area and curd yield. Yield per hectare (YTPH) varied significantly among genotypes, ranging from 14.05 t/ha (CL-2) to 67.07 t/ha (CL-9). The highest yield was recorded in CL-9 (67.07 t/ha), closely followed by CL-13 (63.91 t/ha), CL-12 (61.60 t/ha) and CL-5 (58.56 t/ha). These high-yielding genotypes exhibited favorable combinations of plant biomass due to higher whole plant weight, Number of leaves/plant, higher leaf length and leaf breadth, marketable curd weight, and curd dimensions. In contrast, CL-2 produced the lowest yield (14.05 t/ha) being on par with CL-4 (15.19 t/ha) despite its early maturity, highlighting the trade-off between earliness and yield potential (Hussien *et al.*, 2021; Singh *et al.*, 2023).

Table 2. Mean performance of 16 cauliflower genotypes for 14 quantitative traits

| Genotype | DFCI | DFPCI | DH | WPW (g) | PH (cm) | NLPP | MCW (g) |
|------------|-------|-------|--------|---------|---------|-------|---------|
| CL-1 | 37.00 | 42.00 | 55.00 | 1022.00 | 52.00 | 14.66 | 633.22 |
| CL-2 | 23.00 | 26.00 | 41.10 | 716.67 | 42.10 | 11.30 | 351.33 |
| CL-3 | 42.33 | 46.00 | 72.67 | 2575.00 | 60.78 | 18.00 | 1205.55 |
| CL-4 | 26.00 | 29.00 | 42.67 | 783.33 | 44.90 | 12.07 | 379.67 |
| CL-5 | 56.00 | 59.00 | 72.67 | 2627.67 | 62.27 | 22.39 | 1463.89 |
| CL-6 | 42.00 | 44.67 | 58.33 | 1433.33 | 58.33 | 18.00 | 855.55 |
| CL-7 | 60.00 | 63.33 | 73.67 | 3161.00 | 72.33 | 24.33 | 1415.77 |
| CL-8 | 81.00 | 85.00 | 104.33 | 1222.33 | 50.44 | 18.00 | 928.44 |
| CL-9 | 90.33 | 96.33 | 104.00 | 2483.33 | 53.33 | 22.67 | 1676.67 |
| CL-10 | 86.00 | 97.00 | 106.00 | 1791.33 | 50.00 | 20.00 | 1162.33 |
| CL-11 | 74.67 | 76.00 | 90.33 | 1430.00 | 61.33 | 21.00 | 930.00 |
| CL-12 | 90.00 | 94.00 | 103.00 | 2373.33 | 62.00 | 21.33 | 1540.00 |
| CL-13 | 88.33 | 92.00 | 102.67 | 2628.67 | 63.00 | 26.00 | 1597.67 |
| CL-14 | 87.67 | 89.67 | 107.00 | 1175.00 | 50.63 | 16.07 | 795.00 |
| CL-15 | 60.33 | 62.33 | 93.00 | 1502.33 | 69.33 | 16.00 | 772.33 |
| CL-16 | 73.33 | 77.00 | 95.00 | 1702.67 | 76.67 | 15.33 | 740.00 |
| CV (%) | 1.54 | 1.35 | 3.28 | 5.35 | 4.08 | 6.68 | 8.35 |
| LSD (0.05) | 1.63 | 1.52 | 4.52 | 159.69 | 3.95 | 2.07 | 143.14 |

DFCI=Days to first curd initiation, DFPCI=Days to fifty percent curd initiation, DH=Days to harvest, WPW=Whole plant fresh weight, PH=Plant height, NLPP=Number of leaves per plant, MCW=Marketable curd weight, CV=Co-efficient of Variation, LSD=Least Significant Difference.

Table 2. Continued

| Genotype | CL (cm) | CB (cm) | LL (cm) | LB (cm) | NCW (g) | YTPH |
|------------|---------|---------|---------|---------|---------|-------|
| CL-1 | 7.23 | 17.50 | 42.11 | 19.28 | 402.78 | 25.33 |
| CL-2 | 5.50 | 10.93 | 31.00 | 14.47 | 210.00 | 14.05 |
| CL-3 | 8.58 | 24.57 | 51.03 | 24.82 | 882.22 | 48.22 |
| CL-4 | 5.70 | 11.90 | 34.00 | 15.13 | 250.67 | 15.19 |
| CL-5 | 21.43 | 25.33 | 52.10 | 23.61 | 1123.33 | 58.56 |
| CL-6 | 8.00 | 20.00 | 46.33 | 21.00 | 613.33 | 34.22 |
| CL-7 | 18.33 | 23.67 | 63.00 | 31.33 | 823.33 | 56.63 |
| CL-8 | 15.00 | 21.00 | 43.67 | 20.33 | 633.33 | 37.14 |
| CL-9 | 17.00 | 24.67 | 53.00 | 26.33 | 1100.00 | 67.07 |
| CL-10 | 13.00 | 21.33 | 42.00 | 20.00 | 896.67 | 46.49 |
| CL-11 | 7.67 | 19.33 | 46.67 | 23.33 | 733.33 | 37.20 |
| CL-12 | 19.67 | 24.67 | 50.67 | 22.33 | 1353.33 | 61.60 |
| CL-13 | 18.00 | 24.33 | 54.67 | 25.33 | 1330.00 | 63.91 |
| CL-14 | 9.57 | 18.10 | 41.63 | 21.48 | 625.00 | 31.80 |
| CL-15 | 19.33 | 20.67 | 53.00 | 21.00 | 436.67 | 30.89 |
| CL-16 | 19.00 | 18.00 | 51.00 | 20.33 | 556.67 | 29.60 |
| CV (%) | 5.94 | 4.97 | 5.46 | 5.85 | 8.39 | 8.35 |
| LSD (0.05) | 1.32 | 1.69 | 4.30 | 2.13 | 191.11 | 5.73 |

CL=Curd length, CB=Curd breadth, LL=Leaf length, LB=Leaf breadth, YTPH=Yield tons per hectare

Estimation of genetic variability

A wide range of variability was observed among the sixteen cauliflower genotypes for all the studied traits (Table 3). The values for days to first curd initiation ranged from 23 to 91 days, fifty percent curd initiation 26 to 98 days, and days to harvest 40 to 108 days with mean values of 63.63 ± 0.57 , 67.46 ± 0.53 and 82.59 ± 1.56 days, respectively that revealed notable variations exist in maturity behaviour of cauliflower genotypes. Similarly, the wide ranges in whole plant weight and marketable curd weight were observed 700–3433 g and 342–1800 g with mean values of 1789 ± 55.29 and 1027.96 ± 49.56 g, respectively, reflecting considerable variations in these traits which contributed much in the variability of yield potential of cauliflower genotypes. The ranges for plant height (PH), number of leaves/plant (NLPP), leaf length (LL) and leaf breadth (LB) were observed 41.50–78.00 cm, 10.90–27.00, 30–68 cm and 14.20–32 cm,

respectively and their mean values were recorded 58.09 ± 1.37 cm, 18.57 ± 0.72 , 47.24 ± 1.49 cm and 21.88 ± 0.74 cm, respectively, indicating considerable variability in vegetative growth. Curd length (CL) varied from 5.3 to 22.0 cm, curd breadth (CB) from 10.3 to 27.0 cm, net curd weight (NCW) from 195 to 1480 g and yield per hectare (YTPH) from 13.68 to 72.00 t/ha, with their mean values 13.31 ± 0.46 cm, 20.38 ± 0.58 cm, 748.17 ± 36.26 g and 41.12 ± 1.98 t/ha, respectively that indicates a lot of variability were present in yield and yield related traits. The low environmental coefficient of variation (1.35–8.39%) were noticed in the traits suggested minimal environmental influence in 14 quantitative traits. The phenotypic coefficient of variations in 14 characters was always higher than the genotypic coefficient of variations of those characters, but lower differences were found. This close correspondence between genotypic and phenotypic coefficients of variations indicated that most of the variability was genetic in nature and selection based on phenotype can be effective for improvement of these traits (Begum *et al.*, 2016). Heritability estimates in broad sense for all traits were found very high (0.92–1.00), indicating the low influence of environment on the studied characters and implying strong genetic control and high selection efficiency of these traits. High estimates of heritability for most of the variables suggested that variations were passed down to progeny, implying that a high-yielding variety may be developed by selecting desirable genotypes. High heritability provided more options for selecting plant material with the desired features. High genetic advance (genetic gain) and genetic advance as percentage of mean were recorded for WPW (1536.38 and 85.87%), MCW (847.75 and 82.47%), NCW (708.60 and 94.71%) and curd initiation traits viz. DFCI (48.68 and 76.50%) and DFCI (50.18 and 74.39%), suggesting predominance of additive gene action and high effectiveness of selection for these traits. Johnson *et al.* (1955) reported that heritability estimates with high genetic advance are more helpful in predicting the gain under selection. Traits with high heritability integrated with high genetic advance can be improved effectively through direct selection (Mohana Krishna *et al.*, 2009). High heritability (0.96–0.98) coupled with high genetic advance for CL (0.98 and 87.42%), and YTPH (0.96 and 82.47%) suggested the predominance of additive gene action and high effectiveness of selection for these two traits conversely, traits such as leaf breadth (LB) and curd breadth (CB) exhibited moderate genetic advance as % mean, indicating partial non-additive gene effects (Mohana Krishna *et al.*, 2009).

Table 3. Estimates of variability characters for 14 quantitative traits in 16 cauliflower genotypes

| Traits | Range | | Mean± SEM | ECV | GCV | PCV | h ₂ b | GA | GAM |
|--------|--------|---------|---------------|------|-------|-------|------------------|---------|-------|
| | Mini. | Max. | | | | | | | |
| DFCI | 23.00 | 91.00 | 1331±0.57 | 1.54 | 37.17 | 37.20 | 1.00 | 48.68 | 76.50 |
| DFPCI | 26.00 | 98.00 | 67.46±0.53 | 1.35 | 36.14 | 36.16 | 1.00 | 50.18 | 74.39 |
| DH | 40.00 | 108.00 | 82.59±1.56 | 3.28 | 28.17 | 28.36 | 0.99 | 47.61 | 57.65 |
| WPW | 700.00 | 3433.00 | 1789.25±55.29 | 5.35 | 42.02 | 42.36 | 0.98 | 1536.38 | 85.67 |
| PH | 41.00 | 78.00 | 58.09±1.37 | 4.08 | 16.57 | 17.07 | 0.94 | 19.25 | 33.15 |
| NLPP | 10.90 | 27.00 | 18.57±0.72 | 6.68 | 22.52 | 23.49 | 0.92 | 8.26 | 44.48 |
| MCW | 342.00 | 1800.00 | 1027.96±49.56 | 8.35 | 40.86 | 41.71 | 0.96 | 847.75 | 82.47 |
| CL | 5.30 | 22.00 | 13.31±0.46 | 5.94 | 42.84 | 43.25 | 0.98 | 11.64 | 87.42 |
| CB | 10.50 | 27.00 | 20.38±0.58 | 4.97 | 21.32 | 21.89 | 0.95 | 8.72 | 42.78 |
| LL | 30.00 | 68.00 | 47.24±1.49 | 5.46 | 16.74 | 17.61 | 0.90 | 15.49 | 32.79 |
| LB | 14.20 | 32.00 | 21.88±0.74 | 5.85 | 18.44 | 19.34 | 0.91 | 7.92 | 36.20 |
| NCW | 195.00 | 1480.00 | 748.17±36.26 | 8.39 | 46.71 | 47.46 | 0.97 | 708.60 | 94.71 |
| YTPH | 13.68 | 72.00 | 41.12±1.98 | 8.35 | 40.86 | 41.71 | 0.96 | 33.91 | 82.47 |

Min.= Minimum, Max. = Maximum, SEM = Standard Error of mean, ECV = Environmental Coefficient of Variation, GCV = Genotypic Coefficient of Variation (GCV), PCV = Phenotypic Coefficient of Variation, h₂b = Heritability in broad sense, GA = Genetic advance, GAM = Genetic Advance as percentage of mean

DFCI=Days to first curd initiation, DFPCI=Days to fifty percent curd initiation, DH=Days to harvest, WPW=Whole plant weight, PH=Plant height, NLPP=Number of leaves per plant, MCW=Marketable curd weight, CL=Curd length, CB=Curd breadth, LL=Leaf length, LB=Leaf breadth, NCW= Net curd weight; YTPH=Yield ton per hectare.

Correlation between various traits of cauliflower genotypes

Pearson's correlation coefficient matrix was estimated (Fig. 1) to determine the value of association among the various growth, yield and yield attributes of cauliflower genotypes. Most traits exhibited strong and significant positive correlations, suggesting that improvement in one trait would likely enhance others, thereby contributing to higher yield potential (Sandhu *et al.*, 2024; Nehra, 2023). The analysis revealed yield per hectare (YTPH) was positively and significantly correlated with all the traits studied. YTPH reflected a significant and strong positive correlation with whole plant weight, WPW (0.90***), number of leaves per plant, NLPP (0.89***), marketable curd weight, MCW (1.00***), curd breadth, CB (0.91***), and net curd weight, NCW (0.94***), suggesting that these traits are the most influential determinants of yield per hectare. A very strong positive correlation was observed between net curd weight (NCW) and marketable curd weight (MCW), indicating that heavier curds directly contribute to overall

marketable curd yield. Similarly, MCW showed a highly significant association with curd breadth (0.91**), curd length, CL (0.66***), number of leaves per plant, NLPP (0.89***), leaf breadth, LB (0.78***), and WPW (0.90***). These results imply that plants with greater vegetative biomass and larger curd size tend to produce higher yields. Morphological traits such as plant height, PH (0.38*) and days to harvest, DH (0.56**) showed moderate correlations with yield attributes. PH exhibited a positive but weaker association with MCW (0.38**) and YTPH (0.38**), suggesting that taller plants do not always correspond to higher yield. In contrast, earliness traits, days to first curd initiation (DFCI) and days to 50% curd initiation (DFPCI) showed comparatively weak correlations with most yield parameters, implying that early-maturing genotypes tend to have lower yield due to shorter growth duration and smaller curd development (Singh *et al.*, 2023). Overall, the strong positive correlations among WPW, LB, MCW, CL, CB, NCW, NLPP, and YTPH suggest that these traits are the major contributors to yield improvement in cauliflower genotypes. Therefore, these parameters may be considered as key selection criteria for identifying high-yielding cauliflower genotypes under Gazipur condition.

Path Coefficient Analysis

Path coefficient analysis was performed to partition the correlation coefficients into direct and indirect effects of various traits on curd yield per hectare (YTPH), thereby identifying the most influential yield-contributing parameters (Fig. 2). The analysis revealed that marketable curd weight (MCW) exerted the highest positive direct effect (1.00) on YTPH, indicating that this trait is the principal determinant of curd yield. This finding aligns with the correlation analysis, where MCW also showed the strongest positive association with YTPH, suggesting that genotypes producing heavier curds directly enhance productivity and Singh *et al.*, (2025) found the similar result. Among morphological traits, curd breadth (CB) (0.001) exhibited substantial positive direct effects on YTPH, implying that curd breadth contributes significantly to total yield. The whole plant weight (WPW) (0.001) and leaf length (0.001) showed positive direct effects on yield. The number of leaves per plant (NLPP) (0.0001) showed positive smaller direct effect, indicating their indirect influence on yield through helping in accumulation of photo-synthates contributing in curd development. In contrast, days to 50% curd initiation (DFPCI) (-0.002) and days to harvest (DH) (-0.001), plant height

(PH) (-0.001) and leaf breath (LB) (0.0001) displayed negative direct effects, confirming that early-maturing genotypes generally produce lower yields due to shorter vegetative and curd growth periods. Leaf attributes such as leaf length (LL) and leaf breadth (LB) had moderate indirect effects on curd yield and primarily mediated through their influence on MCW and CB suggesting that larger leaf area enhances photosynthetic capacity and assimilate supply for curd growth.

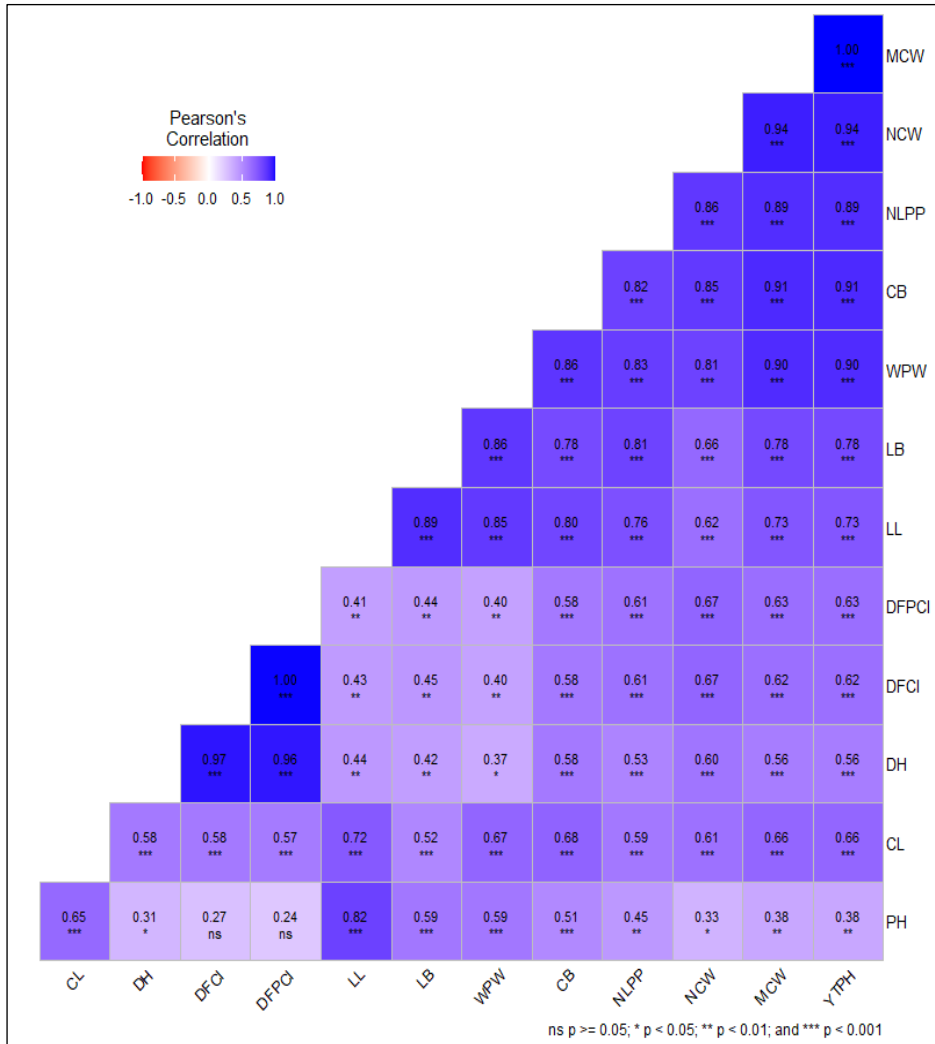


Fig. 1. Pearson correlation for various quantitative traits under study.

[*, **, *** indicate significance at 0.05, 0.01 and 0.001 probability levels, respectively. [DFCI: Days to first curd initiation, DFPCI: Days to 50% curd initiation, DH: days to harvest, WPW: Whole plant weight, PH: Plant height, NLPP: Number of leaves per plant, MCW: Marketable curd weight, CL: Curd Length, CB: Curd breadth, LL: Leaf length, LB: Leaf breadth, NCW: Net Curd weight; YTPH= Yield ton per hectare].

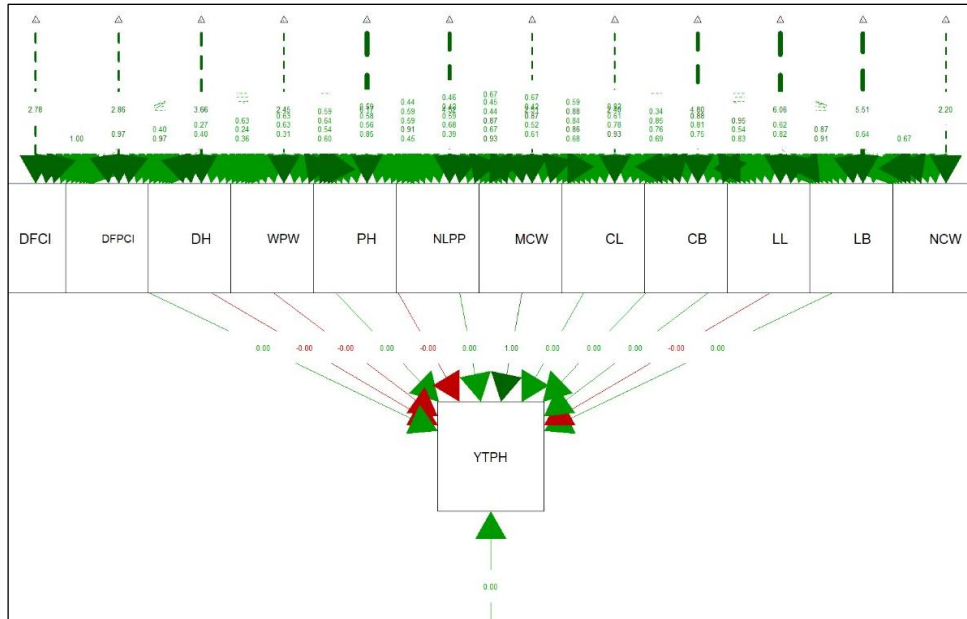


Fig. 2. Path coefficient analysis of 14 characters in 16 cauliflower genotypes.

[DFCI: Days to first curd initiation, DFPCI: Days to 50% curd initiation, DH: days to harvest, WPW: Whole plant weight, PH: Plant height, NLPP: Number of leaves per plant, MCW: Marketable curd weight, CL: Curd Length, CB: Curd breadth, LL: Leaf length, LB: Leaf breadth, NCW: Net Curd weight, YTPH=Yield ton per hectare.]

Conclusion

The experimental results revealed that early-maturing genotypes, namely CL-1, CL-2, and CL-4 showed potential for early market supply due to their short vegetative growth and curd growth period but were generally associated with smaller curds and lower curd yields. In contrast, CL-9, CL-5, CL-7, CL-12, and CL-13 exhibited superior vegetative vigour, larger curd size and higher yield per hectare, making them promising candidates for producing higher yields. The strong positive correlations among marketable curd weight, curd length, curd breadth, net curd weight and number of leaves per plant, whole plant weight and yield per hectare suggest that these traits are the major contributors to yield improvement in cauliflower genotypes. Therefore, these parameters may be considered as key selection criteria for identifying high-yielding genotypes under Gazipur condition. The low environmental coefficient of variation (1.35–8.39%) were noticed in the traits studied in present investigation, and the phenotypic coefficient of variations were higher than the genotypic coefficient of variations for all the characters, but due to lower differences ,the environment had less influence on the studied

characters and implying strong genetic control and high selection efficiency; also indicated that most of the variability was genetic in nature and selection on the basis of phenotype can be effective for improvement for all traits. High heritability (>0.90) combined with high genetic advance as percent of mean (>70%) for days to first curd initiation, days to 50% curd initiation, marketable curd weight, curd length, and net curd weight along with yield per hectare indicated that these traits are commanded by additive gene action. The path analysis emphasized that whole plant weight, leaf length, curd breadth and marketable curd weight are the most critical direct contributors to yield, while plant vigour traits influenced by whole plant weight and number of leaves per plant play supportive indirect roles for yield. Overall, the results revealed ample genetic variability among genotypes, which may be effectively exploited for yield and curd improvement in future cauliflower breeding programs.

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INFLUENCE OF SEED PRIMING AGENTS ON GERMINATION AND EARLY SEEDLING GROWTH OF OKRA (*ABELMOSCHUS ESCULENTUS*)

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Abstract

An experiment was conducted at the laboratory of Plant Physiology Section of Horticulture Research Centre, Bangladesh Agricultural Research Institute during two consecutive years 2023 and 2024 (from 8 May to 16 May 2023 and 6 May to 15 May 2024) to investigate the effect of different priming agents on seed germination and early seedling growth of okra. The experiment was laid out in a completely randomized design with three replications. The treatments consisted of two okra varieties, namely BARI Dheros-2 and OK1820, and 11 priming agents *viz.*, unprimed control, DH₂O (distilled water), 150 ppm GA₃ (gibberellic acid), 200 ppm GA₃, 40 ppm SA (salicylic acid), 50 ppm SA, 0.25% KNO₃ (potassium nitrate), 0.50% KNO₃, 40 mM H₂O₂ (hydrogen peroxide), 100 ppm HA (humic acid) and 200 ppm HA. Seed germination percentage, T₅₀ (time required for 50% germination) value, speed of germination and germination value were enhanced significantly in both the varieties of okra at 40 mM H₂O₂ followed by 200 ppm HA and distilled water. Seedling growth expressed by seedling length and seedling dry weight, and seedling vigour (seedling vigour index-I and seedling vigour index-II) were also increased at 40 mM H₂O₂, 200 ppm HA and distilled water. Therefore, it was concluded that for obtaining better germination and vigorous seedlings in okra the seeds may be soaked in either 40 mM H₂O₂ or 200 ppm HA or distilled water for 18 hours

Keywords: Okra, *Abelmoschus esculentus*, seed priming, germination, growth, seedling vigour.

Introduction

Lady's finger or okra [*Abelmoschus esculentus* (Moench)], a nutritious vegetable of the family Malvaceae, is popularly known as 'dheros'/'bhendi' in Bangladesh. It is also called 'bhindi' in India and Pakistan. It is one of the most significant vegetable crops which are grown throughout the tropical, subtropical and temperate region of the world. The immature, young green seed pods are the edible part which are consumed as vegetable. The fresh okra fruit consists of water 90.19%, energy 33 Kcal, carbohydrate 7.45 g, protein 2 g, fat 0.19g, dietary fiber 1.48 g, Ca 82 mg, Mg 57 mg, Fe 0.62 mg, Zn 0.58 mg, K 299 mg, vitamin A 36

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ug, thiamine 0.2 mg, riboflavin 0.06 mg, niacin 1 mg, ascorbic acid 23 mg, vitamin E 0.2 mg, vitamin K 31.3 ug per 100g fresh weight of edible portion (Kumar *et al.*, 2013).

Okra seeds germinate very slowly and unevenly in the field though the seeds are viable. Poor, reduced, delayed, and erratic emergence is a serious problem in okra cultivation which is caused by seed hardness (Barupal *et al.*, 2022; Poudel *et al.*, 2015). The hard seed coat restricts the water imbibition, and thus germination, uniform growth and development of the embryo are hindered. (Mohammadi *et al.*, 2011). Chan *et al.* (2018) observed that limited permeability can be detrimental as it leads to non-uniform germination. Hard seed coat is reported as the major reason for okra seed dormancy that interferes with seed germination (Mohammadi *et al.*, 2011). Seed priming is considered as a solution to the okra hard seed coat-related low germination issue (Thakur *et al.*, 2023).

Seed germination is very crucial among all growth stages because low germination rate lowers the population density per unit area that ultimately reduced the yield (Rahman *et al.*, 2020). Seed germination is a complex process involves three main phases such as water imbibition, activation of physiological processes and gene expression, and radicle emergence (Tuan *et al.*, 2019). Water uptake by cytoplasmic compounds and macromolecules hydrolysis occurs in initial 24 h that triggers the ATP and protein synthesis followed by radicle emergence after 48 to 72 h of imbibition (Carrera-Castaño *et al.*, 2020).

Seed priming is the process of controlled hydration of seeds which is potentially able to promote rapid and more uniform seed germination and plant growth. Dawood (2018) opined that priming is a controlled process of soaking seeds in water or a low osmotic potential solution and drying them to a stage where germination processes are initiated, allowing early seedling growth under various conditions, but without radicle protrusion. Seed priming is a simple, inexpensive, and effective method for synchronized germination and early seedling growth. It increases the speed of germination and seedling vigor by overcoming dormancy, and better stand establishment under stressful and stress-free environmental conditions (Ventura *et al.*, 2012; Parella *et al.*, 2015; Hussein, 2015).

Priming allows some of the metabolic processes necessary for germination to occur. Seed priming induced synchronized germination, increased seed vigor, and growth of seedlings under stressful conditions (Bajehbaj, 2010). Different seed priming methods have been used to enhance germination and seed vigor of okra. Among them, hydro-priming, hormonal priming, osmo-priming, halo-priming, etc. are commonly used seed priming methods. Accelerated germination, seed growth, and uniform field establishment can be achieved through priming (Yadav *et al.*, 2012). Sheferie (2023) used gibberellic acid and tap water as seed hormonal and hydro-priming agents for improving germination and germination parameters in

okra seed. Lamichhanea *et al.* (2024) obtained the maximum germination percentage using 150 ppm GA₃. Cowpea seedling emergence and field establishment were enhanced by hydropriming and sodium chloride (NaCl) priming (Eskandari and Kazemi, 2011). Hussein (2015) used salicylic acid for priming okra seeds. Rehman *et al.* (2024) reported that seed priming with 50 mM of KNO₃ can be an effective strategy to improve germination in okra. Ebrahim and Miri (2016) used 30 g l⁻¹ humic acid (60%) as seed priming agent to obtain the highest germination rate. Despite the benefits of priming are well documented for uniform and smooth germination, the practice has not yet been widely accepted by the farmers in Bangladesh. This is because there is no easily available and affordable priming agent in the common market. Keeping the above facts in view, the present investigation was conducted to study the effect of various priming treatments on overcoming the germination hindrance of okra seeds.

Materials and Methods

The present investigation was conducted under natural conditions in the laboratory of Plant Physiology Section of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI) during two consecutive years of 2023 and 2024 (in May for 10 days each year) to evaluate the effects of priming agents on germination, germination properties and early seedling growth in okra. The seeds of BARI Dheros-2 and OK1820 were obtained from Olericulture Division of HRC and bought from local market, respectively. The study consisted of two okra varieties namely, V₁ = BARI Dheros-2 and V₂ = OK1820 and eleven priming treatments *viz.*, T₀ = unprimed control, T₁ = DH₂O (Hydropriming), T₂ = 150 ppm GA₃, T₃ = 200 ppm GA₃, T₄ = 40 ppm SA (salicylic acid), T₅ = 50 ppm SA, T₆ = 0.25% KNO₃, T₇ = 0.50% KNO₃, T₈ = 40 mM Hydrogen Peroxide (H₂O₂), T₉ = 100 ppm HA (humic acid, as potassium humate), T₁₀ = 200 ppm HA. The priming of seeds was done in the lab at 35±2°C for 18 hours.

Required number of healthy seeds for each variety (20 × 3 × 11; about 50 g) totaling about 100 g was counted based on two varieties, 11 treatments and 3 replications. Considering each variety and replication total seeds were divided into 11 groups. All seeds were sterilized with 0.1 % Hg₂Cl₂ for 5 min. Then the sterilized seeds were washed well with distilled water to remove the chemicals adhered to seed surface. The sterilized seeds were dried in shade for 30 min. Then, except one group (for unprimed control), 10 groups of seeds were soaked for 18 hrs (Khan *et al.*, 2023) in the respective priming solutions prepared by dissolving calculated amount of priming chemicals in the required amount of distilled water. The ratio of seed weight to solution volume (w/v) was 1:5. After 18 hours, the primed seeds were washed with water for 3-4 times and dried in shade at 35±2°C until the moisture content was decreased to initial moisture content (20%). Required number of petri dishes, each with a diameter of 9 cm were used in the experiment

and arranged in a completely randomized design (CRD) moistened with respective treatment in three replications. Three layers of commercial tissue paper were used in each Petri dish for retaining required amount of water for imbibition of seeds. Twenty equal sized seeds of each variety were selected and placed on sterilized Petri dish lined with filter paper on 8 May 2023 and 6 May 2024. The pet dishes with seeds of the selected varieties of okra were kept in normal room temperature ($35\pm 2^\circ\text{C}$) for germination.

The 5 ml of prime solutions were added separately in the petri dishes. For unprimed control, 5 ml distilled water was added to the Petri dishes. The Petri dishes were covered with glass cover to prevent the loss of moisture by evaporation. The respective priming solutions and distilled water (for unprimed control) were added to the Petri dishes when required. Number of seeds germinated was counted daily and data recording were continued up to 10 days. On 10th day, 10 seedlings (shoot + root) were weighed by the electrical balance and this weight was considered as fresh weight (g) of seedling, and these seedlings (air dried for 01 day) were kept in an oven at 72°C for 02 days (48 hrs) for recording dry weight (mg) of seedling. On 10th day of each year, the shoot and the root length of ten randomly selected seedlings from each replicate were measured. Seeds were considered germinated upon emergence of radicles (≥ 2 mm) (Sharma and Sharma, 2010). From these germination counts, several germination attributes were calculated such as germination percentage (GP), days required for 50% germination (T_{50}), speed of germination (SoG), germination value (GV) by different formulae proposed by different authors and scientists given below:

Germination percentage

Germination percentage was calculated from the daily counted seeds (ISTA, 2014) give as follows:

Germination percentage (GP) = (No. of seeds germinated/Total No. of seeds placed in petridish) \times 100

T_{50} (Time to 50 percent germination): It was the time required to achieve 50% of final/maximum germination (Coolbear *et al.*, 1984).

$$T_{50} = t_i + [(N/2 - n_i) (t_j - t_i)] / (n_j - n_i)$$

Where, T_{50} is the median germination time (time to 50% germination), N is the final number of germinated seeds and n_i and n_j are the total number of seeds germinated in adjacent counts at time t_i and t_j , respectively, when where $n_i < N/2 < n_j$

Speed of Germination:

The number of germinated seeds was counted every two days until the end of the germination test. An index was calculated by dividing the number of seeds that

germinated each day by the number of days that were in the petri dish (Sahib *et al.*, 2014).

Speed of Germination: $N1/C1 + N2/C2 + \dots + NF/CF$

Where N1 (number of germinated seeds at first count), N2 (Number of germinated seeds at the second count), Nf (number of germinated seeds at the final count), C1 (days to first count), C2 (days to the second count), and Cf (days to the final count).

Germination value (GV): It was calculated as (Djavanshir and Pourbeik, 1976)

$$GV = \Sigma DGS/N \times (GP \times 10)$$

Where GV is germination value, DGS is daily germination speed which is computed by dividing cumulative germination percent by the number of days since beginning the test.

Seedling Vigour Index: The seedling vigour index I and seedling vigour index-II was calculated as per the method prescribed by Abdul-Baki and Anderson (1973) and expressed in whole number.

Seedling vigor index I: It was calculated as follows:

$$\begin{aligned} \text{Seedling vigor index I} \\ = \text{Germination percentage (\%)} \times \text{seedling length (cm)} \end{aligned}$$

Seedling Vigor Index II: It was calculated as follows:

$$\begin{aligned} \text{Seedling vigor index II} \\ = \text{Germination percentage} \times \text{seedling dry weight (g)} \end{aligned}$$

The data of both 2023 and 2024 with pooled analyses on germination per cent (GP), speed of germination (SoG), germination value (GV), total seedling length, seedling dry weight and seedling vigour index-I, seedling vigour index-II were subjected to one-way analysis of variance (ANOVA) to establish the significance of differences between the treatments ($p \leq 0.05$) by Tukey HSD test using MSTATC software.

Results and Discussion

Germination Percentage

Seed germination percentage is the measure of how many seeds in a batch successfully sprout into healthy seedlings, indicating their viability and potential for successful planting under ideal conditions. Germination percentage was significantly influenced by the different priming agents (Table 1). The maximum germination percentage was recorded when seeds were primed with 40 mM H₂O₂ (98.87% in 2023, 97.79% in 2024 with pooled mean 98.33% in BARI Dhereos-2

and 94.01% in 2023, 95.33% in 2024 with pooled mean 94.67% in OK1820) closely followed by 100 ppm HA (92.98% in 2023, 93.68% in 2024 with pooled mean 93.33% in BARI Dhereos-2 and 89.99% in 2023, 92.67% in 2024 with pooled mean 91.33% in OK1820), 200 ppm HA (93.35% in 2023, 93.31% in 2024 with pooled mean 93.33% in BARI Dheros-2 and 94.01% in 2023, 93.33% in 2024 with pooled mean 93.67% in OK1820) and hydropriming (85.0% in 2023, 95.00% in 2024 with pooled mean 90.00% in OK1820) and the lowest germination percentage was obtained from 0.50% KNO₃ (62.54% in 2023, 60.80% in 2024 and pooled 61.67% in BARI Dhereos-2 and 53.22% in 2023, 50.12% in 2024 with pooled 51.57% in OK1820) which was almost identical with unprimed control (69.52% in 2023, 71.14% in 2024 with pooled 70.33% in BARI Dheros-2 and 70.01% in 2023, 72.23% in 2024 with pooled 71.12% in OK1820) (Table 1). After HA, hydropriming with distilled water showed better results in respect of germination percentage and in both the varieties, hydro-priming gave higher per cent germination than unprimed control.

It is presumed that H₂O₂ helped increase okra seed germination by acting as a signaling molecule that helps to break seed dormancy, improve oxygen bioavailability. Rehman *et al.* (2024) reported that increased seed germination may be attributed to KNO₃ which acted as a nutrient source, a signaling molecule, and an osmotic agent that breaks dormancy and activates essential metabolic processes. Hussein (2015) opined that salicylic acid (SA) may boost okra germination by acting as a signaling molecule that activates protective responses, repairing cellular damage (like DNA/RNA), improving water uptake, and regulating key enzymes, leading to faster, more uniform germination and helps overcome seed dormancy and hard seed coats, kickstarting metabolic processes crucial for germination. Hydropriming may increase okra germination due to hydropriming which helped overcome its hard seed coat, allowing controlled water intake that activates pre-germinative metabolism (like enzyme activity) without the radical emerging, thus speeding up and synchronizing germination (Sheferie, 2023).

The results for germination obtained from hydropriming corroborate the results of Khan *et al.* (2023) who obtained maximum germination percentage through hydropriming by distilled water in okra for 18 hrs. The results of H₂O₂ are in partial agreement with Alam *et al.* (2024) who obtained maximum per cent germination 2% H₂O₂ primed seeds in okra. The results of DH₂O, 0.5% NaCl, 0.5% KNO₃ and 100 ppm GA₃ are in consonance with Thapa *et al.* (2025) in okra. The results of HA were in agreement with Hussein (2015) who obtained the highest germination % (98%) from 100 ppm SA primed seeds of okra.

Table 1. Effect of different priming agents on seedling length of two okra varieties

| Treatment | Germination Percent | | | | | |
|-----------------|---------------------|----------|---------|----------|----------|---------|
| | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| T ₀ | 69.52cd | 71.14c | 70.33b | 70.01d | 72.23f | 71.12b |
| T ₁ | 85.00ab | 95.00a | 90.00a | 87.12ab | 89.54a-d | 88.33a |
| T ₂ | 91.12a | 85.54abc | 88.33a | 85.02abc | 84.98b-e | 85.00a |
| T ₃ | 87.41ab | 85.93abc | 86.67a | 86.56abc | 86.78a-e | 86.67a |
| T ₄ | 84.58abc | 85.42abc | 85.00a | 79.67bcd | 80.33def | 80.00a |
| T ₅ | 89.68ab | 90.32ab | 90.00a | 86.01abc | 87.33a-e | 86.67a |
| T ₆ | 75.89bcd | 77.45b | 76.67ab | 75.67cd | 77.67ef | 76.67ab |
| T ₇ | 62.54d | 60.80d | 61.67b | 53.22e | 50.12g | 51.67c |
| T ₈ | 98.87a | 97.79a | 98.33a | 94.01a | 95.33a | 94.67a |
| T ₉ | 92.98a | 93.68a | 93.33a | 89.99ab | 92.67ab | 91.33a |
| T ₁₀ | 93.35a | 93.31a | 93.33a | 94.01a | 93.33ab | 93.67a |
| CV (%) | 8.54 | 9.65 | 9.00 | 8.96 | 8.59 | 7.23 |

Figures within a column, having different letter (s) do not differ significantly at $P < 0.05$ by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Time required for 50% germination (T₅₀)

Time required for 50% Germination (T₅₀), essentially measuring the speed of germination, not just the final percentage. It indicates how quickly seeds start sprouting under specific conditions (like temperature), with a lower T₅₀ suggesting faster germination, making it vital for assessing seedling vigor and predicting crop establishment. T₅₀ value was significantly affected by different priming agents (Table 2). The lowest T₅₀ value was obtained from 200 ppm GA₃ (2.50 days in 2023, 2.58 days in 2024 with pooled 2.54 days) which was statistically similar to 40 mM H₂O₂ (2.49 days in 2023, 2.61 days in 2024 with pooled 2.55 days) in case of BARI Dheros-2, whereas in case of OK1820, the lowest T₅₀ value was obtained from 50 ppm SA (3.50 days in 2023, 3.56 days in 2024 with pooled 3.53 days) closely followed by all treatments except control (3.96 days in 2023, 4.02 days in 2024 with pooled 3.99 days) and 0.50% KNO₃ (pooled 3.66 days of 2023 and 2024). In case of BARI Dheros-2, all priming agents performed better except control (3.31 days in 2023, 3.27 days in 2024 with pooled 3.29 days) and 50 ppm SA (2.71 days in 2023, 2.73 days in 2024 with pooled 2.72 days) with regard to T₅₀ value.

Table 2. Effect of different priming agents on time to 50% germination of two okra varieties

| Treatment | Time to 50% germination (T ₅₀) | | | | | |
|-----------------|--|--------|---------|---------|--------|---------|
| | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| T ₀ | 3.31a | 3.27a | 3.29a | 3.96a | 4.02a | 3.99a |
| T ₁ | 2.50cd | 2.82b | 2.66bc | 3.47cd | 3.63bc | 3.55bc |
| T ₂ | 2.55cd | 2.57d | 2.56bc | 3.56bc | 3.52d | 3.54 bc |
| T ₃ | 2.50cd | 2.58d | 2.54c | 3.56bc | 3.52d | 3.54bc |
| T ₄ | 2.65bc | 2.59d | 2.62 bc | 3.44d | 3.68b | 3.56bc |
| T ₅ | 2.71b | 2.73bc | 2.72b | 3.50cd | 3.56cd | 3.53c |
| T ₆ | 2.58bcd | 2.54d | 2.56bc | 3.56bc | 3.54cd | 3.55bc |
| T ₇ | 2.65bc | 2.53d | 2.59bc | 3.64b | 3.68b | 3.66a |
| T ₈ | 2.49d | 2.61cd | 2.55c | 3.54bcd | 3.56cd | 3.55bc |
| T ₉ | 2.57bcd | 2.55d | 2.56bc | 3.51cd | 3.57c | 3.54bc |
| T ₁₀ | 2.64bc | 2.54d | 2.59bc | 3.56bc | 3.54cd | 3.55bc |
| CV (%) | 2.30 | 2.14 | 2.18 | 2.59 | 2.58 | 2.57 |

Figures within a column, having different letter (s) do not differ significantly at P<0.05 by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Hydropriming of okra seeds leads to a decrease in the T₅₀ value because the process accelerates the initial metabolic events of germination, leading to faster and more uniform sprouting of seedlings. Potassium nitrate (KNO₃) treatment may help to decrease T₅₀ value because it accelerates the metabolic processes required for germination. The decrease in T₅₀ value means faster and more uniform germination. Hydrogen peroxide may cause a decrease in the T₅₀ value in okra because it acts as a signaling molecule that promotes germination by enhancing oxygen supply to the embryo and breaking dormancy. Salicylic acid treatment might accelerate okra seed germination by influencing several physiological and biochemical processes. Khan *et al.* (2023) obtained T₅₀ value through hydropriming by distilled water in okra for 18 hrs. Mauro *et al.* (2020) obtained a notable decrease in average germination time from KNO₃ (0.75 %) seed priming

Speed of germination (SoG)

The speed of germination (SoG) refers to how quickly seeds sprout after planting under favorable conditions. It is essentially a measure of the time it takes for a seed to begin the growth process, typically by an index that combines the number of germinated seeds and the time taken. SoG was significantly influenced by different

Table 3. Effect of priming agents on speed of germination and germination value of two okra varieties

| Treatment | Speed of germination | | | | | | Germination value | | | | | |
|-----------------|----------------------|---------|---------|---------|---------|--------|-------------------|----------|----------|-----------|-----------|----------|
| | BARI Dheros-2 | | | OK1820 | | | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | pooled | 2023 | 2024 | pooled | 2023 | 2024 | pooled | 2023 | 2024 | pooled |
| T ₀ | 5.15de | 4.55ef | 4.85bc | 3.75c | 3.69cd | 3.72b | 85.69f | 94.73e | 90.21b | 95.79d | 98.23ef | 97.01b |
| T ₁ | 5.75bc | 5.45cd | 5.60ab | 4.25abc | 4.37abc | 4.31ab | 145.25de | 149.19cd | 147.22ab | 132.40abc | 120.58cde | 126.49ab |
| T ₂ | 5.69bcd | 5.81bc | 5.75ab | 4.15abc | 4.19a-d | 4.17ab | 170.21bcd | 167.09bc | 168.65ab | 118.15bcd | 120.25cde | 119.20ab |
| T ₃ | 5.78abc | 5.56c | 5.67ab | 4.23abc | 4.29a-d | 4.26ab | 164.54bcd | 166.42bc | 165.48ab | 124.75abc | 122.87bcd | 123.81ab |
| T ₄ | 5.37cde | 5.45cd | 5.41abc | 3.98bc | 3.86bcd | 3.92ab | 150.12cde | 149.28cd | 149.70ab | 108.39cd | 100.25def | 104.32ab |
| T ₅ | 5.43cde | 5.65c | 5.54abc | 4.25abc | 4.31a-d | 4.28ab | 148.21cde | 147.33cd | 147.77ab | 124.46abc | 128.52abc | 126.49ab |
| T ₆ | 4.93e | 5.01de | 4.97abc | 3.87bc | 3.65d | 3.76b | 126.54e | 124.26d | 125.40ab | 97.51d | 95.65f | 96.58b |
| T ₇ | 3.98f | 4.06f | 4.02c | 1.08d | 0.98d | 1.033c | 89.25f | 85.36e | 87.303b | 55.02e | 58.54g | 56.783c |
| T ₈ | 6.34a | 6.50a | 6.42a | 4.72a | 4.68a | 4.70a | 212.25a | 209.17a | 210.71a | 146.85a | 148.23a | 147.54a |
| T ₉ | 6.02ab | 6.10ab | 6.06ab | 4.52ab | 4.46ab | 4.49ab | 184.56ab | 186.86ab | 185.71a | 137.24ab | 135.54abc | 136.39ab |
| T ₁₀ | 6.02ab | 5.98abc | 6.00ab | 4.54ab | 4.66a | 4.60a | 176.59c | 180.55ab | 178.57a | 143.38ab | 145.62ab | 144.50a |
| CV (%) | 5.65 | 5.74 | 9.64 | 6.74 | 7.01 | 7.11 | 10.51 | 9.87 | 13.54 | 12.04 | 11.53 | 13.94 |

Figures within a column, having different letter (s) do not differ significantly at P<0.05 by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

priming agents (Table 3). In BARI Dheros-2, priming with 40 mM H₂O₂ gave maximum values of SoG (6.34 in 2023, 6.50 in 2024 with pooled 6.42) which were statistically similar to other priming treatments except 0.50% KNO₃ (3.98 in 2023, 4.06 in 2024 with pooled mean 4.02) and unprimed control (5.15 in 2023, 4.55 in 2024 with pooled 4.85) (Table 3). In Okra1820, the maximum SoG was recorded from 40 mM H₂O₂ (4.72 in 2023, 4.68 in 2024 with pooled 4.70) identical with all other priming treatments except 0.50% KNO₃ (1.08 in 2023, 0.98 in 2024 with pooled mean 1.033) and control (3.75 in 2023, 3.69 in 2024 with pooled 3.72). The lowest SoG was recorded from 0.50% KNO₃ followed by control.

Hydropriming may speed up okra germination by initiating key metabolic processes like enzyme activation and food reserve mobilization, softening the hard seed coat, and preparing the embryo for rapid emergence, overcoming the natural delays caused by okra's tough seed coat and leading to faster, more uniform seedling growth and establishment. This controlled hydration activates systems that break dormancy and energize the seed, essentially giving it a head start. Hydrogen peroxide may increase the speed of okra seed germination by acting as a signaling molecule that helps break seed dormancy, enhancing metabolic activity, and providing crucial oxygen to the embryo. Potassium nitrate priming might increase the speed of okra germination primarily by breaking seed dormancy and activating key metabolic processes through several mechanisms such as hormonal regulation, improving water uptake, enhancing metabolic activities viz., DNA replication, RNA and protein synthesis, and greater ATP (energy) availability (Rehman *et al.*, 2024). Alam *et al.* (2024) obtained speed of germination by using 2% H₂O₂ in okra. Hussein (2015) obtained the highest germination speed index (47.6) from 100 ppm SA primed seeds of Okra.

Germination value (GV)

Germination value (GV) is a single-value index that combines both the speed and the completeness (total percentage) of seed germination. It is used to provide a comprehensive measure of a seed lot's overall quality and vigor. A higher germination value indicates that a seed lot has a high total percentage of viable seeds and that those seeds germinate quickly and uniformly over time. Different priming agents significantly affected germination value (Table 3). In BARI Dheros-2, the highest GV (212.25 in 2023, 209.17 in 2024 with pooled 210.71) was observed from 40 mM H₂O₂ which was statistically similar to 100 ppm HA (184.56 in 2023, 186.86 in 2024 with pooled 185.71), 200 ppm HA (176.59 in 2023, 180.55 in 2024 with pooled 178.57) and other priming treatments except 0.50% KNO₃ (89.25 in 2023, 85.36 in 2024 with pooled 87.30) and control (85.69 in 2023, 94.73 in 2024 with pooled 90.21). In OK1820, the maximum GV was obtained from 40 mM H₂O₂ (146.85 in 2023, 148.23 in 2024 with pooled 147.54) closely followed by 200 ppm HA (143.38 in 2023, 145.62 in 2024 with pooled

144.50) and other treatments except 0.50% KNO₃ (55.02 in 2023, 58.54 in 2024 with pooled 56.78) and control (95.79 in 2023, 98.23 in 2024 with pooled 97.01). The lowest GV value was recorded from 0.50% KNO₃ which was statistically similar to control (Table 3).

Hydropriming may increase the germination value (GV) of okra seeds by initiating crucial pre-germinative metabolic processes, which leads to faster and more uniform seedling growth and other mechanism such as protein synthesis, DNA repair, and ATP generation, upgrade imbibition, enhanced enzyme activation, improved membrane integrity and breaking dormancy (Tania *et al.*, 2020). Maximum germination value was attributed to H₂O₂ treatment which acted as a signaling molecule that breaks seed dormancy, improves metabolic activity, enhances antioxidant capacity, and provides extra oxygen (Ellouzi *et al.*, 2021). Potassium nitrate may increase the germination value (GV) in okra by acting as a nutrient and a signaling molecule that breaks seed dormancy, enhances water uptake, regulates hormones, and improves antioxidant defenses (Rehman *et al.*, 2024). Negi *et al.* (2024) used the germination parameter 'germination value (GV) to evaluate the seeds of *Oroxylum indicum* collected from four different sources in India. Geethanjali *et al.* (2025) reported that GA₃ @ 750 ppm (among 500, 600 ppm and 750 ppm GA₃) recorded highest germination value.

Table 4. Effect of different priming agents on seedling length of two okra varieties

| Treatment | Seedling length (cm) | | | | | |
|-----------------|----------------------|---------|---------|--------|--------|--------|
| | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| T ₀ | 1.46g | 1.50h | 1.48f | 5.65c | 5.49bc | 5.57b |
| T ₁ | 12.45a | 11.87a | 12.16a | 9.95ab | 9.99a | 9.97a |
| T ₂ | 2.74f | 2.50g | 2.62f | 5.21cd | 4.35d | 4.78b |
| T ₃ | 2.06fg | 2.36g | 2.21f | 4.90cd | 4.94c | 4.92b |
| T ₄ | 4.08e | 4.14f | 4.11e | 4.82cd | 4.76cd | 4.79b |
| T ₅ | 6.02d | 5.90e | 5.96d | 4.18d | 4.24d | 4.21b |
| T ₆ | 9.87c | 9.79c | 9.83c | 1.35e | 1.43e | 1.39c |
| T ₇ | 6.70d | 6.74d | 6.72d | 1.20e | 1.16e | 1.18c |
| T ₈ | 11.54ab | 11.42ab | 11.48ab | 10.54a | 10.40a | 10.47a |
| T ₉ | 10.82bc | 10.88b | 10.85bc | 6.10c | 6.30b | 6.20b |
| T ₁₀ | 11.62ab | 11.50ab | 11.56ab | 9.15ab | 9.33a | 9.24a |
| CV (%) | 6.84 | 7.25 | 8.87 | 8.89 | 9.52 | 9.12 |

Figures within a column, having different letter (s) do not differ significantly at P<0.05 by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

Seedling length

Seedling length was significantly influenced by different priming agents (Table 4). In BARI Dheros-2, the highest seedling length was recorded from hydro-priming (12.45 cm in 2023, 11.87 cm in 2024 with pooled 12.16 cm) identical with 40 mM H₂O₂ (11.54 cm in 2023, 11.42 cm in 2024 with pooled 11.48 cm) and 200 ppm HA (11.62 cm in 2023, 11.50 cm in 2024 with pooled 11.56 cm) and unprimed control gave the lowest seedling length (1.46 cm in 2023, 1.50 cm in 2024 with pooled 1.48 cm) (Fig. 4). In OK1820, priming with 40 mM H₂O₂ gave the maximum seedling length (10.54 cm in 2023, 10.40 cm in 2024 with pooled 10.47 cm) which was statistically similar to hydro-priming (9.95 cm in 2023, 9.99 cm in 2024 with pooled mean 9.97 cm) and 200 ppm HA (9.15 cm in 2023, 9.33 cm in 2024 with pooled mean 9.24 cm) and the lowest seedling recorded from 0.50% KNO₃ (1.20 cm in 2023, 1.16 cm in 2024 with pooled 1.18 cm) closely followed by 0.25% KNO₃ (1.35 cm in 2023, 1.43 cm in 2024 with pooled 1.39 cm). Hydrogen peroxide might increase okra seedling length because, at appropriate low concentrations it acts as a signaling molecule that breaks seed dormancy, strengthens the antioxidant system, and promotes vital early growth processes (Badsha *et al.*, 2022). Okra seedling length increase was attributed to potassium nitrate application that supplies two essential nutrients, nitrogen (N) and potassium (K), which work together to promote cell division, cell elongation, and overall robust vegetative growth. Results are supported by the results of Geethanjali *et al.* (2025) who obtained highest plumule length, radicle length in *Lisianthus* using GA₃ @ 750 ppm (among 500 and 600 ppm GA₃) and 0.3% KNO₃, Karta and Abebie (2012) who obtained the highest shoot length, root length from 0.155 M KNO₃ and 0.310 M KNO₃ in *Vicia villosa*. Ebrahim and Miri (2016) who obtained the highest radical length in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA and Hussein (2015) who found maximum shoot length (18 cm) and root length (11 cm), seedling length (29 cm), using 100 ppm SA in okra.

Seedling dry weight

Seedling dry weight was significantly influenced by different priming agents (Table 5). In BARI Dheros-2, maximum seedling dry weight was observed in 40 mM H₂O₂ (35.21 mg in 2023, 35.59 mg in 2024 with pooled 35.40 mg) closely followed by hydro-priming (30.29 mg in 2023, 30.51 mg in 2024 with pooled 30.40 mg), 150 ppm GA₃ (30.20 mg in 2023, 30.06 mg in 2024 with pooled mean 30.13 mg), 40 ppm SA (30.74 mg in 2023, 30.86 mg in 2024 with

pooled 30.80 mg) and its minimum value was obtained when seeds were primed with 200 ppm GA₃ (1654 mg in 2023, 16.40 mg in 2024 with pooled 16.47 mg) (Table 5). In OK1820, maximum seedling dry weight was observed in 40 mM H₂O₂ (35.45 mg in 2023, 35.73 mg in 2024 with pooled 35.59 mg) which was identical with 200 ppm HA (35.68 mg in 2023, 35.30 mg in 2024 with pooled mean of 35.49 mg) and other priming treatments control (20.42 mg in 2023, 20.24 mg in 2024 with pooled 20.33 mg). Hydropriming may help increase okra seedling length by accelerating the metabolic processes required for germination and promoting cell division and elongation during early growth. The increased okra seedling dry weight may be attributed to hydropriming which helped accelerate the seed's metabolic activity, enhancing enzyme function, and promoting the rapid development of an efficient root and shoot system. This improved vigor allows the plant to accumulate more biomass compared to unprimed seeds. Hydrogen peroxide may enhance nutrient and water uptake, increased antioxidant activity, activation of growth-related genes/proteins, improved histological components that improve the plant's physiological efficiency and support greater dry weight accumulation. Essentially, the right concentration of H₂O₂ might help seedling to grow more vigorously by optimizing its metabolic and defensive functions, leading to a more robust plant with higher dry weight. Potassium nitrate may increase okra seedling dry weight primarily by supplying two essential nutrients, nitrogen (N) and potassium (K), which play critical roles in core plant physiological processes like water regulation, and protein synthesis and increase seedling length.

Khan *et al.* (2023) obtained maximum seedling dry weight through hydropriming by distilled water in okra for 18 hrs. Results of seedling growth are in line with Dursan *et al.* (2002) who obtained better seedling growth using 100-200 ppm HA in both eggplant and tomato. With regard to seedling dry weight, the present experimental results are in partial agreement with Debbarma *et al.* (2018) who reported that hydropriming and GA₃ (50 ppm) priming in bitter melon. Results are supported by the results of Geethanjali *et al.* (2025) who obtained highest seedling dry weight in *Lisianthus* using GA₃ @ 750 ppm (among 500 and 600 ppm GA₃) and 0.3% KNO₃, Karta and Abebie (2012) who obtained the highest seedling dry weight from 0.155 M KNO₃ and 0.310 M KNO₃ in *Vicia villosa*, Ebrahim and Miri (2016) who obtained the highest radical length in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA and Hussein (2015) who found maximum seedling fresh weight (0.9988g) and seedling dry weight (0.0603 g) using 100 ppm SA in okra.

Table 5. Effect of different priming agents on seedling length of two okra varieties

| Treatment | Seedling dry weight (mg) | | | | | |
|-----------------|--------------------------|---------|----------|----------|---------|---------|
| | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| T ₀ | 24.01b | 24.31bc | 24.16bc | 20.42e | 20.24b | 20.33b |
| T ₁ | 30.29ab | 30.51ab | 30.40ab | 27.68a-e | 28.20ab | 27.94ab |
| T ₂ | 30.20ab | 30.06ab | 30.13ab | 21.21e | 20.91b | 21.06ab |
| T ₃ | 16.54c | 16.40c | 16.47bc | 23.21e | 23.45b | 23.33ab |
| T ₄ | 30.74ab | 30.86ab | 30.80ab | 24.36de | 24.56b | 24.46ab |
| T ₅ | 24.05b | 24.21bc | 24.13bc | 33.87a-d | 34.13a | 34.00a |
| T ₆ | 24.38b | 24.42bc | 24.40abc | 34.12abc | 34.00a | 34.06a |
| T ₇ | 23.32b | 23.48bc | 23.40bc | 28.36a-e | 28.18ab | 28.27b |
| T ₈ | 35.21a | 35.59a | 35.40a | 35.45ab | 35.73a | 35.59a |
| T ₉ | 25.98b | 26.16b | 26.07abc | 28.85a-e | 29.15ab | 29.00ab |
| T ₁₀ | 29.02ab | 29.24ab | 29.13ab | 35.68a | 35.30a | 35.49a |
| CV (%) | 6.54 | 8.85 | 6.42 | 7.56 | 8.87 | 8.56 |

Figures within a column, having different letter (s) do not differ significantly at $P < 0.05$ by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Seedling vigour

Seedling vigour was presented by two indexes *viz.*, Seedling Vigour Index-I and Seedling Vigour Index-II (Table 6). Seedling Vigour Index-I (SVI-I) is a crucial measure of seed quality, showing how well seeds not only sprout but also develop strong, long seedlings, indicating good overall performance for planting. It's a way to see a seed lot has strong growth potential beyond just germination, helping farmers choose seeds for better crop establishment. Whereas, Seedling Vigour Index-II (SVI-II) is a key measure of seed quality providing a strong indicator of a seed's ability to produce strong, healthy, high-biomass seedlings, reflecting its stored food reserves and overall performance potential beyond just germination.

Maximum seedling vigour index-I was recorded from 40 mM H₂O₂ (1128.3 in BARI Dheros-2 and 956.83 in OK1820) closely followed by 200 ppm HA (1078.2 in BARI Dheros-2 and 847.63 in OK 1820) and hydropriming (1095.6 in BARI Dheros-2 and 883.1 in OK1820). In BARI Dheros-2, the lowest seedling vigour index-I was noted from control (130.82) closely followed by T₃ and T₂. The highest seedling vigour index-II was recorded from 40 mM H₂O₂ (3.48) closely followed by hydropriming (2.74) and 200 ppm HA (2.72) and the lowest value was obtained

Table 6. Effect of priming agents on seedling vigour index-I and seedling vigour index-II of two okra varieties

| Treatment | Seedling Vigour Index I | | | | | | Seedling Vigour Index II | | | | | |
|-----------------|-------------------------|-----------|----------|----------|----------|----------|--------------------------|---------|---------|---------|---------|--------|
| | BARI Dheros-2 | | | OK1820 | | | BARI Dheros-2 | | | OK1820 | | |
| | 2023 | 2024 | pooled | 2023 | 2024 | pooled | 2023 | 2024 | pooled | 2023 | 2024 | pooled |
| T ₀ | 154.65f | 106.99g | 130.82e | 395.56e | 572.80c | 484.18b | 1.67de | 1.73def | 1.70de | 1.68de | 1.50e | 1.59d |
| T ₁ | 1058.25a | 1132.95a | 1095.60a | 866.84b | 899.36a | 883.10a | 2.57bc | 2.90ab | 2.74ab | 2.41bcd | 2.53bcd | 2.47ab |
| T ₂ | 249.67e | 212.07f | 230.87de | 442.95d | 370.29f | 406.62b | 2.75ab | 2.57bc | 2.66b | 1.80cde | 1.78de | 1.79d |
| T ₃ | 209.06ef | 231.24f | 220.15de | 424.14de | 426.60d | 425.37b | 1.45e | 1.41e | 1.43e | 2.01cde | 2.03cde | 2.02bc |
| T ₄ | 345.09d | 359.71e | 352.40cd | 384.01f | 395.25de | 389.63b | 2.60bc | 2.64c | 2.62b | 1.94cde | 1.97cde | 1.96c |
| T ₅ | 539.87c | 532.87d | 536.37c | 359.52f | 371.74ef | 365.63b | 2.16b-e | 2.19b-e | 2.17b-e | 2.91ab | 2.98ab | 2.95ab |
| T ₆ | 749.03b | 752.57c | 750.80b | 102.15g | 112.11g | 107.13c | 1.85cde | 1.89c-f | 1.87cde | 2.58ab | 2.64abc | 2.61ab |
| T ₇ | 419.02d | 411.64e | 415.33c | 63.86g | 57.68h | 60.77d | 1.46e | 1.43ef | 1.44e | 1.51e | 1.41e | 1.46e |
| T ₈ | 1140.96a | 1115.64a | 1128.30a | 990.87a | 922.79a | 956.83a | 3.46a | 3.50a | 3.48a | 3.33a | 3.41a | 3.37a |
| T ₉ | 1006.04a | 1014.16b | 1010.10a | 548.94c | 605.92c | 577.43b | 2.42bcd | 2.45bcd | 2.43bcd | 2.60abc | 2.70abc | 2.65bc |
| T ₁₀ | 1084.73a | 1071.67ab | 1078.20a | 860.19b | 835.07b | 847.63ab | 2.71abc | 2.73ab | 2.72ab | 3.35a | 3.29ab | 3.32a |
| CV (%) | 7.89 | 7.87 | 6.85 | 7.41 | 7.56 | 6.95 | 7.45 | 5.87 | 6.25 | 9.92 | 8.95 | 8.54 |

Figures within a column, having different letter (s) do not differ significantly at P<0.05 by Tukey W test. T₀ (unprimed control), T₁ (Hydropriming), T₂ (150 ppm GA₃), T₃ (200 ppm GA₃), T₄ (40 ppm SA), T₅ (50 ppm SA), T₆ (0.25% KNO₃), T₇ (0.50% KNO₃), T₈ (40 mM H₂O₂), T₉ (100 ppm HA), T₁₀ (200 ppm HA); GA₃ = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

from 200 ppm GA₃ (1.43) being identical with 0.50% KNO₃ (1.44) in BARI Dheros-2. Whereas, in OK1820, the maximum seedling vigour index-II was found in 40 mM H₂O₂ (3.37) closely followed by 200 ppm HA (3.32), and its lowest value was noticed in 0.50% KNO₃ (0.94). Hydropriming might boost okra seedling vigor by initiating pre-germination metabolic processes, activating DNA repair, strengthening antioxidants, and breaking seed dormancy from hard coats, leading to faster, more uniform germination, quicker water uptake, and robust root/shoot growth, ultimately improving crop establishment and yield, especially under stress (Tania *et al.*, 2020). Maximum seedling vigour was attributed to hydrogen peroxide treatment (priming) that helped increase okra seedling vigour by acting as a signaling molecule that breaks seed dormancy, improves the mobilization of stored nutrients, and enhances the antioxidant defense system of the plant (Ellouzi *et al.*, 2021). Potassium nitrate may increase seedling vigour in okra by acting as both an essential nutrient and a vital signaling molecule, can improve early growth by accelerating metabolic activities, enhancing water uptake, modulating hormone level.

Results of seedling vigour index-I was supported by Alam *et al.* (2024) using 2% H₂O₂, Khan *et al.* (2023) through hydropriming in okra for 18 hrs, Karta and Abebie. (2012) from 0.155 M KNO₃ and 0.310 M KNO₃ in *Vicia villosa*, Ebrahim and Miri (2016) in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA, and Hussein (2015) using 100 ppm SA in okra. Results of seedling vigour index-II corroborate the results of Debbarma *et al.* (2018) who obtained best results from hydropriming and GA₃ (50 ppm) priming for 12 hours in bitter melon and Karta and Abebie (2012) who obtained maximum seedling vigour index-II using KNO₃.

Conclusion

The results of the experiment revealed that H₂O₂, humic acid and distilled water were found to be the most important priming agents to increase seed germination, germination speed, seedling length and seedling dry weight and seedling vigour index. It is suggested that prior to sowing seeds of okra, okra seeds should be soaked in either 40 mM H₂O₂ or 200 ppm HA or distilled water for 18 hours to obtain better germination and vigorous seedlings by overcoming poor and erratic germination due to the presence of hard seed coat.

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YIELD ADVANTAGE AND LAND USE EFFICIENCY OF BUSH BEAN - SORGHUM INTERCROPPING SYSTEMS

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AND M. A. H. KHAN⁵

Abstract

The experiment was conducted at the Agronomy Research Field of Bangladesh Agricultural Research Institute (BARI), Gazipur during *rabi* seasons of 2021-22 and 2022-23 to find out the suitable crop combination of bush bean with sorghum for increasing total productivity, economic return, maximizing land utilization through intercropping system. Six treatments *viz.*, T₁= Sorghum normal row 100% (60 cm line to line × 20 cm plant to plant) + 1 row bush bean (30 cm line to line × 5 cm plant to plant; 43.75%) in between two rows of sorghum, T₂= Sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.75%) in between two rows of sorghum T₃= Sorghum paired row 100% (30 cm-120 cm-30 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 37.50%) in between two paired rows of sorghum, T₄= Sorghum paired row 100% (30 cm-120 cm-30 cm X 20 cm) + 3 row bush bean (30 cm × 5 cm; 56.25%) in between two paired rows of sorghum, T₅= Sole sorghum (60 cm × 20 cm) and T₆= Sole bush bean (30 cm × 5 cm) were used. Light availability on bush bean decreased with the increase of shade produced by sorghum canopy over the time up to 65 Days After Sowing (DAS) (). The lowest light availability on bush bean was in T₂ treatment which was sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.75%) in between two rows of sorghum. The maximum grain yield of sorghum was observed in sole crop 4.58 t ha⁻¹ and it was decreased by 2.84-20.74% among the intercrop combination. The highest sorghum equivalent yield (SEY) of 9.00 t ha⁻¹, gross return (Tk. 1,79,900 ha⁻¹), gross margin (Tk. 1,33,900 ha⁻¹) and benefit cost ratio (BCR) of 3.91 were obtained from T₂ treatment. The highest land equivalent ratio (LER) of 1.70 was also found in the same treatment. The results revealed that sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.50%) could be agronomically feasible and economically profitable intercropping.

Keywords: Sorghum, bush bean, intercropping, land equivalent ratio, light interception, yield.

Introduction

Intercropping is a traditional practice in Bangladesh. It increases total productivity per unit area through maximum utilization of land, labour and growth resources

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(Ahmed *et al.*, 2013; Islam *et al.*, 2006; Mahfuza *et al.*, 2012). By judicious choice of compatible crops and adopting appropriate planting geometry, inter/intra specific competition may be minimized resulting higher total productivity (Alom *et al.*, 2013). Canopy architecture of tall stature crop regulates the availability of light under storied crop (Faruque *et al.*, 2006). Sorghum (*Sorghum bicolor* L. Moench) is an unbranched and erect cereal crop grown with wider spacing. Several short duration and short stature vegetable like bush bean may be grown in association with sorghum. Sorghum grain is as nutritious as other cereal grains; contains about 11% water, 340 k cal⁻¹ of energy, 11.6% protein, 73% carbohydrate and 3% fat by weight (Thimmaiah, 2002; Taylor *et al.*, 2006; Yan *et al.*, 2012). Sorghum is used as food, feed, fodder and fuel. On a field basis, sorghum yields have exceeded 11 t ha⁻¹ with above average yields ranging 7-9 t ha⁻¹, where moisture is not a limiting factor (Mohamed, 2011).

Bush bean (*Phaseolus vulgaris*. L) is an important high yielding legume crop. It can be used as vegetable, soup and in other form. Bush bean contains vitamin A (23%), vitamin C (27%), vitamin K (12%) carbohydrates (5.5%), and protein (3%) (Davis *et al.*, 2001). Generally, legumes in association with non-legumes not only helps in utilization of the nitrogen being fixed in the current growing season, but also helps in residual nutrients buildup of the soil (Islam *et al.*, 2006). Farmers often demand for quick return from their crops, and they can get quick return by growing short duration vegetable crops with sorghum. But literature is meager regarding sorghum + bush bean intercropping under different planting systems in Bangladesh condition. By adopting appropriate planting geometry in the intercropping system, the total productivity of the crops can be enhanced (Umrani *et al.*, 1984). This experiment was, therefore, conducted to find out suitable planting system of sorghum and bush bean (short duration crop) intercropping for higher productivity and economic return.

Materials and Methods

The experiment was conducted at the research field of Agronomy Division BARI, Gazipur during *rabi* season of 2020-21 and 2022-23. The soil of the research area belongs to AEZ-28. The soil was clay loam with pH 6.3. Treatments included in the experiment were T₁= Sorghum normal row 100% (60 cm line to line × 20 cm plant to plant) + 1 row bush bean (30 cm line to line × 5 cm plant to plant; 43.75%) in between two rows of sorghum, T₂= Sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.75%) in between two rows of sorghum T₃= Sorghum paired row 100% (30 cm-120 cm-30 cm × 20 cm) + 2 row bush bean

(30 cm × 5 cm; 37.50%) in between two paired rows of sorghum , T₄= Sorghum paired row 100% (30 cm-120 cm-30 cm X 20 cm) + 3 row bush bean (30 cm × 5 cm; 56.25%) in between two paired rows of sorghum , T₅= Sole sorghum (60 cm × 20 cm) and T₆= Sole bush bean (30 cm × 5 cm) The experiment was laid out in a randomized complete block design with three replications and the unit plot size was 4.8 m × 5 m. Sorghum (Var. BARI Sorghum-1) and Bush bean (Var. BARI Jharsheem-2) were used in the experiment. Sorghum and bush bean seeds were sown on 22 November 2021 and 27 November 2022, respectively. The seeds of both crops were treated with provex @ 3g kg⁻¹ of seed. Fertilizers were applied at the rate of 120-48-75-30-3-1 kg ha⁻¹ of N-P-K-S-Zn-B (FRG, 2018) as urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate and boric acid for sole sorghum and intercrop. One third of N, whole amount of TSP, MoP, gypsum, zinc sulphate and boric acid were applied as basal. Remaining 2/3 N was top dressed at 25 and 45 days after sowing (DAS) of sorghum. In intercrop, extra N (40 kg ha⁻¹) was applied in 2 splits at 25 and 45 DAS of bush bean. Sole bush bean was fertilized at the rate of 88- 35-53-11-2.2-1.5 kg ha⁻¹ of N-P-K-S and Zn (FRG, 2018). 1/3 N and all other fertilizers were applied as basal at the time of final land preparation. Remaining N was applied as side dress at 20 and 35 DAS under moist soil condition and mixed thoroughly with the soil as soon as possible for better utilization. Light availability or Photosynthetically active radiation (PAR) was measured by PAR Ceptometer (Model – LP-80, Accu PAR, Decagon, USA). The PAR was measured at 5-day intervals from 25 to 65 days after sowing (DAS) at around 11:30 am to 13:00 pm. Four readings each of PAR_{inc} and PAR_t were recorded at different spots of each plot. The proportion of intercepted PAR (PAR_{int}) was calculated using the following equation and expressed in percentage (Ahmed *et al.*, 2013):

$$\text{Light availability } \{ \text{PAR}_{\text{int}} (\%) \} = \frac{\text{PAR}_{\text{t}}}{\text{PAR}_{\text{inc}}} \times 100$$

whrer, PAR_{inc}= Incident PAR, PAR_t= Transmitted PAR, PAR_{int}= Intercepted PAR.

Data on yield contributing characters of sorghum were taken from randomly selected 10 plants from each plot. Yields of both the crops were taken from whole plot area. Sorghum was harvested on 04 April, 2022 and 09 April 2023 and bush bean was harvested 2 times on 02 and 10 February, 2022 and 06 and 12 February 2023, respectively. Sorghum equivalent yield (SEY) was calculated by converting yield of intercrops on the basis of prevailing market price of individual crop following the formula (Islam *et al.*, 2012) as given below:

$$SEY = Y_{is} + \frac{Y_{ibn} \times P_{bn}}{P_s}$$

Where, Y_{is} = Yield of intercropped sorghum, Y_{ibn} = Yield of intercropped bush bean,

P_{bn} = Market price of bush bean and P_s = Market price of sorghum.

Land equivalent ratio (LER) was obtained according to Willey (1979) as follows:

$$LER = \frac{S_{IY}}{S_{SY}} + \frac{B_{IY}}{B_{SY}}$$

Where,

S_{IY} = Yield of intercrop sorghum

S_{SY} = Yield of sole sorghum

B_{IY} = Yield of intercrop (Component crop)

B_{SY} = Yield of sole crop (Component crop)

Collected data of both the crops were analyzed statistically and pooled data were also analyzed statistically and mean separations were done by LSD test at 5% level of significance. Economic analysis was also done considering local market price of harvested crops. Mean separations were done by Least Significant Difference (LSD) test at 5% level of significance.

Results and Discussion

Light availability

Availability of light on sorghum and bush bean was not markedly affected with each other because bush bean was harvested at 67-74 DAS. At that time sorghum canopy could not produce much shade which might affect bush bean. Irrespective of treatments, availability of light on bush bean canopy was almost 100% at earlier growth stage, 30 DAS of bush bean, and it decreased with the increase of shade produced by sorghum canopy over the time up to 74 DAS or up to harvest of bush bean. However, among the intercropping treatments the higher light availability on bush bean was observed in T_3 treatment (SPR 100% (30 cm/ 120 cm/ 30 cm × 20cm) + 2 row bush bean 37.50% (30 cm × 5 cm) followed by T_4 treatment (SPR 100% (30 cm/ 120 cm/ 30 cm × 20cm) + 3 rows bush bean 56.25% (30 cm × 5 cm) throughout the growing period. The lowest light availability on bush bean was observed in T_2 treatment (SNR 100% + 2 rows bush bean 87.50%) followed by T_1 treatment (SNR + 2 rows bush bean 43.75%) at 65 DAS of bush bean. Among all

treatments, the highest light availability was observed in sole bush bean, T₅ treatment (Fig.1).

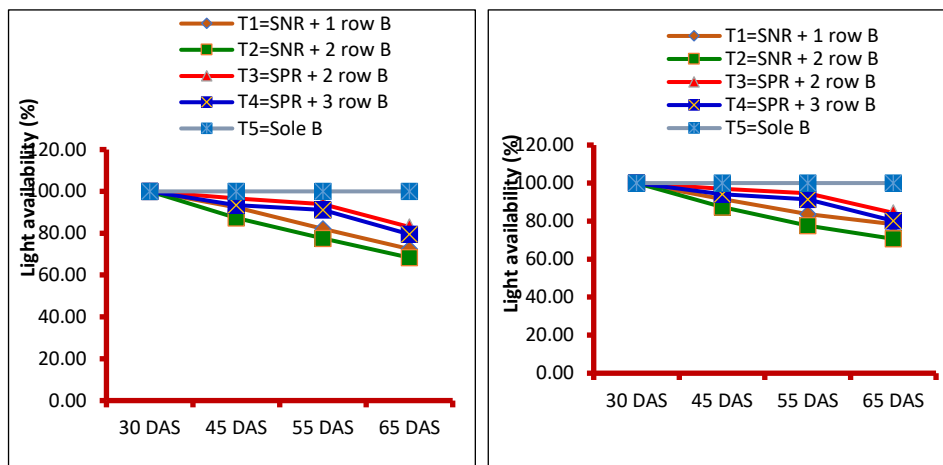


Fig. 1. Light availability on bush bean canopy in sorghum + bush bean intercropping system during *rabi* season 2021-22 and 2022-23 at Gazipur.

Grain yield and yield contributing characters of sorghum

Panicle length (cm), number of grains panicle⁻¹, 1000-grain weight (g), and grain yield (t ha⁻¹) of sorghum was significantly varied due to intercropping of sorghum with bush bean and sole crop of sorghum, except plant height which was insignificant (Table 1). Higher panicle length (18.94 cm) was obtained from sole planting of sorghum and it was statistically identical with T₁ (17.88 cm) and T₂ (17.40 cm) treatment. The lowest panicle length (16.40 cm) was recorded in T₄ treatment and it was statistically identical with and T₃ (16.88 cm). Similar trend was found in case of number of grains panicle⁻¹ and 1000-grain weight. The highest number of grains panicle⁻¹ (1841) and 1000-grain weight (36.49 g) was recorded in sole sorghum (T₅ treatment). Among the intercropping situation, the maximum number of grains panicle⁻¹ (1662) and 1000-grain weight (33.64 g) was obtained from T₁ treatment and it was statistically identical with T₂ (1630 and 32.71 g) and T₃ (1550 and 31.26 g) treatments and the lowest number of grains panicle⁻¹ (1457) and 1000-grain weight (31.07 g) was in T₄ treatment. The maximum grain yield 4.58 t ha⁻¹ was obtained in sole sorghum (T₅) followed by T₅, which was probably due to less intercrop competition for growth resources like light, nutrient, moisture and space. It was apparent that all the yield contributing characters and yields in the intercrops increased gradually with the decreased of bush bean population. This was possibly due to competition between sorghum and bush bean crop for growth resources like moisture, light, nutrient. Bandyopadhyay *et al.* (1984) also reported that significant difference was not found in yield and yield attributes of sorghum

due to intercropping with bush bean i. e. growing of the intercrops in interspaces between sorghum rows did not affect the base crop. Under intercropping, the maximum grain yield 4.45 t ha⁻¹ was recorded in T₁ treatment which was statistically identical with T₃ (3.84 t ha⁻¹) treatment. The lowest grain yield 3.63 t ha⁻¹ was recorded in T₄ treatment. However, grain yield of sorghum in different treatments were attributed by the cumulative effect of yield components. Islam *et al.* (2012) also reported similar result when bush bean was intercropped with maize.

Table 1. Grain yield and yield attributes of sorghum under sole and intercropping system

| Treatment | Plant height (cm) | Panicle length (cm) | Grains panicle ⁻¹ (no.) | 1000- grain wt. (g) | Grain yield (t ha ⁻¹) |
|-----------------------|-------------------|---------------------|------------------------------------|---------------------|-----------------------------------|
| T ₁ | 184.60 | 17.88 | 1662 | 33.64 | 4.45 |
| T ₂ | 179.17 | 17.40 | 1630 | 32.71 | 3.66 |
| T ₃ | 181.73 | 16.88 | 1550 | 31.26 | 3.84 |
| T ₄ | 178.57 | 16.40 | 1457 | 31.07 | 3.63 |
| T ₅ | 191.18 | 18.94 | 1841 | 36.49 | 4.58 |
| LSD _(0.05) | NS | 1.45 | 245 | 2.11 | 0.64 |
| CV (%) | 3.63 | 4.41 | 8.02 | 3.39 | 8.38 |

Note: T₁= Sorghum normal row 100% (60 cm line to line × 20 cm plant to plant) + 1 row bush bean (30 cm line to line × 5 cm plant to plant; 43.75%) in between two rows of sorghum, T₂= Sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.75%) in between two rows of sorghum T₃= Sorghum paired row 100% (30 cm-120 cm-30 cm X 20 cm) + 2 row bush bean (30 cm × 5 cm; 37.50%) in between two paired rows of sorghum , T₄= Sorghum paired row 100% (30 cm-120 cm-30 cm × 20 cm) + 3 row bush bean (30 cm × 5 cm; 56.25%) in between two paired rows of sorghum , T₅= Sole sorghum (60 cm × 20 cm) and T₆= Sole bush bean (30 cm × 5 cm).

Green pod yield and yield contributing characters of bush bean

Plants m⁻², plant height, number of pods plant⁻¹, pod length (cm), 10-green pod weight (g) and green pod yield (t ha⁻¹) of bush bean were markedly differed by intercrop combinations (Table 2). The maximum number of plants m⁻² of bush bean (59) was obtained from T₆ treatment (Sole bush bean). Among the intercropping situation, the maximum number of plants m⁻² of bush bean (46) was obtained from T₂ treatment and the minimum number of plants m⁻² of (24) in T₃ treatment and it was statistically identical with T₁ (27 m⁻²) and T₄ (31 m⁻²) treatments, which were probably due to variation of planting system. The maximum plant height (46.63 cm), number of pods plant⁻¹ (7.54), pod length (11.67 cm) and 10-green pod weight (56.40 g) was recorded in T₆ treatment (sole bush bean). Among the intercropping situation the highest plant height (46.37 cm) was obtained from T₃ treatment which

was statistically identical with T₁ (44.33 cm). The lowest plant height (40.08 cm) was obtained from T₂ treatment. Similar trend was found in case of pods plant⁻¹, pod length and 10-green pod weight. The maximum number of pods plant⁻¹ (7.07), pod length (10.92 cm), and 10-green pod weight (53.19 g) was obtained from T₃ treatment which was statistically identical with T₁ treatment. The minimum number of pods plant⁻¹ (5.84), pod length (8.78 cm) and 10-green pod weight (47.04 g) was recorded in T₂ treatment. The highest green pod yield of bush bean 11.86 t ha⁻¹ was obtained from T₆ treatment (Sole bush bean) followed by T₂ treatment due to higher plant population per unit area. There was no intercrop competition for growth resource in sole bush bean. Among the intercropping situation, the highest green pod yield of bush bean 10.67 t ha⁻¹ was obtained from T₂ treatment, whereas the lowest green pod yield of bush bean 4.31 t ha⁻¹ was obtained from T₃ treatment followed by T₁ due to the lowest number of plant population per unit area. The higher green pod yield in bush bean was attributed to maximum number of plant m⁻². Faruque *et al.* (2006) also reported similar result in maize/spinach-red amaranth intercropping system.

Table 2. Green pod yield and yield attributes of bush bean under sole and intercropping system

| Treatment | Plant m ⁻² (no.) | Plant height (cm.) | Pods plant ⁻¹ (no.) | Pod length (cm) | 10-green pod (g) | Green pod yield (t ha ⁻¹) |
|----------------|--------------------------------|-----------------------|--------------------------------------|--------------------|---------------------|--|
| T ₁ | 27 | 44.33 | 7.06 | 10.08 | 51.36 | 5.15 |
| T ₂ | 46 | 40.08 | 5.84 | 8.78 | 47.04 | 10.67 |
| T ₃ | 24 | 46.37 | 7.07 | 10.92 | 53.19 | 4.31 |
| T ₄ | 31 | 41.03 | 6.18 | 9.91 | 47.47 | 6.79 |
| T ₆ | 59 | 46.63 | 7.54 | 11.67 | 56.40 | 11.86 |
| LSD (0.05) | 4.64 | 4.21 | 0.96 | 1.02 | 4.99 | 0.95 |
| CV (%) | 6.60 | 5.12 | 7.54 | 5.28 | 5.19 | 6.47 |

Note: T₁= Sorghum normal row 100% (60 cm line to line × 20 cm plant to plant) + 1 row bush bean (30 cm line to line × 5 cm plant to plant; 43.75%) in between two rows of sorghum, T₂= Sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.75%) in between two rows of sorghum T₃= Sorghum paired row 100% (30 cm-120 cm-30 cm X 20 cm) + 2 row bush bean (30 cm × 5 cm; 37.50%) in between two paired rows of sorghum , T₄= Sorghum paired row 100% (30 cm-120 cm-30 cm × 20 cm) + 3 row bush bean (30 cm × 5 cm; 56.25%) in between two paired rows of sorghum , T₅= Sole sorghum (60 cm × 20 cm) and T₆= Sole bush bean (30 cm × 5 cm).

Sorghum equivalent yield

Sorghum and bush bean intercrop productivity was evaluated on the basis of sorghum equivalent yield (SEY) and land equivalent ratio (Bandyopadhyay,1984). Sorghum equivalent yield (SEY) and land equivalent

ratio are presented in Table 3. Sorghum equivalent yield expressed the total productivity of the intercropping system. Sorghum equivalent yield was higher in all the intercrops (6.00 to 9.00 t ha⁻¹) than the sole crop of sorghum 4.58 t ha⁻¹ (Table 3). In intercrop combination, the highest sorghum equivalent yield 9.00 t ha⁻¹ was recorded in T₂ treatment followed by T₁ (7.03 t ha⁻¹) and T₄ treatments. The lowest sorghum equivalent yield (6.00 t ha⁻¹) was obtained from T₃ treatment over the sole sorghum. Total productivity also increased by 96.40%, 53.38% and 30.90% in T₂, T₁, T₄ and T₃ treatments, respectively. Ahmed *et al.* (2013) also reported that intercrop combination of leafy vegetables with okra increases the equivalent yield.

Land equivalent ratio

The highest land equivalent ratio (1.70) was recorded in T₂ treatment (Table 3) and the lowest (1.20) was recorded in T₃ treatment. LER of different crop combinations ranged from 1.20 to 1.70 which indicating that land utilization was increased to 20 to 70% by intercropping. The mean value of LER (more than one) in all intercropping treatments indicated that land was more efficiently utilized under intercropping than sole cropping of sorghum and bush bean.

Table 3. Sorghum equivalent yield (SEY), land equivalent ratio (LER) and % increase of SEY over sole sorghum in sorghum + bush bean intercropping system.

| Treatment | SEY (t/ha) | % increase of SEY over sole sorghum | LER |
|---|------------|-------------------------------------|------|
| T ₁ (SNR + 1 row bush bean) | 7.03 | 53.38 | 1.41 |
| T ₂ (SNR + 2 rows bush bean) | 9.00 | 96.40 | 1.70 |
| T ₃ (SPR + 2 rows bush bean) | 6.00 | 30.90 | 1.20 |
| T ₄ (SPR + 3 rows bush bean) | 7.03 | 53.38 | 1.37 |
| T ₅ (Sole sorghum) | 4.58 | - | 1.00 |
| T ₆ (Sole bush bean) | 5.93 | | 1.00 |

Note: SEY= Sorghum equivalent yield (t/ha), LER= Land equivalent ratio.

Cost benefit analysis

Cost and return analysis, an important tool to evaluate the economic feasibility of intercropping system and monetary advantage, was evaluated according to Shah *et al.* (1991). Cost and return analysis of bush bean with sorghum intercropping system is presented in Table 4. Gross return and BCR depends on equivalent yield. Intercropping combination of bush bean with sorghum showed higher monetary return than sole crop of sorghum and bush bean (Table 4). The highest gross return (Tk. 1,79,900 ha⁻¹) was recorded from T₂ treatment. This intercropping combination also gave the highest gross margin (Tk. 1,33,900 ha⁻¹) and benefit cost ratio (BCR) 3.91 followed by T₁ treatment owing to gross return (Tk. 1,40,500 ha⁻¹), gross margin (Tk. 96,500 ha⁻¹) and benefit cost ratio (3.19). The lowest gross

return (Tk. 91,600/ha), gross margin (Tk. 49,600/ha) and BCR (2.18) was obtained from sole sorghum (T₅) treatment. The results of increased productivity and returns were consistent with the earlier reports of yield advantage of crop mixture compared to monoculture (Ahmed *et al.*, 2013 and Islam *et al.*, 2012).

Table 4. Cost and return analysis of sole sorghum and sorghum + bush bean intercropping system.

| Treatment | Gross return (Tk. ha ⁻¹) | Cost of cultivation (Tk. ha ⁻¹) | Gross margin (Tk. ha ⁻¹) | Benefit cost ratio (BCR) |
|----------------|---|--|---|-----------------------------|
| T ₁ | 1,40,500 | 44,000 | 96,500 | 3.19 |
| T ₂ | 1,79,900 | 46,000 | 1,33,900 | 3.91 |
| T ₃ | 1,19,900 | 45,000 | 74,900 | 2.66 |
| T ₄ | 1,40,500 | 48,000 | 92,500 | 2.93 |
| T ₅ | 91,600 | 42,000 | 49,600 | 2.18 |
| T ₆ | 1,18,600 | 43,000 | 75,600 | 2.76 |

Price: Sorghum: Tk. 20/Kg and Bush bean: Tk. 10/Kg according the prevailing market price.

Conclusion

All intercropping combinations were more productive and profitable than growing sole sorghum and bush bean. Among the tested several sorghums - bush bean intercropping systems, sorghum normal row 100% (60 cm × 20 cm) + 2 row bush bean (30 cm × 5 cm; 87.50%) was found agronomically feasible and economically profitable with respect to SEY (Sorghum equivalent yield) and BCR (benefit cost ratio).

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