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## BANGLADESH JOURNAL OF AGRICULTURAL RESEARCH

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## MAIZE YIELD FORECASTING MODEL FOR USING SATELLITE MULTISPECTRAL IMAGERY AT KAHAROLE IN DINAJPUR DISTRICT

N. MOHAMMAD<sup>1</sup>, M. A. ISLAM<sup>2</sup>, M. G. MAHBOOB<sup>3</sup>  
M. M. RAHMAN<sup>4</sup> AND I. AHMED<sup>5</sup>

### Abstract

The cultivation of maize, a high-yielding grain, has seen increased in Northern Bangladesh. Traditional crop yield prediction is costly and error-prone, often delaying its post-harvest activities. This study used remote sensing (RS) techniques for forecasting pre-harvest maize yield to improve the management system. The normalized difference vegetation index (NDVI) was widely used to predict crop yield. The study used Landsat 8 (~ 30 m) and Sentinel 2A (~ 10 m) high resolution data for 2018-2019 and 2019-2020 to predict maize yield based on the year 2020-2021 at Kaharole upazila in Dinajpur district. The single cloud free image acquisition date based on maximum NDVI for both satellite images was used for each maize growing period to develop the yield prediction model. A regression model was performed between NDVI values and 20 farmers filed-level maize yields. The absolute mean error of prediction was about 10.15% for Landsat 8 and 8.82% for Sentinel 2A compared to the actual maize yield during 2020-2021. It can be concluded that NDVI data extracted from Sentinel 2A high resolution satellite images can be successfully used to predict the maize yield with appreciable accuracy. This research recommends the implementation of satellite multispectral imagery for accurate maize yield forecasting to enhance agricultural planning and resource management.

Keywords: NDVI, Landsat 8, Sentinel 2A, Maize, Prediction and Satellite image.

### Introduction

Timely and accurate prediction of crop yields is necessary for effective agricultural land management, decision making and sustainability of agricultural food production (Masson-Delmotte et al., 2018). Remote sensing technology plays a vital role in the agriculture sector by providing timely and accurate information (Atzberger, 2013). Maize (*Zea mays L.*) is also known as corn, is the world's fourth major staple food crop after Rice, Wheat and Potato. Maize is initially grown for grain and secondly for fodder and raw material for industrial purposes. It is one of the important coarse cereal crops grown in the distinct agronomical conditions of Bangladesh. Maize cultivation mainly increased rapidly in the northern part of Bangladesh. It has the highest potential of per day carbohydrate productivity. During the last decades, maize cultivation in Bangladesh showed an increasing

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

trend (1.39%). During 2011-12, total maize cultivation area and yield were 0.2 million ha and 1.3 million metric tons, respectively, while in 2019-20, these figures rose to 0.47 million ha and 4.02 million metric tons, respectively (BBS, 2020). These indicate that the prospects of maize production in Bangladesh is quite bright. However, maize growth monitoring and its yield estimation have become a major issue of consideration.

Traditional field based crop data collection becomes clumsy, costly, time consuming, and have the possibility of error (Reynolds *et al.*, 2000). In addition, yield estimations with conventional methods are no longer beneficial for planners as they take too much time. During the last few years, many empirical models have been developed to predict crop yield before harvesting, but many of them have become unpractical, especially those are depending on field data collection. As the satellite-based remote sensing is one of the best tools to provide vital information about the distribution of crops and its growing conditions over large areas, it can be applied for maize growth monitoring and yield forecast. The combination of data acquired by Landsat 8 and Sentinel 2 (2A, 2B) remote sensing satellites can provide a high temporal resolution (3–5 days) (Li *et al.*, 2017) which is crucial for several applications requiring dense satellite data time series. A global equal area projection grid defined every  $0.05^\circ$  is used considering each sensor and combined together. The temporal observation frequency improvements afforded by sensor combination are shown to be significant. In particular, considering Landsat-8, Sentinel-2A, and Sentinel-2B together will provide a global median average revisit interval of 2.9 days, and, over a year, a global median minimum revisit interval of 14 min ( $\pm 1$  min) and maximum revisit interval of 7.0 days. Segarra *et al.*, (2020) conclude that Sentinel-2 has a wide range of useful applications in agriculture, yet still with room for further improvements. Even though a combination of Landsat 8 and Sentinel 2 proposes a high frequency of observations, discrepancies in available cloud-free data, however, will still exist.

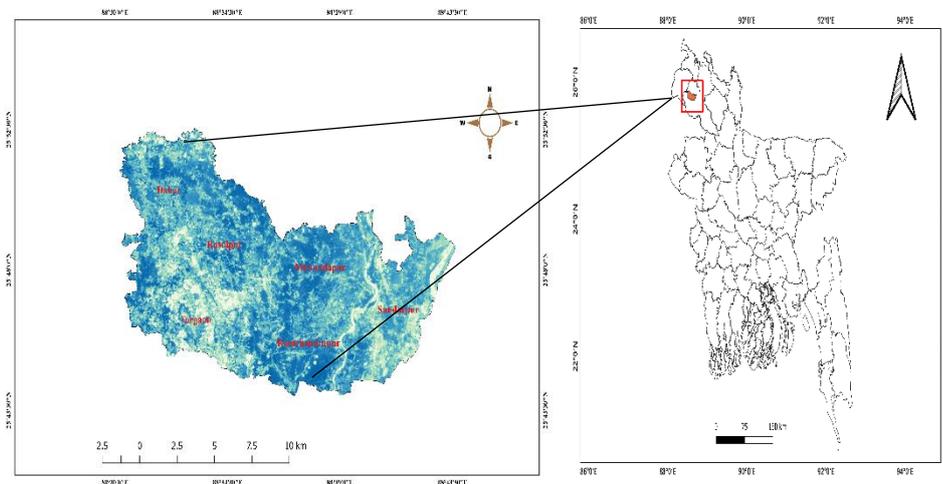
Several studies have been carried out by the correlation of normalized difference vegetation index (NDVI) with yield (Liu *et al.*, 2002). Recent studies took the benefit of Landsat and Sentinel 2 data to approach crop yield forecasting at a moderate spatial resolution. For example, Lambert *et al.* (2018) applied Sentinel 2 data and a peak LAI (Leaf area index) procedure to predict the yields of cotton, maize, millet, and sorghum in Mali. The multiple coefficient of determination ( $R^2$ ) ranged from 0.48 to 0.80 for distinct crops on training data. Lai *et al.* (2018) applied time-integrated Landsat NDVI for wheat yield estimation in Australia. They applied an asymmetric bell-shaped growth model to fit NDVI against time. Shakun *et al.* (2019) applied the combination of Landsat 8 and Sentinel 2 high frequency of observations (3–5 days) at moderate spatial resolution (10–30 m), which is important for crop yield studies that were executed for the model with near infrared (NIR) and red spectral bands and derived the area under the ROC Curve (AUC), constant, quadratic and linear coefficients of the quadratic model. The best model yielded a root mean square error (RMSE) of 0.201 t/ha (5.4%) and coefficient of

determination ( $R^2$ ) = 0.73 on cross-validation. Rahman et al. (2020) used the Simple Linear Machine Learning (ML) algorithm, the extracted Landsat derived the average green normalized difference vegetation index (GNDVI) values for each of the blocks were converted to Sentinel GNDVI and found strong correlations ( $R^2 = 0.92$  to  $0.99$ ) in Bundaberg growing region of Australia. Lima et al. (2019) observed that both satellites showed the same performance in terms of accuracy for Sentinel-2 and Landsat 8, respectively. However, Landsat 8 mapped 36.9% more area of selective logging compared to Sentinel-2 data for mapping small-scale logging in the Brazilian Amazon. In some studies, predict grain yield 2–3 months prior to the harvest. More advanced regression models for yield prediction apply a time series of NDVI which allow one to obtain better forecasting (Panek et al., 2021). In Bangladesh, Bala and Islam (2009) expanded potato yield estimations models by using NDVI, LAI (leaf area index), and fraction of photosynthetically active radiation (fPAR) vegetation indices for Munshiganj District of Bangladesh by applying Moderate Resolution Imaging Spectroradiometer (MODIS) (with lowest resolution greater than 250m) 8-day composite surface reflectance data and noticed that an average error of estimation is about 15% for the study location. Islam et al. (2011) used the NDVI indicator developed from time series MODIS satellite images, the phenological growth of wheat has been monitored during the Rabi season of 2007-2008 for the greater Dinajpur area of Bangladesh. A strong correlation between the wheat production and satellite represented wheat area was found ( $R^2=0.71$ ) which represents the effectiveness of the remote sensing tools for crop monitoring and production estimation. Rahman et al. (2012) applied NOAA-AVHRR data for prediction of potato yield in Bangladesh. However, a high resolution (~ 30 m) satellite image from Landsat is cost freely available since 1984. The availability of Landsat 8 images contributes an ample opportunity for long-term frequent environmental monitoring (Mandanici et al., 2016). Newton et al. (2018) improved a potato yield prediction model by applying 16-day high resolution (~ 30 m) Landsat surface reflectance data to identify the maximum normalized difference vegetation index (NDVI) value of a potato growing season in the Munshiganj district of Bangladesh. The maximum coefficient of determination ( $R^2$ ) of the yield forecasting equation was found to be 0.81 between the mean NDVI and potato yield and the result revealed that the difference between predicted and actual filed yield is about 10.4%.

However, very few studies have been conducted on the relationship between high resolution (~ 30 m) Landsat 8 and Sentinel 2A (~ 10 m) satellite data and maize yield in Bangladesh. The objective of the present study is to construct a maize yield prediction model based on NDVI at Kaharole Upazila in Dinajpur district of Bangladesh respectively using high-resolution Landsat 8 Operational Land Imager (OLI) and Sentinel 2A Multi-Spectral Instrument (MSI) surface reflectance data. The combined use of high resolution Landsat 8 and Sentinel 2A images have been applied in this study to improve the yield assessment model for the maize crop.

### Study Area

The study was conducted at Kaharole Upazila in Dinajpur district especially in Rabi season which was the highest maize growing areas of Bangladesh. It covered 26.36% and 14.15% maize cultivation areas in the northern part and all over Bangladesh respectively (BBS, 2020). Kaharole upazila lie between 25° 44' to 25° 53' N latitude and 88° 30' to 89° 43' E longitude respectively (Figure 1). It covers 205.54 km<sup>2</sup> area where 59% areas is cultivable land. The climate condition of this area is hot and humid from April to October (summer) and cool and dry from November to March (winter). This upazila receives an annual average rainfall of 1965 mm and 2417 mm, where 90% of rainfall occurs between May and October. In Kaharole upazila, the maximum and minimum mean temperature during the winter varies between 23.6 to 16.8 and 24 to 16.8°C, respectively. During summer, the maximum and minimum mean temperatures vary between 33.2 to 26.0°C and 29.8 to 25.6°C respectively. The average monthly minimum and maximum humidity varies from 68 to 86%, where the maximum humidity during the summer and the minimum humidity observed during the dry season. The agricultural pattern of this area is categorized by two growing seasons, *Rabi* and *Kharif*. *Rabi* is the main growing season, which is dominated by maize and wheat that starts in late-October or early November and ends in April. Again, *Kharif* is dominated by rice and jute, which starts in May and ends in September. Other food crops which include potato, pepper, onion, pulses, sugarcane, and oilseed are also cultivated in the study areas. The soil condition of this area is prevailed by non-calcareous brown floodplain soils and grey floodplain soils.

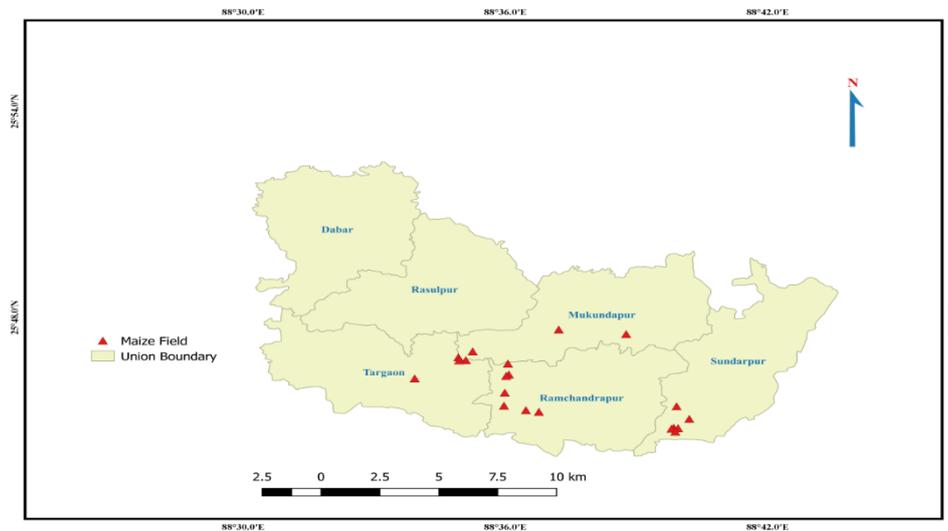


**Fig. 1.** Map of the study location Kaharole Upazila Dinajpur.

## Materials and Methods

### Yield data collection from farmer's fields

Twenty maize fields were selected from Kaharole Upazila of Dinajpur district for the three maize growing seasons 2018-2019, 2019-2020 and 2020-2021 with the agreement of the farmers (Figure 2). Data were collected from those 20 maize fields for each season. Crop information data such as field GPS locations, planting and harvesting time and yield were collected from this selected Upazilas farmers' fields.



**Fig. 2. Location of selected 20 maize fields (red triangles) over Kaharole, Dinajpur district**

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

Landsat 8 images (OLI) were obtained from the United States Geological Survey (USGS) Earth Explorer website (<http://earthexplorer.usgs.gov/>). Landsat 8 (OLI) is a sun-synchronous satellite staying at an altitude of 705 km above the earth with a 16-day repeat cycle. Landsat 8 has two types of sensors, especially the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The OLI sensor equips nine spectral bands, including a pan band, and TIRS produces two spectral bands. Sentinel-2A images (MSI) were obtained from the European Space Agency (ESA) Copernicus portal (<https://scihub.copernicus.eu>). Sentinel-2A carries a multispectral instrument (MSI). Images furnished by Sentinel-2A are publically available for free and have 13 spectral bands with a spatial resolution ranging from 10 m to 60 m (depending on the band) and a current temporal resolution of about 10 days (depending on the latitude). A total of 6 maximum cloud-free images were downloaded: 3 images from Landsat 8 OLI and the remaining 3 images from Sentinel 2A MSI satellite data for Kaharole Upazila in

Dinajpur district, covering the consecutive years 2018-19, 2019-20, and 2020-21, respectively (Table 1). The single date of image acquisition based on maximum greenness was used for each growing period i.e. 2018-2021 for maize cultivation. The maize sowing date was considered to be the last week of November and the first week of December for each growing season 2018-19, 2019-20 and 2020-21 respectively for the entire study site based on the information taken from the location visits. Every single image was calculated from the starting day of the plantation. The dates of image acquisition of Landsat 8/OLI and Sentinel 2A/MSI for this study are presented in Table 1.

**Table 1. Model development using Landsat 8 and Sentinel 2A satellite image at Kaharole Upazila, Dinajpur district**

Satellite images	Landsat 8			Sentinel 2A		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
Growing Season	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
IAD	10/03/2019	12/03/2020	15/03/2021	16/03/2019	20/03/2020	05/03/2021
DAP	95	97	103	101	105	93

IAD=Image acquisition date; DAP= Days after plantation

### Satellite Image Pre-processing

For Landsat data, raw digital numbers (DN) were adjusted to top-of-atmosphere (TOA) reflectance values following reference (Simonetti *et al.*, 2015). Two techniques were used to preprocess the satellite images: (1) radiometric calibration and (2) atmospheric correction. Remote sensing data adopted from satellite sensors are influenced by several factors, such as atmospheric scattering and absorption, sensor-target-illumination geometry, sensor calibration, and data processing procedures (Teillet, 1986). For that, radiometric calibration is needed. Radiometric calibration means a set of correction techniques that are associated with the correction of the sensitivity of satellite sensors, topography and sun angle, atmospheric scattering, and absorption (Kim *et al.*, 1990). The radiometric calibration was done by transforming the digital numbers (DNs) to surface reflectance by radiance conversion. Open source-based Quantum Geographic Information System (QGIS) software 2.18.13 version allows a plugin, which gives a tools for atmospheric correction, known as dark object subtraction (DOS-1) level 1. In this study, this tool was used in the radiometrically calibrated images to the minimize atmospheric scattering effect. DOS-1 searches each pixel of a band to find the darkest value. The scattering is eliminated by subtracting this value from every pixel in the band.

Two approaches were followed to download and process Sentinel-2A imagery. The first was a simplified process for farmers and advisors to monitor the crop status during the season. The free and open-source QGIS 2.18.13 version software together with the Semi-automatic Classification Plugin (SCP) was used for those

purposes (Congedo, 2016). The advantage of using the SCP is that the user can preview and download per date and tile single bands and correct the Sentinel-2 images in the same interface. Afterward, the vegetation indices can be computed, stored and compared with other dates within the same QGIS environment. The only limitation is that in the conversion of top-of-atmosphere (TOA) reflectance values into bottom-of-atmosphere (BOA) the image-based Dark Object Subtraction (DOS-1) technique is applied. This process is less accurate than the physically-based correction that could be applied to Sentinel-2 images using the attached metadata (Congedo, 2016).

### **Normalized Difference Vegetation Index (NDVI)**

Prediction and estimation of yield are closely associated with the capability of identifying crop species and certain agronomic parameters, such as maturity, density, vigor and disease, which can be used as yield indicators. Remote sensing can arrange these types of information to a great extent. There are distinct types of vegetation indices (VIs) generated from different spectral reflectances that are specially used to get these types of information. The NDVI is generally applied extensively around the world to monitor the vegetation quality, growth, and distribution over a large area. Differences in the phenological growth stages of different plants are reflected in the temporal NDVI profiles, since NDVI can measure growth conditions (greenness of vegetation) (Belgiu and Csillik, 2018; Croitoru et al., 2012). It is a dimensionless index, which is performed from the ratio between the surface reflectance of the NIR and RED bands of the spectrum as follows (Equation 1) (Rouse et al., 1974).

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad (1)$$

Where RED (Visible red) and NIR (Near infrared) are reflectance measurements for RED and NIR bands, respectively. Here for Landsat 8/OLI, band 4 and band 5 represented RED and NIR bands and for Sentinel 2A/MSI, band 4 and band 8 represented Red and NIR bands (Tucker, 1979). Factors like strong reflectance in NIR and strong absorption in Visible Red of specific vegetation distinguish the vegetation from bare soil. NDVI for a given pixel can always output in a number that ranges from - 1 to +1; however, for natural surfaces NDVI values are within the 0 to +1 range. Negative values of NDVI i.e. values approaching -1 correspond to water. An NDVI close to 0 corresponds to no vegetation, while Values between -0.1 to 0.1 generally correspond to barren areas of rock, sand or snow.

### **Maize yield estimation by satellite-based remote sensing technique**

The red band and NIR of the calibrated images were selected from each dataset and exported into QGIS 2.18.13. A simple raster calculation was done by QGIS 2.18.13 using Equation 1 to find the NDVI images. Finally, the NDVI images were

masked using the shape file from the study area. The field points of the location were imported, and the mean NDVI values for each point were extracted from the satellite image considering a  $3 \times 3$  matrix surrounded by each point on the image.

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

### **Yield prediction model**

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

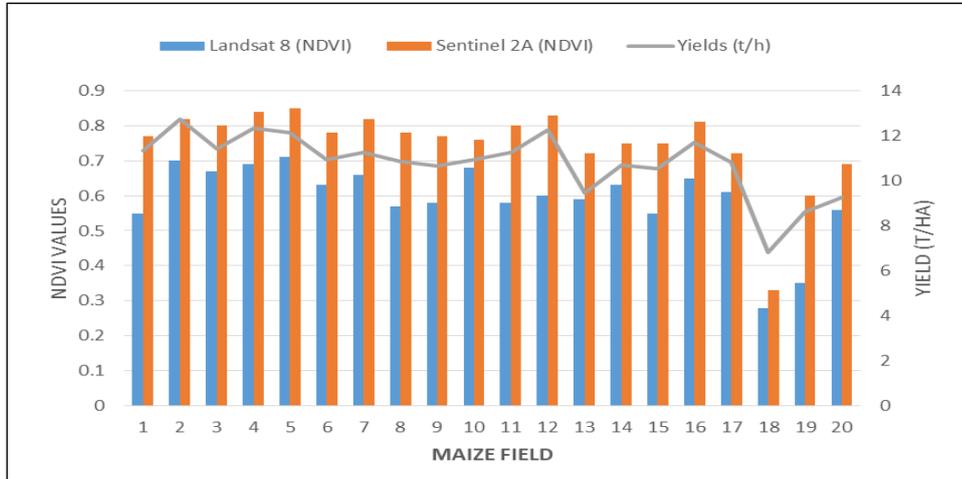
$$y = f(x) \quad (2)$$

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

## **Results and Discussion**

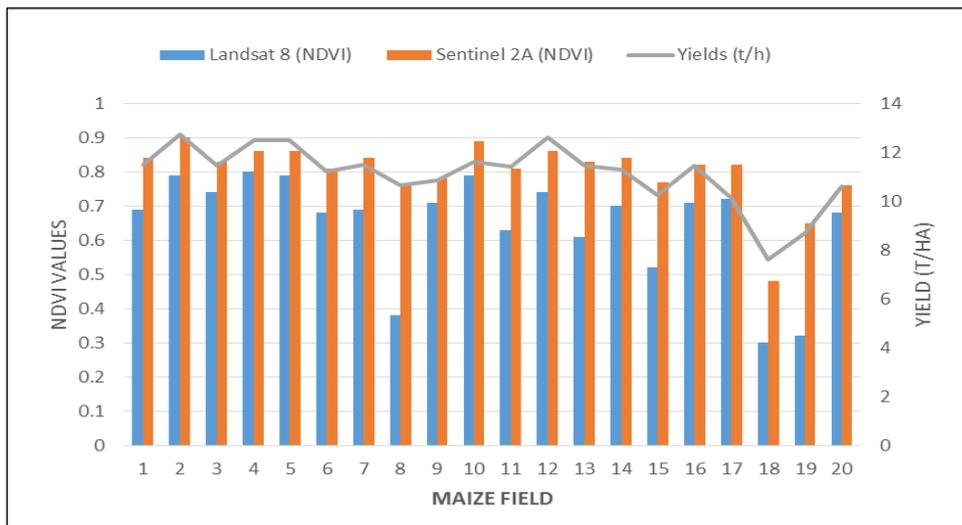
### **Maize yield from farmers' field and corresponding NDVI values for different locations**

Maize yield data and NDVI values from different date satellite images of Landsat 8 and Sentinel 2A for corresponding farmers' fields have been collected from Kaharole Upazila during the maize growing season 2018-19 and 2019-20 respectively. Twenty farmers' field yield data collected from study area and their corresponding NDVI values for two satellite images have been presented in Figure 3 and 4 for consecutive maize growing seasons 2018-19 and 2019-20 respectively.



**Fig. 3. NDVI values of satellite images and yields of corresponding Farmer’s fields at Kaharole, Dinajpur during the season of 2018-19**

Figure 3 shows that NDVI values are 0.71 and 0.85 which were the highest for Landsat 8 and Sentinel 2A and the yield was 12.12 t/ha for farmer’s field 5 but the yield is a maximum of 12.72 t/ha for field 2; NDVI values are 0.28 and 0.33 that were the lowest and yield was 6.8 t/ha for farmer’s field 18 during 2018-19.

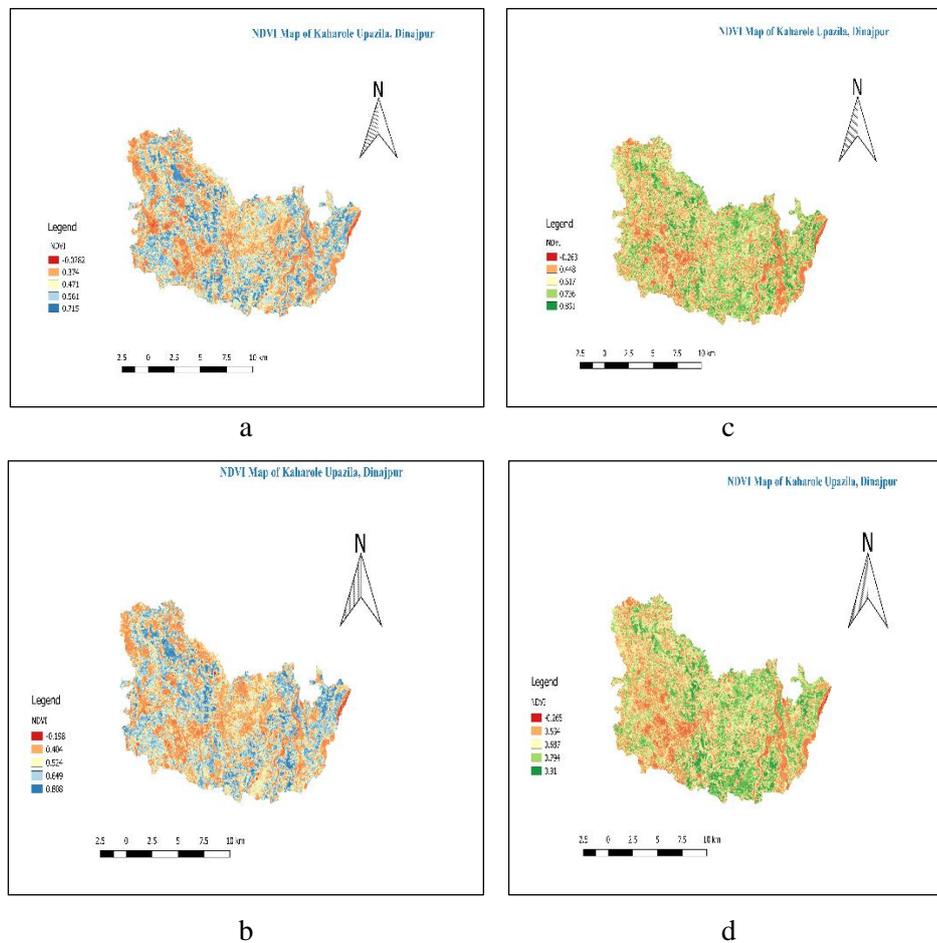


**Fig. 4. NDVI values of satellite images and yields of corresponding Farmer’s fields at Kaharole, Dinajpur during the season of 2019-20**

Maximum NDVI for Kaharole were 0.80 and 0.90 for farmer’s field 4 and 2 and minimum NDVI were 0.30 and 0.48 for Landsat 8 and Sentinel 2A for farmer’s field 18, but the highest and lowest yield were 12.74 t/ha and 7.6 t/ha for farmer’s field 2 and 18, respectively during 2019-20 in Figure 4.

### Regression analysis of the NDVI values over the field locations

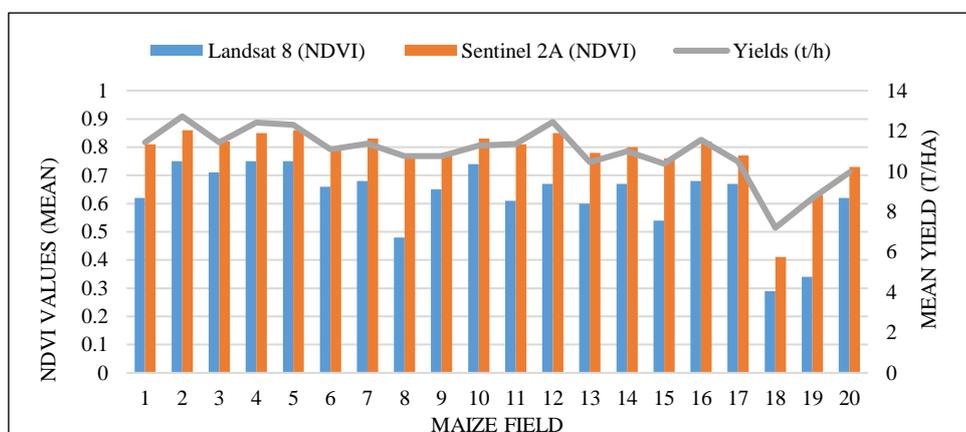
A total of four satellite images (2 images each for Landsat 8 and Sentinel 2A) from two growing seasons during 2018-2019 and 2019-2020 were selected. Based on available images, those sowing the maximum NDVI in each growing season were found 95th, and 97th days after plantation for Kaharole Upazila from Landsat 8 images as well as 101th, and 105th days after plantation for Kaharole upazila from Sentinel 2A images for 2018-2019 and 2019-2020 growing seasons, respectively. The spatial distribution of the NDVI varies from year to year. Spatial distribution of the NDVI over the selected location for selected distinct satellite images against different growing seasons is presented in Figure 5.



**Fig. 5.** Spatial distribution of the NDVI for different satellite images during the growing season 2018-19 and 2019-20. a. 95th days after plantation during 2018-19; b. 97th days after plantation during 2019-20 for Landsat 8; c. 101th days after plantation during 2018-19; d. 105th days after plantation during 2019-20 for Sentinel 2A at Kaharole Upazila.

For Landsat 8 data, NDVI distribution was maximum during 2019-2020 and distribution was minimum during the season 2019-20 at Kaharole Upazila in Figure 3. On the other hand, for Sentinel 2A data, NDVI distribution was maximum during the season 2019-2020 and minimum during the season 2019-20 at Kaharole Upazila in Figure 5. The NDVI distribution from different locations of Sentinel 2A data is outperformed Landsat 8 data during the maize growing season 2018-2019 and 2019-2020, respectively in Figure 5.

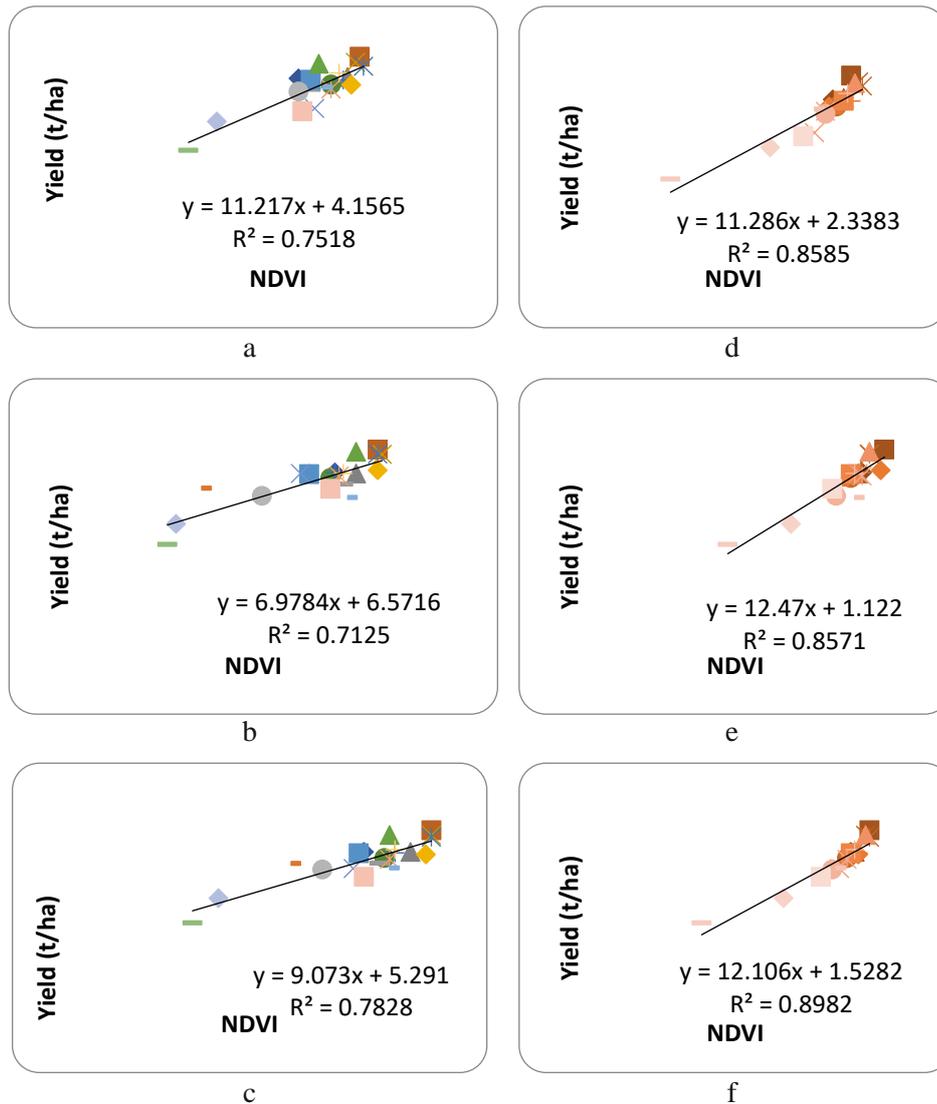
For two satellites viz., Landsat 8 and Sentinel 2A, the NDVI values and their corresponding yields for twenty farmers' maize field from different locations i.e., Kaharole Upazila during individual maize growing season 2018-2019 and 2019-2020, respectively are shown in Figure 3 and 4. From Figure 3 and 4, the mean NDVI and mean yield for two satellite data, Landsat 8 and Sentinel 2A for this location during the combined season 2018-2019 and 2019-2020 respectively were calculated which are represented below in Figure 6. Mean NDVI and mean yield are calculated for two satellite images for combined two season because maize yield in each season i.e., 2018-19 and 2019-20 is mostly the same for this location. Mean NDVI and mean yield of combined maize season performed better than NDVI and its corresponding yield of individual maize season for each satellite image in this location because according to best model criteria viz. Multiple determination of coefficient ( $R^2$ ), Mean Absolute Percentage Error (MAPE), Normalized Root Mean Square Error (NRMSE) and Root Mean Square Error (RMSE) fitted best for mean NDVI and mean yield of the combined maize season rather than single maize growing seasons like 2018-19 and 2019-20 (Figure 5). Mean NDVI is the largest which is 0.75 for farmers' field 2, 4 and 5 as well as the smallest is 0.29 for farmers' field 18 for Landsat 8 and for Sentinel 2A, the largest and lowest are 0.86 and 0.41 for farmers' field 2, 5 and 18 for Kaharole Upazila for the combined year respectively. The highest and lowest mean yields of the two satellite data is 12.73 (t/ha) and 7.2 (t/ha) for this Upazila for the combined year respectively in Figure 6.



**Fig. 6. Mean NDVI values for two satellite images and corresponding mean yields of Farmer's Maize Fields at Kaharole, Dinajpur during the combined season of 2018-19 and 2019-20**

### Maize yield and NDVI relationship using regression model

Regression analysis of maize yield against the single season basis NDVI and combined season basis mean NDVI for Kaharole was performed for two satellite images, Landsat 8 and Sentinel 2A, and are graphically presented in Figure 7.



**Fig. 7.** Yield prediction model established from regression analysis between yield data collected from 20 farmers' maize fields for different images; [a. yield vs NDVI, 2018-19 b. yield vs NDVI, 2019-20 c. yield vs NDVI (mean), combined 2018-19 and 2019-20 for Landsat 8.]; [d. yield vs NDVI, 2018-19 e. yield vs NDVI, 2019-20 f. yield vs NDVI (mean), combined 2018-19 and 2019-20 for Sentinel 2A] at Kaharole Upazila.

The yield vs. NDVI relationship for Landsat 8 and Sentinel 2A satellite image are shown in Figure 7 revealing that  $R^2$  which are highest and other accuracy criterion like MAPE, RMSE and NRMSE of mean NDVI for combined maize growing season i.e., 2018-2019 and 2019-2020 is better fitted than the single maize growing season i.e., 2018-2019 and 2019-2020, respectively for the selected location. The parameters of the regression analysis estimated from the yield vs. NDVI relationship for the combined season, together with the value of  $R^2$ , MAPE, RMSE and NRMSE are presented in Table 2. The relationship between mean NDVI for the combined two maize growing seasons and yield is provided almost well compared to the single-season basis NDVI vs. yield relationship for two satellite images.

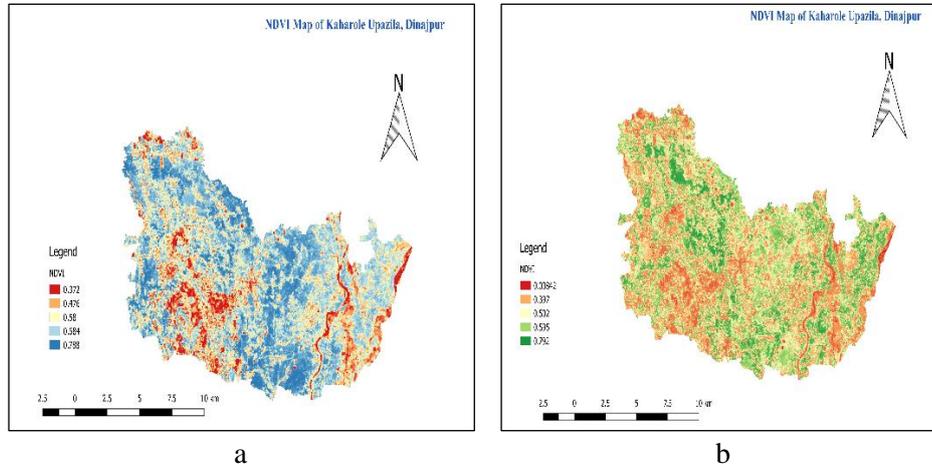
**Table 2. Regression parameter and model criterion for the combined season at Farmers’ maize field**

Location	Satellite Data	Regression parameter for mean value				Best Model Criteria			
		$\beta_0$	$\beta_1$	SE( $\beta_1$ )	P-Value	MAPE	RMSE	NRMSE	$R^2$
Kaharole	Landsat 8	5.291	9.073	1.126	0.0000	0.046	0.589	5.37	0.782
	Sentinel 2A	1.528	12.10	0.961	0.0000	0.031	0.403	3.68	0.898

Here, the regression coefficients of all the fitted model of two satellite images are show a highly significant effect for Kaharole upazila in Table 2. Multiple determination of coefficient ( $R^2=0.898$ ) along with MAPE (0.031), RMSE (0.403) and NRMSE (3.68) are performed better for Sentinel 2A satellite image than Landsat 8 satellite image for Kaharole Upazila, Dinajpur that are shown in Table 2.

**Development and validation of the yield prediction model**

The yield prediction model based on the regression analysis was developed based on the yield data collected from the 2018–2019 and 2019–2020 maize growing season. To evaluate the performance of the model validation is essential. Based on the deviation from the estimated and model prediction, model performance can be determined. Hence, the model has been further validated using yield data for the 2020-2021 maize growing seasons. After 103rd and 93rd days after plantation, an NDVI image was selected for two satellite images viz., Landsat 8 and Sentinel 2A from the 2020 to 2021 growing season at Kaharole Upazila, Dinajpur in Figure 8.



**Fig. 8.** Spatial distribution of the NDVI over the different locations for Landsat 8 and Sentinel 2A satellite images during the growing season of 2020-2021. (a+b): 103rd and 93rd days after plantation for Kaharole Upazila, Dinajpur for different satellite images.

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

$$\text{Yield} = \beta_0 + \beta_1 * \text{NDVI}_{\text{mean (Combined maize growing season)}} \quad (3)$$

$$\text{For Landsat 8: Yield} = 5.291 + 9.073 * \text{NDVI}_{\text{mean (Combined maize growing season)}} \quad (4)$$

$$\text{For Sentinel 2A: Yield} = 1.528 + 12.10 * \text{NDVI}_{\text{mean (Combined maize growing season)}} \quad (5)$$

The actual yield (t/ha) of maize and predicted yield (t/ha) using equations 4 and 5 for two different satellite images for Kaharole Upazila during the 2020-2021 maize growing season were also presented in Table 3.

**Table 3. Estimated yield and predicted yield from selected Farmer's Maize Fields at Kaharole, Dinajpur during the season of 2020-2021**

Farmer's Field	Actual Yield(t/ha)	NDVI Values		Predicted Yield (t/ha)		Error of Yield (%)	
		Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A
1	11.25	0.53	0.73	10.1	10.36	10.22	7.91
2	11.65	0.57	0.74	10.46	10.48	10.21	10.04
3	11.95	0.61	0.77	10.82	10.85	9.46	9.20
4	12.55	0.67	0.78	11.37	10.97	9.40	12.59
5	11.53	0.53	0.71	10.09	10.12	12.49	12.23
6	10.67	0.44	0.66	9.28	9.51	13.02	10.87
7	12.37	0.61	0.77	10.83	10.85	12.44	12.28
8	12.2	0.6	0.77	10.73	10.85	12.04	11.06
9	12.15	0.61	0.77	10.83	10.85	10.86	10.69
10	10.89	0.52	0.75	10.01	10.6	8.08	2.66
11	12.35	0.58	0.76	10.55	10.72	14.57	13.19
12	10.35	0.48	0.69	9.64	9.88	6.85	4.54
13	10.87	0.5	0.71	9.83	10.12	9.56	6.89
14	11.42	0.58	0.76	10.55	10.72	7.61	6.12
15	11.1	0.44	0.67	9.28	9.64	16.39	13.15
16	11.25	0.54	0.72	10.19	10.24	9.42	8.97
17	10.34	0.41	0.65	9.01	9.39	12.86	9.18
18	9.1	0.39	0.62	8.82	9.03	3.07	0.77
19	9.5	0.43	0.64	9.19	9.27	3.26	2.42
20	11.04	0.54	0.72	10.19	10.24	7.69	7.25

The highest and lowest observed yield of maize were 12.55 (t/ha) and 9.1 (t/ha) as well as maximum and minimum NDVI values were 0.67 and 0.39 for Landsat 8; 0.78 and 0.62 for Sentinel 2A for farmers' field 4 and 18 respectively during the maize growing season 2020-2021 (Table 3). Largest and smallest predicted yield of maize for Landsat 8 were 11.37 (t/ha) and 8.82 (t/ha) as well as for Sentinel 2A these were 10.97 (t/ha) and 9.03 (t/ha) for farmers' field 4 and 18 respectively during the maize growing season 2020-2021 (Table 3). Maximum and minimum yield gap (%) for Landsat 8 were 16.39 and 3.07 for farmers' field 15 and 18 respectively and also for Sentinel 2A were 13.19 and 0.77 for farmers' field 11 and 18 respectively in selected areas during the maize growing season 2020-2021 (Table 3). The predicted yield of maize for two satellite data was less than the actual yield of maize (under estimated) in each farmer's field for the study areas

are shown in Table 3. Depending on the value of Table 3, the validation of maize yield for two satellite images viz., Landsat 8 and Sentinel 2A was presented in Table 4 during the maize season 2020-2021.

**Table 4. Validation of maize yield during the season 2020-2021**

Location	Actual Yield (Mean)	Predicted Yield (Mean)		Mean Error of Yield (%)	
		Landsat 8	Sentinel 2A	Landsat 8	Sentinel 2A
Kaharole, Dinajpur	11.23	10.09	10.23	10.15	8.82

The estimated farmers' field yield (mean) was 11.23 (t/ha) and the predicted yield (mean) for Landsat 8 and Sentinel 2A were 10.09 (t/ha) and 10.23 (t/ha) respectively in this study areas during the maize growing season 2020-2021. The percentage of mean yield error was 10.15 for Landsat 8 and 8.82 for Sentinel 2A. Error of mean yield (%) of Sentinel 2A was performed better than Landsat 8 during the maize growing season 2020-2021 (Table 4). In Bangladesh, a few researchers used satellite data to forecast the yield of some crops like potatoes, rice, wheat etc. but not for maize. The mean error of potato yield prediction was found 15% by using MODIS (~250m) data at Munshiganj (Bala *et al.*, 2009) and Newton *et al.* (2018) revealed that mean error of potato yield was 10.4% using Landsat 8 (~30m) satellite data at the same location. However, some researchers used the yield-NDVI relationship for maize yield prediction globally. Strong relationships ( $R^2$  from 0.77 to 0.84) were observed between NDVI and the grain yield of maize using RapidEye imagery satellite and promising results for yield prediction were found with a 5% error of estimation in Hungary (Bu *et al.*, 2017).

### Conclusion

The study has investigated the prediction capacity of remote sensing NDVI data for maize yield in selected locations viz. Kaharole Upazila, Dinajpur of Bangladesh. It has also investigated the relationship between NDVI and yield for the study region. Here the two satellite images Landsat 8 (OLI) and Sentinel 2A (MSI) which were high spatial resolution data were used in this study in the consecutive years 2018-19, 2019-20 and 2020-21 respectively. Mean NDVI and mean yield of combined maize season performed better than NDVI and its corresponding yield of single maize season for each satellite image and Kaharole Upazila. The yield prediction equations were found based on mean values of NDVI for the combined growing season against the yield of maize. The yield against NDVI relationship for both satellite images showed that  $R^2$  along with MAPE, RMSE and NRMSE of mean NDVI for the combined maize growing season performed better than the single maize growing season for the study area. The absolute mean error of prediction was found to be about 10.15% for Landsat 8 and

8.82% for Sentinel 2A compared to the actual yield during the maize growing season 2020-2021. The predicted yield (mean) of Sentinel 2A which is 1.33% closer to the actual yield than Landsat 8 was observed in this research. The yield prediction model for Sentinel 2A images performed better than the Landsat 8 because of the high spatial resolution (~10m) that was revealed in this study. It was found that NDVI data extracted from Sentinel 2A high resolution satellite images can be successfully used to predict the maize yield for the study area with appreciable accuracy. So, the high resolution Sentinel 2A images can be an effective means for early prediction of maize yield.

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## PERFORMANCE OF SELECTED SPINACH GERMPLASM AGAINST SALINITY UNDER POT CULTURE

R. KHATOON<sup>1</sup> AND M. MONIRUZZAMAN<sup>2</sup>

### Abstract

A pot experiment on spinach (*Spinacia oleracea* L.) genotypes was conducted against NaCl salt stress at the research field of Plant Physiology Section, HRC, BARI, Gazipur for three consecutive years (2016-17, 2017-18 and 2018-19) to find out salt tolerant genotypes at vegetative stage. In 2016-17 eight genotypes (SO-0046, SO-0047, SO-0048, BD-4323, BD-4333, BD-4339, BD-1062 and BARI Palongshak-1) and in 2017-18 seven genotypes (SO-0047, SO-0048, BD-4323, BD-4333, BD-4339, BD-1062 and BARI Palongshak-1) were tested against four varying levels of salinity viz. control, 4, 8 and 12 dS/m in pot. In 2018-19, two selected genotypes viz. SO-0047, SO-0048 and BARI Palongshak-1 which performed best in the previous years were examined against control (tap water), 8 and 12 dS/m in pot. The genotypes showed significant variation in plant height, number of leaves/plant, leaf length, leaf width, SPAD value, total dry matter/plant and leaf yield/pot. Among the genotypes, SO-0047 performed better at 8 and 12 dS/m in respect of all the characters studied followed by SO-0048. Therefore, it can be inferred that the genotype SO-0047 is relatively salt tolerant and can be recommended as a variety for cultivation in saline area of Bangladesh and SO-0048 might be used for breeding purpose to develop salt tolerant variety of spinach.

Keywords: Spinach (*Spinacia oleracea* L.), salinity, growth, SPAD value, tolerant.

### Introduction

Among the abiotic stresses, drought, salinity, extreme temperatures, chemical pollutants, nutritional deficiency, and oxidative stress are the foremost abiotic stresses that reduce the global productivity of major crops (Kaushal and Wani, 2016; Singh *et al.*, 2018). Both stresses can reduce several morphological, physiological, biochemical, and metabolic alterations through various mechanisms, eventually influencing plant growth, development, and productivity. Salinity along with drought is one of the leading abiotic stresses in agriculture which foster growth retardation, physiological abnormalities, and lower production output of field crops throughout the world (Majeed and Muhammad, 2019). Out of 2.85 million hectares of the coastal and off shore areas about 1.00 million hectares are arable lands, which cover over 30% of the total cultivable lands of Bangladesh (Haque, 2006). Salinity intrusion is an increasing problem in the coastal areas of Bangladesh (Mahmuduzzaman *et al.*, 2014). Climate change

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<sup>1</sup>Senior Scientific Officer, Plant Physiology Section, HRC, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh, <sup>2</sup>Chief Scientific Officer, Planning and Evaluation Wing, BARI, Gazipur, Bangladesh.

and its associated hazards like cyclone, sea level rise, and storm surge have been increasing the salinity problem in many folds. Salinity in the country received very little attention in the past.

Spinach (*Spinacia oleracea* L) in an annual herb belongs to the family Chenopodiaceae. It is locally known as 'palongshak' which is one of the most important winter leafy vegetables commercially grown in Bangladesh. It is a good source of minerals (iron, copper, phosphorous, zinc, selenium), vitamin B complex and is a relatively quick-growing vegetable (Roughani and Mri, 2019). It was found that spinach was considerably more salt tolerant under cool season late winter conditions than under warmer climatic conditions (Ors and Suarez, 2016). Among different abiotic stresses, soil or water salinity is the major constraint in reducing vegetable growth and productivity in many vegetable producing areas of the world (Machado and Serralheiro, 2017). Most work on spinach has focused on cultural practices (e.g., irrigation), fertilization, cultivars, and their effect of growth, biomass accumulation (Nemadodzi *et al.*, 2017) and the nutritional value of the crop irrigated with low-salinity water. In contrast, recent studies report no significant loss in spinach yield and nutritional value with saline water levels up to 9 dS m<sup>-1</sup> (Ors and Suarez, 2016; Ferreira *et al.*, 2018). In another study, spinach yield was increased at EC levels of 4 and 7 dS m<sup>-1</sup> and subsequently declined at EC 9.0 dS m<sup>-1</sup> and above (Ors and Suarez, 2017). In a recent study, Ferreira *et al.* (2020) suggested that the threshold level of EC for spinach was between 7 to 10 dS m<sup>-1</sup> for water salinity and from 5.6 to 8.9 dS m<sup>-1</sup> for soil salinity. Little effort has been made where the impact of saline water on spinach crop (*Spinacia oleracea* L.) and potential salt-tolerant spinach cultivars are identified (Turhan *et al.*, 2011, 2013). Screening of different genotypes against salinity is one of the accepted methods to select genotypes for saline soil. Therefore, this experiment was carried out to find out the salt-tolerant spinach genotypes.

### Materials and Methods

The experiment was conducted at the research field of Plant Physiology Section, Horticulture Research Center, Bangladesh Agricultural Research Institute (BARI) (23.99297 N, 90.41227 E) during three consecutive years of 2016-17, 2017-18 and 2018-19. Eight genotypes of spinach (SO-0046, SO-0047, SO-0048, BD-4323, BD-4333, BD-4339, BD-1062, and BARI Palongshak-1) were screened out of 21 germplasm which were collected from Olericulture Division of Horticulture Research Centre and Plant Genetic Resources Centre, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur were used in the study during 2016-17 and 2017-18 against four NaCl concentrations (control, 4 dS/m, 8 dS/m, 12 dS/m). In 2018-19, the selected three genotypes SO0047, SO0048 and BARI Palongshak-1 were studied against three NaCl concentrations viz; control (tap water), 8 dS/m and 12 dS/m. The average values of three years of SPAD, plant dry weight and leaf yield were presented graphically. Soil salinity was measured during experimental periods at two days intervals by soil EC Meter (HI 9833, direct soil

conductivity & temperature meter, HANNA instruments) and EC Meter (Model 6061, Made in Taiwan). The study was evaluated under Randomized Complete Block Design (RCBD) with three replications. Spinach was grown in plastic pot (height 25 cm, dia 25 cm at the top and 12.5 cm at the bottom; capacity 10 L) in every year which contained around 10 kg air dried soil collected from Kodda, Kaliakoir, Upazilla, Gazipur district. Fertilizers were applied to each pot @ Urea 2.25 g, TSP 1.5 g, MOP 1.70 g, Gypsum 1.5 g and Boric Acid 1.0 g during pot filling with air dried soil (7.5 % moisture). Weeding was done as per requirements. In each pot, 10 seeds were sown on 1<sup>st</sup> week of December in every year. The seedlings were emerged within 6-7 days after sowing. The pots used five small holes at the bottom where some pieces of broken bricks kept and the brick pieces were covered with a small piece of mosquito net. Initial soil properties of pot soil are Sand 40.22%, Silt 29.64%, Clay 3.45%, Texture- clay loam pH-6.12, Organic carbon 1.60%, Total nitrogen 0.56%, Available P 1.18 (mg /100g dry soil), Exchangeable K 0.25 (meq/100g dry soil) and CEC 14.60 (meq/100g dry soil). Thinning of seedling was done at 15 days after sowing by keeping five plants in each pot. Salinity treatment was imposed at 4 leaf stage at 25 days after sowing. Salt solution was prepared by dissolving calculated amount of commercially available NaCl with tap water. The salt solution was applied with an increment of 2.5 dS/m in every alternate day till respective salinity level was attained. Treatment solution was applied in excess so that the extra solution dripped from the bottom of the pots. The root and shoot sample were collected prior to harvest. The collected sample was oven dried at 72°C, for 1 week. For root sampling, plastic pots were soaked in water, soil was washed with water and the roots were recovered by passing the soil water suspension through a 2 mm mesh sieve. Electrical conductivity of the top pot soil at different time after the treatment imposition during 2016-2019 (mean value of 2016-2017, 2017-2018 and 2018-2019) are given in Table 1. Data on plant height, number of leaves/plant, leaf length of the biggest leaf, leaf width of the biggest leaf, SPAD value, dry weight of plant, leaf yield (g/pot) were recorded. SPAD value was recorded by SPAD meter (502 plus, Konika, Minolta, Japan). All the recorded data were analyzed with the help of R-software and mean separation was done by least significant different (LSD) test at 5% level of probability.

**Table 1. Electrical conductivity of the top pot soil at different time after the treatment imposition at two days interval (mean value).**

Treatment	Electrical conductivity (dS/m) at different days after sowing												
	1	3	5	7	9	11	13	15	17	19	21	23	25
Control	0.34	0.33	0.43	0.28	0.34	0.33	0.34	0.33	0.38	0.37	0.33	0.33	0.34
4 dS/m	1.87	2.36	3.90	3.80	3.74	4.00	3.67	4.00	3.80	3.90	3.64	4.20	4.22
8 dS/m	3.48	3.55	4.50	4.88	4.67	5.25	4.80	6.10	6.80	6.80	7.30	7.55	7.80
12 dS/m	5.55	5.83	6.63	6.80	8.00	8.50	9.00	10.8	10.00	10.50	10.28	10.45	10.53

## Results and Discussion

### *Plant height*

In the present investigation, plant height of all the genotypes decreased with the increased levels of salinity over the years, however there exist variability among the genotypes. In 2016-2017, plant height of eight genotypes under control and different levels of salinity is shown in Table 2. Significant variation among the genotypes was observed in plant height. The maximum plant height was found in SO-0047 (24.87 cm) followed by SO-0048 (22.86 cm), BARI Palongshak-1 (22.80 cm) at control treatment. At 4 dS/m, SO-0047 produced the maximum plant height (22.33 cm) followed by BARI Palongshak-1 (21.67 cm), SO-0048 (21.43 cm) and the shortest by the genotype BD-4333 (6.80 cm). At 8 dS/m, SO-0047 produced the tallest plant (15.67 cm) and the shortest by BD-4339 (5.10 cm). At 12 dS/m, the genotype SO-0047 also produced the maximum plant height (11.13 cm) followed by SO-0048 (10.47 cm) and BARI Palongshak-1 (10.00 cm) and the shortest by the genotype BD-4339 (5.03 cm).

Significant variation among the genotypes was also observed in plant height during 2017-2018 (Table 2). The maximum plant height was found in SO-0047 (24.26 cm) followed by BARI Palongshak-1 (22.54 cm), SO-0048 (22.38 cm) and minimum by BD-4339 (12.38 cm) in control treatment. At 4 dS/m, SO-0047 also produced the maximum plant (22.63 cm) followed by SO-0048 (20.57 cm), BARI Palongshak-1 (20.71 cm) and the minimum by BD-4339 (9.48 cm). At 8 dS/m, SO-0047 also produced the maximum plant (15.62 cm) followed by SO-0048 (13.43 cm) and BARI Palongshak-1 (13.52 cm) and the shortest by BD-4323 (6.75 cm). At 12 dS/m, the genotype SO-0047 also produced the maximum plant (11.35 cm) followed by SO-0048, (10.59 cm) BARI Palongshak-1 (10.27 cm) and the minimum plant was obtained from BD-4339 (5.31 cm).

Significant variation among the genotypes was observed in plant height during 2018-2019 (Table 2). The maximum plant height was found in SO-0048 (23.30 cm) which was statistically similar to BARI Palongshak-1 (23.01 cm), SO-0047 (23.25 cm) in control treatment. At 8 dS/m, SO-0047 produced the tallest plant (16.99 cm), which was identical with SO-0048 (16.21 cm) and the shortest by BARI Palongshak-1 (15.29 cm). At 12 dS/m, the genotype SO-0047 also produced the tallest plant (13.36 cm) followed by SO-0048 (12.34 cm) and the shortest by BARI Palongshak-1 (11.29 cm). Bhatti *et al.*, 2021 reported that the growth and yield parameters of spinach genotypes were constantly decreased with an increase in EC levels of irrigation water. Ors and Suarez (2016) studied spinach (cv. Racoon) response under saline water treatments and reported that higher salinity decreased shoot height of the plant.

Table 2. Effect of different levels of salinity on plant height of spinach genotypes

Genotypes	2016-2017						2017-2018						2018-2019					
	Plant height (cm)						Plant height (cm)						Plant height (cm)					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	12	Control	4	8	12	Control	4	8	12	Control	4	8	12		
SO-0046	22.06	21.00	9.17	8.90	-	-	-	-	-	-	-	-	-	-	-	-		
SO-0047	24.87	22.33	15.67	11.13	24.26	22.63	15.62	11.35	23.25	16.99	13.36	23.30	16.21	12.34	12.34	12.34		
SO-0048	22.86	21.43	10.84	10.47	22.38	20.57	13.43	10.59	23.30	16.21	12.34	23.30	16.21	12.34	12.34	12.34		
BD-4323	12.60	11.13	5.37	5.20	12.46	10.48	6.75	5.59	-	-	-	-	-	-	-	-		
BD-4333	19.05	6.80	6.10	5.36	16.38	12.73	6.76	5.59	-	-	-	-	-	-	-	-		
BD-4339	9.90	9.47	5.10	5.03	12.38	9.48	7.46	5.31	-	-	-	-	-	-	-	-		
BD-1062	17.93	12.46	8.27	8.13	15.59	12.47	8.62	6.69	-	-	-	-	-	-	-	-		
BARI Palongshak-1	22.80	21.67	10.93	10.00	22.54	20.71	13.32	10.27	23.01	15.29	11.29	23.01	15.29	11.29	11.29	11.29		
CV (%)	11.26						2.24						3.24					
LSD (0.05)	2.38						2.27						1.38					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19.

### *Number of leaves/plant*

Number of leaves/plant of eight genotypes in 2016-2017 under control and different levels of salinity is shown in Table 3. In control treatment, number of leaves/plant was found maximum in SO-0047 (15.20) followed by SO-0048 (14.97), BARI Palongshak-1 (14.92) and the lowest number of leaves/plant was found in BD-4333 (11.25). At 4 dS/m, SO-0047 also produced the maximum number of leaves/plant (13.69) which was statistically similar to SO-0048 (13.54), BARI Palongshak-1 (13.48 cm) and BD-4333 produced the least number of leaves/plant (8.58). At 8 dS/m, SO-0047 produced the maximum leaves/plant (8.85) which was statistically identical to SO-0046 (8.84), SO-0048 (8.84) and BARI Palongshak-1 (8.80). But at 12 dS/m, maximum number of leaves/plant was obtained from the genotype SO-0047 (7.84) followed by SO-0048 (7.80) and minimum leaves/plant (5.25) was obtained from BD-4333 and BD-4339 genotypes.

In 2017-2018, number of leave/plant of seven genotypes under control and different levels of salinity is shown in Table 3. Number of leaves/plant was found maximum in SO-0047 (14.67) followed by SO-0047 (14.60), BARI Spinach-1 (14.52) and minimum number of leaves/plant (11.25) was obtained from BD-4333 in control treatment. At 4 dS/m, SO-0047 also produced the maximum number of leaves/plant (12.93) followed by SO-0048 (12.86), BARI Palongshak-1 (12.86) and BD-4323 produced the least number of leaves/plant (9.25). At 8 dS/m, SO-0047 also produced the maximum number of leaves/plant (12.25) and minimum (5.67) was found in BD-1062. At 12 dS/m, maximum number of leaves/plant was also obtained from the line SO-0047 (8.93) followed SO-0048 (8.93), BARI Palongshak-1 (8.87) and the minimum number of leaves/plant (5.31) was obtained from BD-1062. The genotype SO0048 and BARI Palongshak-1 also did not differ significantly in terms of number of leaves/plant at 12 dS/m salinity level.

Performance of three genotypes in respect of number of leaves/plant in 2018-2019 under control and different levels of salinity are shown in Table 3. Maximum number of leaves/per plant was found in SO0047 (14.84) followed by SO-0048 (14.80) and BARI palongshak-1 (14.31), but there was no significant difference among them in control treatment. At 8 dS/m, SO-0047 also produced the maximum number of leaves/plant (11.08) followed by SO0048 (10.57) and BARI Palongshak-1 produced the least number of leaves/plant (8.63). At 12 dS/m, maximum number of leaves/plant was obtained from the line SO-0047 (10.31) followed by SO0048 (9.93) and minimum was obtained from BARI Palongshak-1 (7.51). The growth and yield parameters of spinach plants were decreased with increasing EC levels of saline water. The decline in growth and yield parameters in spinach genotypes may be attributed to many factors including lowering of water potential by the salts (Flowers and Flowers, 2005). Bhatti *et al.*, (2021) reported that the plants irrigated with EC 6.0 and 8.0 dS/m had less number of leaves than the plants that were irrigated with canal water.

**Table 3. Effect of different levels of salinity on number of leaves/plant of spinach genotypes**

Genotypes	2016-2017						2017-2018						2018-2019						
	Number of leaves/plant						Number of leaves/plant						Number of leaves/plant						
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)						
	Control	4	8	8	12	12	Control	4	8	8	12	12	Control	4	8	8	12	12	
SO-0046	11.65	10.25	8.84	8.84	6.80	6.80	-	-	-	-	-	-	-	-	-	-	-	-	
SO-0047	15.20	13.69	8.85	8.85	7.84	7.84	14.67	12.93	12.25	12.25	8.93	14.84	14.84	11.08	11.08	10.31	10.31	10.31	
SO-0048	14.97	13.54	8.84	8.84	7.80	7.80	14.60	12.86	11.26	11.26	8.93	14.80	14.80	10.57	10.57	9.93	9.93	9.93	
BD-4323	11.42	9.25	7.25	7.25	6.48	6.48	11.33	9.25	7.25	7.25	6.85	-	-	-	-	-	-	-	-
BD-4333	11.25	8.58	6.25	6.25	5.25	5.25	11.25	8.27	6.93	6.93	6.51	-	-	-	-	-	-	-	-
BD-4339	12.52	9.65	6.93	6.93	5.25	5.25	12.33	9.80	6.82	6.82	5.63	-	-	-	-	-	-	-	-
BD-1062	12.93	9.65	7.25	7.25	6.47	6.47	12.33	9.25	5.67	5.67	5.31	-	-	-	-	-	-	-	-
BARI Palongshak-1	14.92	13.48	8.80	8.80	6.84	6.84	14.52	12.86	10.00	10.00	8.87	14.31	14.31	8.63	8.63	7.51	7.51	7.51	7.51
CV (%)	3.70						2.12						7.24						
LSD (0.05)	0.29						0.17						0.65						

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19.

### ***Leaf length and leaf width***

There was significant variation in leaf length and leaf width among the genotypes under control and saline condition in 2016-2017 (Table 4 and 5). The maximum leaf length was obtained from SO-0047 (25.75 cm) followed by SO-0048 (25.47 cm) and the minimum from BD-4339 (15.06 cm) in control treatment. At 4 dS/m, SO-0047 also gave the maximum leaf length (21.81 cm) followed by SO-0048 (21.50 cm) and the lowest in BD-4339 (8.36 cm). At 8 dS/m, SO-0047 again gave the highest leaf length (19.11 cm) and the lowest in BD-4339 (6.95 cm). At 12 dS/m, the maximum leaf length (17.57 cm) was obtained from SO-0047 and the lowest (5.38 cm) in BD-4323. The maximum leaf width (10.63 cm) was obtained from SO-0046 followed by SO-0047 (10.59 cm) and the minimum (5.66 cm) from BD-4339 at control treatment. At 4 dS/m, SO-0047 gave the maximum leaf width (9.54 cm) followed by SO-0048 (9.18 cm) and the lowest (5.16 cm) was obtained from BD-4333. At 8 dS/m, SO-0047 gave the maximum leaf width (7.85 cm) closely followed by SO-0048 (7.54 cm), BARI Palongshak-1. (7.50 cm) and the lowest (3.33 cm) in BD-1062. At 12 dS/m, SO-0047 also gave the highest leaf width (7.24 cm) and the lowest (2.21 cm) from the genotype BD-4323.

In 2017-2018, the maximum leaf length (24.28 cm) was obtained from SO-0047 followed by SO-0048 (24.24 cm) and the minimum (16.36 cm) from BD-4339 in control treatment (Table 4). At 4 dS/m, SO-0047 gave the highest leaf length (22.65 cm) followed by SO-0048 (22.37 cm) and the lowest (8.28 cm) from the genotype BD-4339. At 8 dS/m salinity level, SO-0048 gave the maximum leaf length (18.33 cm) followed by SO-0047 (18.28 cm) and the lowest (5.85 cm) was recorded from BD-4323. At 12 dS/m, SO-0047 gave the highest leaf length (17.52 cm) and the lowest (5.24 cm) was recorded from BD-4323. The maximum leaf width (9.68 cm) was obtained from SO-0047 followed by SO-0048 (9.57) and the minimum (6.03 cm) from BD-4339 in control treatment (Table 5). At 4 dS/m, SO-0047 gave the maximum leaf width (8.85 cm) followed by SO-0048 (8.83 cm) and the lowest (4.78 cm) in BD-4339. At 8 dS/m, BARI Palongshak-1 gave the maximum leaf width (7.77 cm) followed by SO-0047. (7.67 cm), SO-0048 (7.57 cm) and the lowest (3.28 cm) was recorded in BD-4339. At 12 dS/m, SO-0047 gave the maximum leaf width (7.25 cm) which was identical to SO-0048 (7.25 cm) and the lowest (2.22 cm) was recorded in BD-4339 (Table 5).

In 2018-2019, there was significant variation in leaf length and leaf width among the genotypes under control and saline conditions and these parameters decreased with the increasing salinity level up to 12 dS/m in all the genotypes (Table 4 and 5). Maximum leaf length was recorded from SO-0047 (24.66 cm) and the lowest from BARI Palongshak-1 (23.00 cm) at control. At 8 dS/m salinity level, the genotype SO-0047 gave maximum leaf length (22.09 cm) followed by SO-0048 (19.69 cm) and BARI Palongshak -1 produced the lowest leaf length (16.22 cm) At 12 dS/m, maximum leaf length (17.31 cm) was found in SO-0047 followed by BARI Palongshak-1 (14.34 cm) and minimum (13.07 cm) in SO-0048. There was

no significant difference among SO-0047, SO-0048 and BARI Palongshak-1 in leaf width in control treatment. At 8 dS/m, the genotype SO-0047 gave the highest leaf width (8.38 cm) and SO-0048 produced the lowest leaf width (7.11 cm). At 12 dS/m, maximum leaf width (8.27 cm) was found in SO-0047 and minimum (6.28 cm) in BARI Palongshak-1. Batti *et al.* (2021) reported that a significant decrease in growth, leaf length, width was observed when spinach plants were irrigated with saltwater of 8.0 dS m<sup>-1</sup> salinity level.

### ***SPAD value***

In 2016-2017, the maximum SPAD value (48.35) was obtained from SO-0047 followed by BARI Palongshak-1 (48.33) and the minimum (46.13) from the genotype BD-4339 in control treatment (Table. 6). At 4 dS/m salinity level, SO-0047 gave the highest SPAD value (51.49) and the lowest SPAD value (47.83) from the genotype BD-1062. At 8 dS/m, SO-0047 gave the highest SPAD value (53.97) and the lowest SPAD value (47.89) in BD-1062. At 12 dS/m, SO-0047, SO-0048 gave the highest SPAD value (46.96) and the lowest SPAD value (38.03) from the genotype BD-1062.

In 2017-2018, the maximum SPAD value (47.15) was obtained from SO-0047 followed by SO-0048 (47.14) and the minimum (45.05) from BD-4323 in control treatment (Table. 6). At 4 dS/m salinity level, SO-0047 gave the highest SPAD value (50.58) and the lowest SPAD value (45.84) was recorded in BD-4339. At 8 dS/m, SO-0047 gave the maximum SPAD value (55.44) followed by SO-0048 (55.28) and the lowest SPAD value (48.87) in the genotype BD-4323. At 12 dS/m, SO-0047 gave the maximum SPAD value (44.23) followed by SO-0048 (44.15) and the lowest SPAD value (37.25) in BD-1062.

In 2018-2019, the maximum SPAD value (48.75) was obtained from SO-0047 followed by SO-0048 (45.20) and the minimum (38.91) from BARI Palongshak-1 in control treatment (Table. 6). At 8 dS/m, SO-0048 gave the maximum t SPAD value (56.32) followed by SO-0047 (56.15) and the lowest SPAD value in BARI Palongshak-1 (45.09). At 12 dS/m, and SO-0048 gave the maximum SPAD value (50.98) followed by SO-0047 (50.05) and the lowest SPAD value (35.85) in BARI Palongshak-1.

In average SPAD value of three years, the maximum SPAD was obtained from SO-0047 (48.08) followed by SO-0048 (46.33) and the least from BARI Palongshak-1 (44.18) at control treatment (Figure 1). At 8 dS/m, the maximum SPAD value was recorded from SO-0047 (55.19) followed by SO-0048 (54.48) and minimum value (49.43) from BARI Palongshak-1. At 12 dS/m, the maximum SPAD value (47.36) was obtained from SO-0048 followed by SO-0047 (47.08) and minimum value (39.82) BARI Palongshak-1. Salinity treatment decreased chlorophyll content and increased chlorophyll content without salt stress (Xu and Mou, 2016). Spinach plants treated with saline irrigation water maintained their SPAD chlorophyll levels up to 8 dS/m, but high saline concentration it was decreased.

Table 4. Effect of different levels of salinity on leaf length of spinach genotypes

Genotypes	2016-2017						2017-2018						2018-2019					
	Leaf length (cm)						Leaf length (cm)						Leaf length (cm)					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	12	Control	4	8	12	Control	4	8	12	Control	4	8	12		
SO-0046	25.30	14.75	10.39	6.61	-	-	-	-	-	-	-	-	-	-	-	-		
SO-0047	25.75	21.81	19.11	17.57	24.28	22.65	18.28	17.52	24.66	22.09	17.31	24.66	22.09	17.31	24.66	17.31		
SO-0048	25.47	21.50	18.47	16.79	24.24	22.37	18.33	15.16	24.45	19.69	13.07	24.45	19.69	13.07	24.45	13.07		
BD-4323	22.21	17.39	6.33	5.38	21.16	17.82	5.85	5.24	-	-	-	-	-	-	-	-		
BD-4333	18.50	15.69	8.97	6.33	17.73	13.62	7.84	6.01	-	-	-	-	-	-	-	-		
BD-4339	15.06	8.36	6.95	6.26	16.36	8.28	6.14	5.84	-	-	-	-	-	-	-	-		
BD-1062	18.02	16.73	9.01	6.63	18.24	14.98	9.36	6.25	-	-	-	-	-	-	-	-		
BARI Palongshak-1	24.40	21.29	16.27	13.71	23.89	20.77	17.15	15.24	23.00	16.22	14.34	23.00	16.22	14.34	23.00	14.34		
CV (%)	2.81						2.54						5.78					
LSD (0.05) 0.33	0.31						0.31						4.17					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19

Table 5. Effect of different levels of salinity on leaf width of spinach genotypes

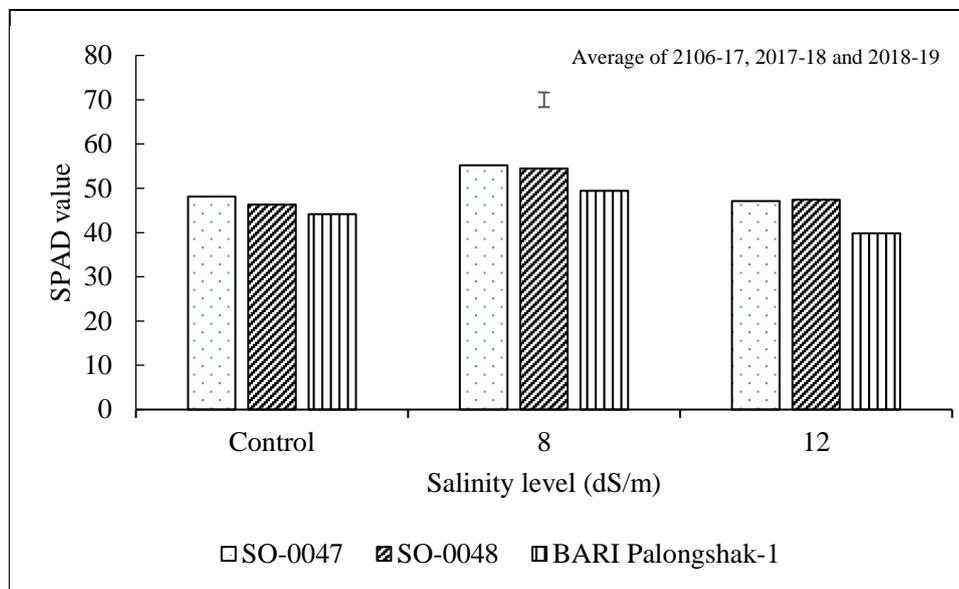
Genotypes	2016-2017						2017-2018						2018-2019					
	Leaf width (cm)						Leaf width (cm)						Leaf width (cm)					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	8	12	12	Control	4	8	8	12	12	Control	8	8	12		
SO-0046	10.63	6.90	3.20	3.20	2.54	2.54	-	-	-	-	-	-	-	-	-	-		
SO-0047	10.59	9.54	7.85	7.85	7.24	7.24	9.68	8.85	7.67	7.25	7.25	8.39	8.38	8.38	8.27	8.27		
SO-0048	8.74	9.18	7.54	7.54	6.67	6.67	9.57	8.83	7.57	7.25	7.25	7.82	7.11	7.11	6.55	6.55		
BD-4323	8.91	5.68	4.28	4.28	2.21	2.21	7.93	6.15	5.28	3.56	3.56	-	-	-	-	-		
BD-4333	6.96	5.16	4.60	4.60	3.35	3.35	6.42	5.24	4.33	3.18	3.18	-	-	-	-	-		
BD-4339	5.66	5.31	3.37	3.37	2.52	2.52	6.03	4.78	3.28	2.22	2.22	-	-	-	-	-		
BD-1062	7.94	6.67	3.33	3.33	2.28	2.28	8.07	7.16	4.16	2.23	2.23	-	-	-	-	-		
BARI Palongshak-1	8.91	8.89	7.50	7.50	5.83	5.83	8.15	7.86	7.77	6.25	6.25	7.78	7.34	7.34	6.28	6.28		
CV (%)	8.06						2.84						4.67					
LSD (0.05) 0.41	0.13						0.13						0.98					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19.

Table 6. Effect of different levels of salinity on SPAD value of spinach genotypes

Genotypes	2016-2017						2017-2018						2018-2019					
	SPAD value						SPAD value						SPAD value					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	12	Control	4	8	12	Control	4	8	12	Control	4	8	12		
SO-0046	47.56	48.78	49.17	38.41	-	-	-	-	-	-	-	-	-	-	-	-		
SO-0047	48.35	51.49	53.97	46.96	47.15	50.58	55.44	44.23	48.75	48.75	56.15	50.05	48.75	56.15	50.05	50.05		
SO-0048	46.65	50.63	51.84	46.96	47.14	48.67	55.28	44.15	45.20	45.20	56.32	50.98	45.20	56.32	50.98	50.98		
BD-4323	46.37	48.55	49.20	40.50	46.15	48.85	48.87	38.67	-	-	-	-	-	-	-	-		
BD-4333	46.65	48.40	48.57	37.45	45.05	48.53	50.24	37.25	-	-	-	-	-	-	-	-		
BD-4339	46.13	48.58	49.20	38.25	45.25	45.84	50.47	38.06	-	-	-	-	-	-	-	-		
BD-1062	46.61	47.83	47.89	38.03	46.05	48.28	50.58	37.25	-	-	-	-	-	-	-	-		
BARI Palongshak-1	48.33	50.60	50.94	42.47	45.25	48.56	52.25	41.15	38.91	38.91	45.09	35.85	38.91	45.09	35.85	35.85		
CV (%)	4.75						2.44						8.27					
LSD (0.05)	0.23						0.17						5.96					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1 were used in 2018-19.



**Figure 1. Influence of different levels of salinity on SPAD value of spinach genotypes.**

### *Dry weight of plant*

In 2016-2017 maximum dry weight was found in control treatment in all genotypes compared to salt concentrations (Table 7). Dry matter was decreased gradually with the increasing salinity levels. The genotype SO-0047 produced the maximum total dry matter/plant (4.07 g) and minimum dry weight (1.70 g) from BD-4339 at control (Table 7). At 4 dS/m salinity level, the genotype SO-0047 produced the maximum dry matter (3.51 g) and minimum dry weight (1.19 g) from BD-4339. At 8 dS/m salinity level, the genotype SO-0047 produced the maximum dry matter (2.54 g) followed by SO-0048 (2.50 g) and minimum dry weight (0.45 g) from BD-4333. At 12 dS/m salinity level, the genotype SO-0047 also produced the maximum total dry matter (1.54 g) and minimum dry weight (0.35 g) from the genotype BD-4333.

In 2017-2018 dry matter was decreased gradually with the increasing salinity levels and the genotype SO-0047 produced the maximum total dry matter/plant (4.12 g) and minimum dry weight (2.52 g) from BD-4323 in control treatment (Table 7). At 4 dS/m salinity level, the genotype SO-0047 produced the maximum dry matter (3.40 g) followed by SO-0048 (3.35 g), BARI Palongshak-1 (3.24 g) and the lowest dry matter (1.14 g) from the genotype BD-4333. Dry matter was found higher in control treatment in all genotypes. At 8 dS/m salinity level, the genotype SO-0047 produced the maximum dry matter (2.64 g) followed by SO-0048 (2.43 g) and the lowest dry matter (0.53 g) in BD-4333. At 12 dS/m salinity level, the genotype SO-0047 also produced the maximum dry matter (1.47 g) and the lowest dry matter (0.37 g) from the genotype BD-1062.

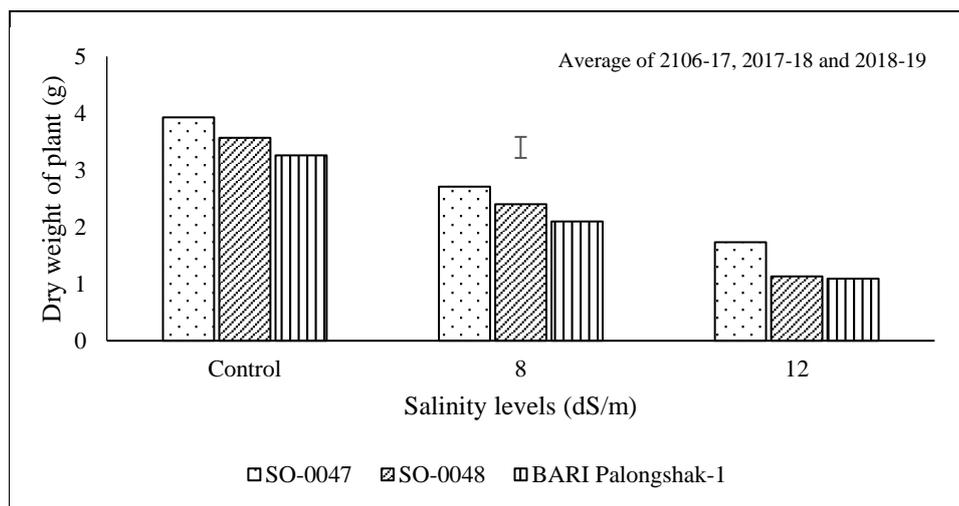
Table 7. Effect of different level of salinity on total dry weight of spinach genotypes

Genotypes	2016-2017						2017-2018						2018-2019					
	Dry weight/plant (g)						Dry weight/plant (g)						Dry weight/plant (g)					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	8	12	12	Control	4	8	8	12	12	Control	8	8	12		
SO-0046	3.10	2.54	0.67	0.47	0.47	-	-	-	-	-	-	-	-	-	-	-		
SO-0047	4.07	3.51	2.54	1.54	1.54	4.12	3.40	2.64	2.64	1.47	1.47	3.60	2.95	2.95	2.19	2.19		
SO-0048	3.81	3.05	2.50	1.08	1.08	3.97	3.35	2.43	2.43	1.17	1.17	2.93	2.28	2.28	1.15	1.15		
BD-4323	2.38	1.47	1.12	0.50	0.50	2.52	1.40	1.24	1.24	0.54	0.54	-	-	-	-	-		
BD-4333	1.70	1.19	0.45	0.35	0.35	2.63	1.14	0.53	0.53	0.38	0.38	-	-	-	-	-		
BD-4339	2.19	1.34	0.60	0.49	0.49	2.91	1.34	0.62	0.62	0.51	0.51	-	-	-	-	-		
BD-1062	2.85	1.31	1.01	0.39	0.39	2.99	1.22	1.11	1.11	0.37	0.37	-	-	-	-	-		
BARI Spinach-1	3.70	3.01	1.96	1.03	1.03	3.6	3.24	2.29	2.29	1.14	1.14	2.49	2.05	2.05	1.11	1.11		
CV (%)	12.79						4.99						4.84					
LSD (5%)	0.18						0.23						0.33					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19.

In 2018-19, dry weight of plant i.e. total dry matter/plant (TDM) was decreased gradually with the increasing salinity level and the genotype SO-0047 (3.60 g) produced the maximum total dry matter/plant and the lowest in BARI Palongshak-1 (2.49 g) in control treatment (Table 7). At 8 dS/m salinity level, SO-0047 (2.95 g) gave the maximum TDM and minimum from BARI Palongshak-1 (2.05 g). At 12 dS/m salinity level, SO-0047 (2.19 g) also gave the highest TDM and minimum from BARI Palongshak-1 (1.11 g). In 2018-19, at 8 and 12 dS/m, maximum TDM (2.95 g and 2.19 g respectively) was recorded from SO0047.

In average dry weight of three years, the maximum dry weight of plant was obtained from SO0047 (3.93 g) followed by SO-0048 (3.57) and the least (3.26 g) from BARI Palongshak-1 in control treatment (Figure 2). At 8 dS/m, the highest TDM (2.71 g) was recorded from SO-0047 and minimum from BARI Palongshak-1 (2.10 g). At 12 dS/m, SO-0047 also produced maximum TDM (1.73 g) and SO-0048, BARI Palongshak-1 gave identical TDM. Salinity significantly decreased dry weight of leaf relative to controls after 4 weeks of treatment (Xu and Mou, 2016). In a greenhouse study on spinach, irrigated by a range of saline waters, the fresh and dry weights were decreased with increasing the salinity levels of saline waters (Suleiman *et al.*, 2002). Bhatti *et al.*, 2021 reported that the growth and yield parameters (number of leaves, and fresh and dry weight) of spinach genotypes were significantly decreased with increasing the EC levels of saline water.



**Fig. 2. Influence of different levels of salinity on plant dry weight of spinach genotypes.**

### **Leaf yield**

Leaf yield/pot in all the genotypes was decreased gradually with the increasing salinity levels (Table. 8). In 2016-2017, SO-0047 significantly recorded the

highest leaf yield/pot (234.21 g/pot) and the genotype BD-4333 gave the lowest leaf yield (179.25 g/pot) in control treatment. At 4 dS/m salinity level, the highest leaf yield (223.25 g/pot) was recorded from SO0047 and minimum (145.24 g/pot) from the genotype BD-4333.

In 2017-2018, the genotype SO-0047 significantly recorded the maximum leaf yield/pot (211.81 g/pot) followed by SO-0048 (210.52 g/pot) and BD-4333 gave the lowest leaf yield (180.43 g/pot) at control treatment (Table. 8). At 4 dS/m salinity level, maximum leaf yield (189.10 g/pot) was recorded from SO0047 followed by SO-0048 (187.61 g/pot) and minimum from BD-4333 (138.31 g/pot). At 8 dS/m salinity level, maximum leaf yield (135.72 g/pot) was recorded from SO-0047 followed by SO-0048 (134.51 g/pot) and minimum from BD-4333 (75.44 g/pot). At 12 dS/m, the maximum leaf yield was recorded from SO-0047 (81.60 g/pot) followed by SO-0048 (79.84 g/pot) and minimum from the genotype BD-4323 (53.27 g/pot).

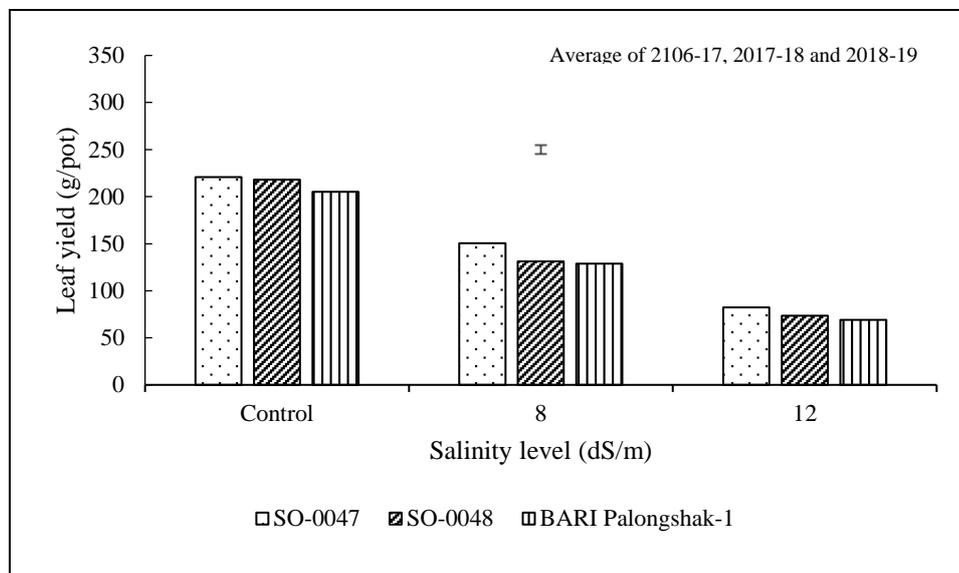
In 2018-19, Leaf yield/pot was decreased gradually with the increasing salinity level (Table. 8). At control treatment, SO-0047 significantly recorded the maximum leaf yield/pot (216.66 g) followed by SO-0048 (216.61 g/pot) and BARI Palongshak - 1 (205.22 g/pot) lowest leaf yield. At 8 dS/m salinity level, maximum leaf yield was recorded from SO0047 (180.97 g/pot) followed by SO-0048 (179.23 g/pot) and minimum from BARI Palongshak-1 (128.45 g/pot). At 12 dS/m salinity level, the highest leaf yield was also recorded from SO-0047 (83.83 g/pot) followed by SO-0048 (82.77 g/pot) and its minimum value (66.50 g/pot) was obtained from BARI Palongshak-1.

In average leaf yield of three years, the maximum leaf yield was obtained from SO-0047 (220.89 g/pot) followed by SO-0048 (218.04 g/pot) and the least from BARI Palongshak-1 (205.23 g/pot) in control treatment (Figure 3). At 8 dS/m salinity level, the highest leaf yield was recorded from SO-0047 (150.61 g/pot) and minimum (128.71 g/pot) from BARI Palongshak-1. At 12 dS/m, the genotype SO-0047 also produced maximum leaf yield (82.34 g/pot) followed by the genotype SO-0048 and BARI Palongshak. Increasing soil and/or irrigation water salinities can decrease spinach (*Spinacia oleracea* L.) yield (Ors and Suarez, 2017). Bhatti *et al.* (2021) reported that the growth and yield parameters of spinach genotypes were constantly decreased with an increase in EC levels of irrigation water. The decline in yield parameters in spinach genotypes may be attributed to many factors including lowering of water potential by the salts (Flowers and Flowers, 2005). Negative impacts of salinity on spinach growth, yield and physiological attributes have been documented previously (Turhan *et al.*, 2013; Xu and Mou, 2016). Ors and Suarez (2016) studied spinach (cv. Raccoon) response under saline water treatments and reported that higher salinity decreased all vegetative and yield parameters.

**Table 8. Effect of different level of salinity on leaf yield of spinach genotypes during 2016-17, 2017-18 and 2018-19**

Genotypes	2016-2017						2017-2018						2018-2019					
	Leaf yield (g)						Leaf yield (g)						Leaf yield (g)					
	Salinity levels (dS/m)						Salinity levels (dS/m)						Salinity levels (dS/m)					
	Control	4	8	12	Control	4	8	12	Control	4	8	12	Control	4	8	12		
SO-0046	219.45	135.14	85.25	64.87	-	-	-	-	-	-	-	-	-	-	-	-		
SO-0047	234.21	223.25	135.14	81.58	211.81	189.10	135.72	81.60	216.66	180.97	83.83	216.66	180.97	83.83	83.83	83.83		
SO-0048	226.98	162.61	80.19	75.66	210.52	187.61	134.51	79.84	216.61	179.23	82.77	216.61	179.23	82.77	82.77	82.77		
BD-4323	188.56	145.24	76.22	52.24	185.25	138.90	78.26	54.24	-	-	-	-	-	-	-	-		
BD-4333	179.25	155.32	74.65	50.27	180.43	138.31	75.44	53.27	-	-	-	-	-	-	-	-		
BD-4339	188.65	148.25	75.00	62.65	185.50	150.20	77.18	61.77	-	-	-	-	-	-	-	-		
BD-1062	200.25	165.24	80.00	60.28	198.48	167.51	78.25	62.64	-	-	-	-	-	-	-	-		
BARI Palongshak-1	209.84	203.24	128.54	65.45	200.62	168.90	129.15	74.80	205.22	128.45	66.50	205.22	128.45	66.50	66.50	66.50		
CV (%)	6.74						1.75						1.32					
LSD (5%)	7.53						1.83						1.81					

In 2017-18, SO-0046 was not germinated. Only three best genotypes (SO-0047, SO-0048 and BARI Palongshak-1) were used in 2018-19.



**Figure 3. Influence of different levels of salinity on leaf yield/pot of spinach genotypes.**

### Conclusion

Based on the above results, it might be concluded that the genotype SO-0047 was more salt tolerant than other genotypes. This genotype might be recommended as a variety for cultivation in the saline areas of Bangladesh. The genotype SO-0048 could be used as breeding material for development of saline tolerant spinach variety.

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## DETERMINATION OF CROP CO-EFFICIENTS OF CAULIFLOWER AT DIFFERENT GROWTH STAGES BY DRAINAGE LYSIMETER

A. J. MILA<sup>1</sup>, M. S. RAHMAN<sup>2</sup>, P. K. SARKAR<sup>3</sup>  
A. R. AKANDA<sup>4</sup> AND M. A. HOSSAIN<sup>5</sup>

### Abstract

Crop coefficient ( $K_c$ ) values are essential in estimating the water requirements of crops. The  $K_c$  values depend on crop evapotranspiration ( $ET_c$ ) and reference crop evapotranspiration ( $ET_0$ ). Again,  $ET_0$  is a function of climatic factors like temperature, humidity, wind speed, and sunshine hours, together with latitude, longitude, and altitude. These climatic factors vary from location to location, hence, the  $K_c$  values. So, location-specific  $K_c$  values are essential to determine crop water requirements on a regional basis. One of the most reliable methods of determining the  $K_c$  values of crops is the drainage lysimeter. Thus, the experiment was conducted in the research farm of the Irrigation and Water Management Division of Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, to determine  $ET_c$  using a drainage lysimeter during the *rabi* season of 2009-10. In the experiment, there were four irrigation treatments: irrigation at 15, 25, 35, 45, and 55 days after planting (DAP) ( $T_1$ ), irrigation at 15, 25, 35, 50 and 60 DAP ( $T_2$ ), irrigation at 15, 25 and 40 DAP ( $T_3$ ), and irrigation at 15, 30 and 45 DAP ( $T_4$ ). The highest curd yield (43.0 t/ha) of cauliflower was recorded from treatment  $T_1$  and was considered ideal for estimating  $ET_c$  and  $K_c$  values. The seasonal  $ET_c$  under the local agro-climatic conditions was 135 mm, and the  $K_c$  values were 0.37, 0.99, 1.29, and 0.84 for initial, development, mid- and late-season stages, respectively. The estimated mean  $K_c$  value was 0.87. These  $K_c$  values can also be required to calculate the crop water requirement for similar agro-climatic conditions in Bangladesh.

**Keywords:** Crop Coefficient, Crop evapotranspiration, Curd yield, Micro-lysimeter, Penman-Monteith method, Yield attributes.

### Introduction

Global fresh water availability among countries varies; some are sufficient but unevenly distributed, while others face severe water crises. It is projected that global crop productivity needs to increase by 0.5% per year to feed 9.3 billion people by 2050 (Grafton *et al.*, 2015). It can be done by increasing the area under cultivation or increasing the productivity of the land by introducing high-yielding

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<sup>1</sup>Senior Scientific Officer, Irrigation and Water Management Division (IWMD), Bangladesh Agricultural Research Institute (BARI), Gazipur, <sup>2</sup>Ex-Senior Scientific Officer, IWMD, BARI, Gazipur, <sup>3</sup>Ex-Principal Scientific Officer and Head, IWMD, BARI, Gazipur, <sup>4</sup>Ex-Chief Scientific Officer and Head, IWMD, BARI, <sup>5</sup>Chief Scientific Officer and Head, IWMD, BARI, Gazipur, Bangladesh.

and high-value crop cultivars through efficient irrigation and water management (Hossain *et al.*, 2023). At the same time, the focus should be on increasing water use efficiency or water productivity. In this case, the knowledge of crop coefficient values is essential. In addition, this information is necessary for policy planning on regional-scale water management (Mainuddin *et al.*, 2015) and fitting crops in cropping patterns for increasing net farm income (Mila *et al.*, 2016a).

Cauliflower (*Brassica oleracea* var. *botrytis* L.), a member of the Brassicaceae family, is one of the popular winter vegetables in Bangladesh, which is characterized by biannual and herbaceous nature. It is popularly known as ‘foolkopy’ in Bangladesh and grows well throughout the country. In Bangladesh, it covers an area of 22,853 hectares with a production of 343758.71 metric tons in 2022-23 (Anon., 2024). It grows well in a cool moist climate. In addition, proper irrigation is an important criterion for getting a potential yield of cauliflower in Bangladesh (Hossain *et al.*, 2016) and other countries (Job *et al.*, 2018; Kumar *et al.*, 2022; Sidhartha *et al.*, 2021; Yanglem and Tumbare, 2014). A three-year study on cauliflower in Bangladesh showed that irrigation at 10-day intervals through check basin method gave higher curd yield and water productivity (Hossain *et al.*, 2016). In India, the highest curd yield of cauliflower was recorded using drip irrigation at 90%-100% of potential evapotranspiration along with mulch (Job *et al.*, 2018; Kumar *et al.*, 2022; Sidhartha *et al.*, 2021; Subhan *et al.*, 2021; Yanglem and Tumbare, 2014). A study in Pakistan found higher cauliflower yield from 100% irrigation requirements through the conventional furrow irrigation method, while higher water productivity was recorded at 100% irrigation requirement through alternate furrow irrigation method (Subhan *et al.*, 2021). In semi-arid regions like Bangladesh, full and supplemental irrigation plays an important role in winter (November–March) and *kharf 1* (March–July) crops for increasing yield (Mila *et al.*, 2016a).

The crop coefficient ( $K_c$ ) is estimated by the ratio of the actual crop evapotranspiration ( $ET_c$ ) to potential evapotranspiration ( $ET_0$ ) (Allen *et al.*, 1998).  $K_c$  values are required to estimate crop water requirement or crop evapotranspiration (ET) to irrigate the crops of similar agro-climatic conditions where this value is unknown. The determination of water requirements of a particular crop cultivar in slightly varied climates and soils by conducting experiments repeatedly is cumbersome. But, it is possible to accurately estimate crop ET using the above formula (i.e., a product of  $K_c$  and  $ET_0$ ). However,  $K_c$  values for different crops are available in the literature (Allen *et al.*, 1998; Doorenbos and Pruitt, 1977). In addition, these values can be estimated from the tabulated values by adjusting some factors like temperature, humidity, irrigation

sequences, and soil textures (Allen *et al.*, 1998). However, for the best output, it is recommended to determine the factors locally. Further, the physiological characteristics of a crop cultivar differ from others within crop seasons, soil types, and agroclimatic zones. Consequently, it shows varying physiological demands that give rise to a change in the ET process. Therefore, the local estimation of the  $K_c$  values is paramount.

Crop evapotranspiration and crop coefficient can either be estimated by lysimeter (Akanda *et al.*, 2017; Khan *et al.*, 1993; Mila *et al.*, 2016a and 2016b; Mila *et al.*, 2018) or by remote sensing approaches of spectral vegetation indices, METRIC and SEBAL (Elsayed *et al.*, 2022; Pôças *et al.*, 2020; Taheri *et al.*, 2021). Among them, the lysimeter method is more accurate and reliable because of its capacity to estimate regional-scale  $K_c$  value. A lysimeter is a device hydrologically protected from the surrounding soil by inserting a container where plants are grown (Michael, 2014). Drainage lysimeter was used because of its simple, and multipurpose uses (Khan *et al.*, 1993). Previously, many researchers determined crop coefficient values of cauliflower using different lysimeters in various locations around the world (Allen *et al.*, 1998; Andrian *et al.*, 2021; Doorenbos and Pruitt, 1977; Martin *et al.*, 1996; NRCS, 2010; Sahin *et al.*, 2009; Simonne *et al.*, 2004; Van der Gulik and Nyvall, 2001). No information is available for the determination of  $K_c$  values of cauliflower by drainage lysimeter in Bangladesh environment. Therefore, this study was conducted to determine crop coefficient values of cauliflower by drainage micro-lysimeter in Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

## Materials and Methods

### Information on study location, soil, and weather conditions

The experiment was conducted at the research farm of Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Gazipur (latitude, longitude, and elevation from MSL were 24°00'N, 90°25'E and 8.4 m) during 2009-10. The weather data during the crop period was collected from an agro-meteorological station close to the experimental field. The soil was silty clay loam with field capacity and bulk density of 28% (dry weight basis) and 1.5 g cm<sup>-3</sup>, respectively. Maximum and minimum temperatures during the day and night varied from 16.0-29.5°C and 8.0-15.8°C (Figure 1a). The maximum and minimum relative humidity during the day and night periods varied from 39-89% and 82-99%, respectively (Figure 1b). Similarly, maximum wind speeds during the season ranged from 0 to 49 m s<sup>-1</sup> and the minimum from 0 to 25 m s<sup>-1</sup> (Figure 1c). Total rainfall during the season was only 6 mm at planting (Figure 1d). Solar radiation over the season varied from 6 to 18 MJm<sup>-2</sup>s<sup>-1</sup> (Figure 1d).

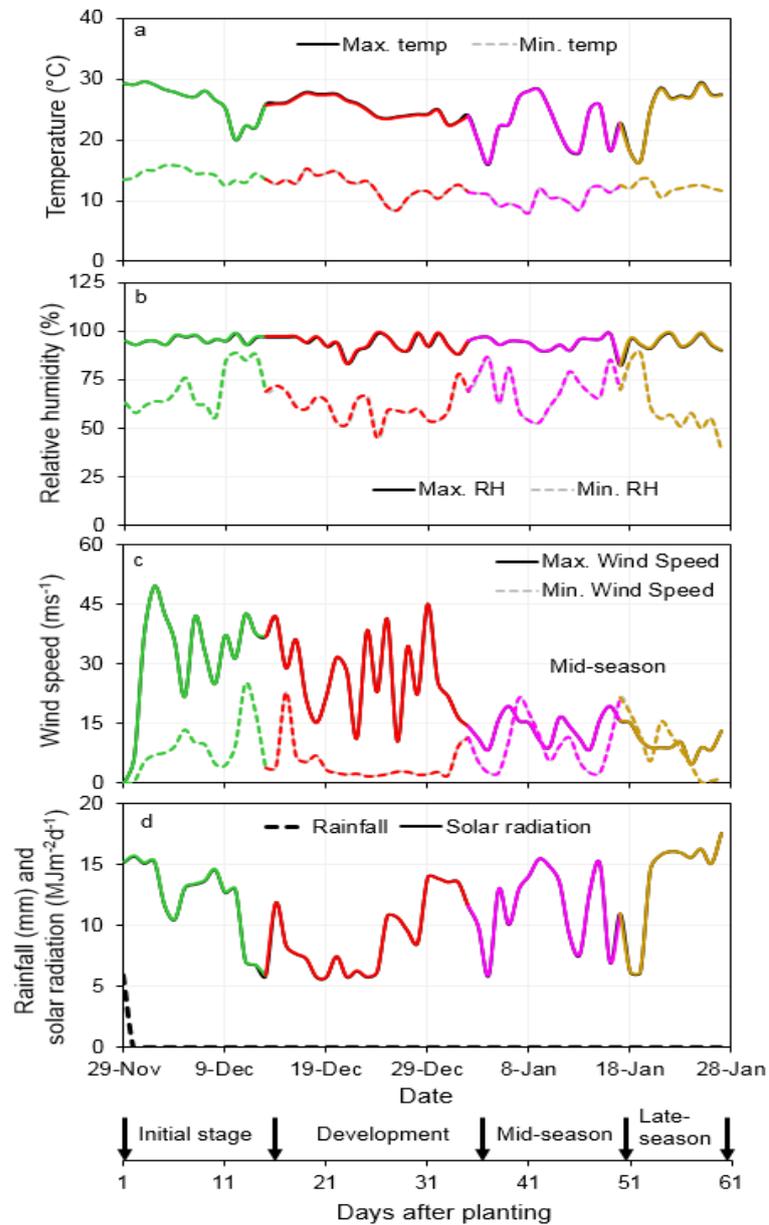


Fig. 1. Daily maximum and minimum air temperatures (a), relative humidity (b), wind speed (c), rainfall, and solar radiation (d) during the 2009-10 crop season. In Fig. shown against date or days after planting. Green, red, purple, and gold lines are used on top of the total crop season line for four crop growth stages- initial, development, mid-season, and late season. In the x-

axis, the duration of crop growth stages is marked as a black-filled downward arrow.

### Experimental design and crop management

Thirty day-old cauliflower seedlings (variety: Snow white) were planted on 29 November 2009 in four lysimeter tanks with row-to-row and plant-to-plant spacing of 60 cm and 45 cm, respectively. To create a similar environment, the same crop was grown in the entire field around the lysimeter tanks. The intercultural operation was done as and when necessary. Recommended fertilizer was applied following Anon. (2011). The crop was harvested on 27 January 2010. The selected treatments were:

T<sub>1</sub> = Irrigations at 15, 25, 35, 45 and 55 days after planting (DAP) allowing drainage

T<sub>2</sub> = Irrigations at 15, 25, 35, 50 and 60 DAP allowing drainage

T<sub>3</sub> = Irrigations at 15, 25, and 40 DAP allowing drainage

T<sub>4</sub> = Irrigations at 15, 30, and 45 DAP allowing drainage

The micro-lysimeter contained four tanks, each having an area of 1 m x 1 m, designed and installed by Khan *et al.* (1993). A similar approach was also used by other researchers (Akanda, *et al.*, 2017; Mila *et al.*, 2016a and 2026b; Mila *et al.*, 2018) for estimating K<sub>c</sub> values of sunflower, jute, soybean, and potato at Gazipur. The crop was irrigated as per design of the treatments. The measured quantity of water was applied to the tanks ensuring drainage. Soil moisture was measured during planting, before irrigation, and at maturity to determine the irrigation quantity and depleted residual soil moisture.

### Determination of crop evapotranspiration (ET<sub>c</sub>)

ET<sub>c</sub> of cauliflower was determined from the best yielder treatment grown in a lysimeter tank. For each treatment, ET<sub>c</sub> was calculated as shown in Table 2. It was determined by subtracting stored soil moisture during the period under consideration and drainage amount from the applied water and rainfall. The following formula was used:

$$ET_c = (W_a + R_e) - (D_w + S_s)$$

where ET<sub>c</sub> = crop evapotranspiration, mm

W<sub>a</sub> = applied water, mm

R<sub>e</sub> = effective rainfall, mm

D<sub>w</sub> = drainage water, mm

$S_s$  = stored soil moisture, mm

### **Estimation of reference evapotranspiration ( $ET_0$ )**

Daily reference evapotranspiration ( $ET_0$ ) was estimated by the CROPWAT model (version 8). The Penman-Monteith Equation was used in the above model to estimate  $ET_0$  by inserting daily weather parameters of minimum and maximum temperatures, relative humidity, wind speed, and sunshine hour together with location information of altitude, latitude, and longitude (Smith *et al.*, 1992). Then  $ET_0$  for each of the frequencies of irrigation for the highest yield treatment was determined.

### **Estimation of Crop coefficients**

The crop coefficient ( $K_c$ ) for the frequency of irrigation events for the highest yield treatment was calculated by the ratio of  $ET_c/ET_0$ . Then, the length of the crop growth stages (initial, development, mid, and late season stages) were identified and adjusted for the calculated  $K_c$  values (Allen *et al.*, 1998 and Table 3).

### **Collection of crop and water data**

During harvest, the data on curd length, curd diameter, individual curd weight, and curd yield were recorded from all four plants in each lysimeter. However, no data were recorded from the non-lysimetric plots adjacent to the lysimeter. Applied water and percolation data were recorded after each irrigation event, as shown in Table 2.

## **Results and Discussion**

### **Curd yield and yield attributes of cauliflower**

The data on curd yield and yield attributes of cauliflower are presented in Table 1. The treatment  $T_1$  (irrigation at 15, 25, 35, 45, and 55 DAP) produced the highest curd yield ( $43.2 \text{ t ha}^{-1}$ ) among the treatments. Irrigation at 10-day intervals created favourable soil moisture conditions for the successful growth of the cauliflower plants. As a result, the highest individual curd weight (1148 g) was found from this treatment. In addition, cauliflower, a shallow-rooted vegetable crop (20–30 cm), and frequent irrigation application were necessary to provide optimal soil moisture throughout its growing period. Treatment  $T_2$  gave the second-highest curd yield ( $42 \text{ t ha}^{-1}$ ) by receiving five irrigations at 15, 25, 35, 50, and 60 DAP. The yield gap between the two treatments was  $1.2 \text{ t ha}^{-1}$ . By contrast, treatments  $T_3$  and  $T_4$  received three irrigations but 15-day intervals produced the lowest curd yield ( $34.8 \text{ t ha}^{-1}$ ). Therefore, it was obvious that irrigation at the 10-day interval was found suitable to maximize the curd yield of cauliflower under the studied environment. Doorenbos and Pruitt (1977) recommended that the best-growing plants producing

the highest yields are appropriate for calculating the crop coefficients for different growth stages. Therefore, the treatment T<sub>1</sub> was selected to determine the crop coefficient values of cauliflower.

**Table 1. Curd yield and yield attributes of cauliflower**

Treatments	Plant population (no. m <sup>-2</sup> )	Curd length (cm)	Curd diameter (cm)	Individual curd weight (g)	Curd yield (t ha <sup>-1</sup> )
T <sub>1</sub>	4	9.8	14.7	1148	43.2
T <sub>2</sub>	4	9.7	15.1	1100	42.0
T <sub>3</sub>	4	7.8	13.7	880	36.0
T <sub>4</sub>	4	7.6	12.4	900	34.8

#### Determination of crop evapotranspiration (ET<sub>c</sub>) from Lysimeter

Table 2 presents the stage-wise ET<sub>c</sub> for the irrigation events during the growing season. Total ET<sub>c</sub> over the season was 135 mm for T<sub>1</sub>. A study in the Research Institute of Soil and Water Conservation in Melnik, Czech Republic, determined seasonal ET<sub>c</sub> of late-grown cauliflower using the water balance method and found seasonal ET<sub>c</sub> of 278, 252, and 211 mm from 2003 to 2005 cropping seasons (Zavadil, 2006). The ET<sub>c</sub> values were double that of the present study because they used different varieties (cv. Fremont), and the crop season was 36 days longer than the present study. Usually, the longer growing season costs higher crop water requirements for a particular crop. Another study at the Agricultural Research Station of Ataturk University, Erzurum, Turkey, revealed that the seasonal ET<sub>c</sub> of cauliflower was 475 mm (Sahin *et al.*, 2009). The crop duration lasted from May to August, and the daily evaporation remained about 3 times higher than that of the present study. The daily evaporation recorded in the present study varied from 0.94 to 2.1 mm over the season. The calculated ET<sub>c</sub> value of the present study was lower than the value found by other researchers. The variation in the growing season, crop duration, crop variety, location, and weather conditions might affect ET<sub>c</sub>, showing the changes between this and the other studies.

**Table 2. Crop evapotranspiration (ET<sub>c</sub>) determination by drainage lysimeter**

Duration in days	Applied water (mm)	Effective rainfall (mm)	Percolation (mm)	Soil water content <sup>†</sup> storage (mm)	ET <sub>c</sub> (mm)
0–15	5	-	0	(-)10.8	15.8
15–25	30	-	4.0	8.5	17.5
25–35	40	-	5.9	(-)3.3	37.4
35–45	45	-	4.6	6.3	34.1
45–55	50	-	4.7	15.1	30.2
Total	-	-	-	-	134.9

The negative sign in stored soil water content indicates the depleted soil water used by the crop. On the other hand, the positive values indicate water stored in the soil above ET.

### Determination of crop coefficient ( $K_c$ )

The duration of the crop growth stage depends on the duration of the growing season of a particular crop and climate (Doorenbos and Pruitt, 1977; Smith *et al.*, 1992). Here, the crop duration was 60 days, and the individual durations of the crop growth stages were identified, as mentioned earlier (Table 3). The estimated  $K_c$  values for the frequency of irrigation events from Figure 3a were adjusted for the crop growth stages. Then,  $K_c$  values of 0.37, 0.99, 1.29, and 0.84 were found to be the initial, development, mid, and late-season stages (Table 3 and Figure 3b). The highest  $K_c$  value was recorded at the mid-season stage and the lowest (0.37) at the initial stage. The variation of  $K_c$  among the stages contributed to the variation of crop water requirements.  $K_c$  value was initially low (0.37), then gradually increased to 1.29 at the mid-season stage and again decreased to 0.84 at the late-season stage (Table 3 and Figure 3b). The mean  $K_c$  value over the season was 0.87 mm (Table 3).

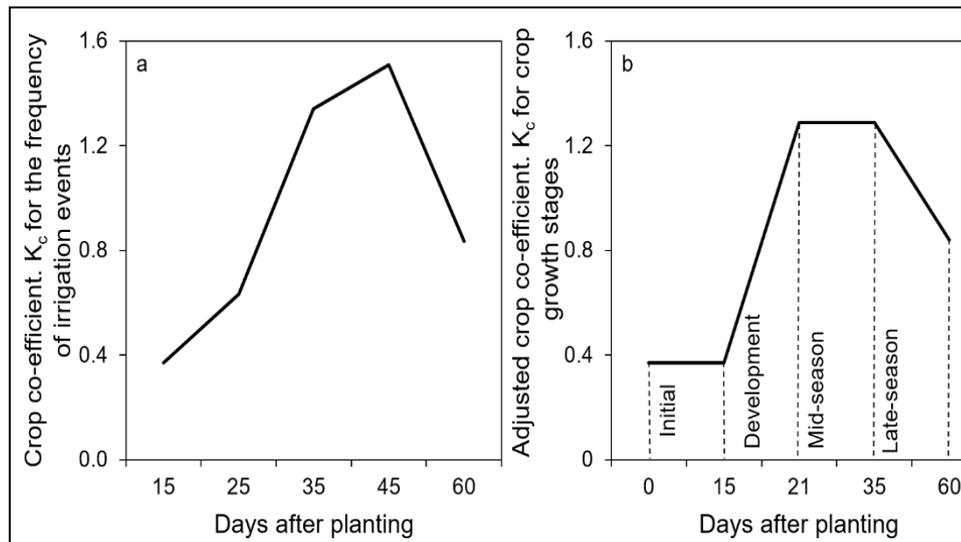


Fig. 3. Crop coefficient of cauliflower for (a) the frequency of irrigation events for 15, 25, 35, 45, and 55 days after planting and (b) the crop growth stages for initial development, mid and late season stage.

**Table 3. Estimated crop co-efficient values of cauliflower**

Crop growth stage <sup>†</sup>	Duration (days)	Crop water requirement (mm)	Reference crop ET (ET <sub>0</sub> ) (mm)	Crop co-efficient, K <sub>c</sub>
Initial (1–15 DAP)	15	15.8	42.6	0.37
Development (16–35 DAP)	20	55.0	55.6	0.99
Mid-season (36–50 DAP)	15	42.3	32.8	1.29
Late season (51–60 DAP)	10	21.8	25.9	0.84
Total	60	135	157	0.87 (mean)

DAP denotes days after planting.

K<sub>c</sub> is sensitive to weather parameters. It can not be changed without field experimentation because it depends on two variables- actual crop water requirement and reference crop evapotranspiration. Actual crop water requirements can accurately be determined using a lysimeter study. By contrast, reference crop evapotranspiration can be determined using known climatic parameters (See Results sub-sections of Reference evapotranspiration).

Several studies at different locations across the world determined the K<sub>c</sub> values of cauliflower (Doorenbos and Pruitt, 1977; Martin *et al.*, 1996; NRCS, 2010; Sahin *et al.*, 2009; Simonne *et al.*, 2004; Van der Gulik and Nyvall, 2001). A study on cauliflower at the Agricultural Research Station of Atatürk University, Erzurum, Turkey found a seasonal K<sub>c</sub> value of 0.84 (Sahin *et al.*, 2009). Simonne *et al.* (2004) in Florida, USA, reported that K<sub>c</sub> values of cauliflower for the head development stage ranged from 0.9 to 1.0, and the crop growing season ranged from 70–84 days. Another study in British Columbia found the cauliflower K<sub>c</sub> values to be 0.70, 1.05, and 0.95 for the initial, mid-season, and late-season stages (Van der Gulik and Nyvall, 2001). A study at the Maricopa Agricultural Center in Maricopa, Arizona, found the K<sub>c</sub> values of cauliflower at initial, development, mid-, and late season 0.50, 0.61, 0.75, and 0.38 (Martin *et al.*, 1996). Doorenbos and Pruitt (1977) reported that the K<sub>c</sub> values of cauliflower for mid-season and at harvest were 0.95–1.0 and 0.80–0.85, respectively, depending on the minimum relative humidity of >70% and those were 1.05–1.10 and 0.9–0.95 depending on the minimum relative humidity of <20%. Another study in the USA reported that the K<sub>c</sub> values of cauliflower for the 10% to 100% growing season were 0.25, 0.28, 0.44, 0.59, 0.75, 0.90, 0.95, 0.95, 0.94, and 0.80, respectively, and their growing season lasted from 20 June to 30 September (NRCS, 2010). These K<sub>c</sub> values were slightly different from those recommended by FAO (Doorenbos and Pruitt, 1977). Besides, FAO values are the standard values and need calibration for a specific region or location as per guidelines suggested in FAO Irrigation and Drainage paper no 56 (Allen *et al.*, 1998). They did an experiment in the California Desert, USA, and the planting date was September, and the total crop period was 140 days (Initial–40, development–50, mid-season–40, and late season–15). They reported that the K<sub>c</sub> values of cauliflower for initial, development, and late season were 0.70, 1.05, and 0.95.

### Determination of crop water requirement

The crop water requirement of cauliflower was 15.8, 55.0, 42.3, and 21.8 mm for the initial, development, mid, and late seasons, respectively. These values can be used in similar agro-climatic conditions where  $K_c$  values are not available or the values have not been determined precisely. Therefore,  $K_c$  value determination using the lysimetric method is paramount for efficient irrigation water management on the regional level.

### Conclusion

Irrigation at 10-day intervals gave the highest curd yield of cauliflower in semi-arid regions like Bangladesh. Seasonal crop evapotranspiration under this study for 10 days irrigation interval was 135 mm. The study revealed that cauliflower required 16, 55, 42, and 22 mm water for irrigation at initial, development, mid-season, and late-season stages to achieve the potential curd yield. The crop coefficient values of cauliflower (Snow White) from the lysimeter study were 0.37, 0.99, 1.29, and 0.84 for the initial, development, mid-season, and late-season stages, respectively. The mean value of  $K_c$  was 0.87. This locally determined crop coefficient value is more reliable and recommended for determining the crop water requirement of cauliflower for Joydebpur and similar other environments.

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## EFFECT OF FOLIAR APPLICATION OF BORON ON FRUIT SET AND YIELD OF BARI *Bt* BEGUN

S. SULTANA<sup>1</sup>, H. M. NASER<sup>2</sup> AND M. AKTER<sup>3</sup>

### Abstract

A field experiment on *Bt* brinjal (var. BARI *Bt* Begun-2) was carried out to investigate the effect of boron on its flowering, fruit sets and yield at the Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur during 2018. The experiment was laid out in a Randomized Complete Block Design with three replications. The experimental treatment comprised four doses of boron (B), viz. 0.0 (control), 50, 100 and 150 ppm B. Boron in the form of boric acid ( $H_3BO_3$ ) was applied at full bloom stage and then the other two sprays were given at an interval of 10 days. Results revealed that the yield and yield contributing characters of *Bt* begun were significantly influenced by foliar application of boron. Plant height (70.4 cm), number of fruits/plant (30.4), length of fruit (13.4 cm), individual fruit weight (79.0 g), fruit yield/9.0 m<sup>2</sup> (2433 g) were found to be maximum with spraying of B @ 100 ppm compared to the other treatments. Spraying of 100 ppm B recorded the highest fruit yield (24.30 t/ha) which was significantly higher than 150 ppm B and control treatment. According to regression equation, the optimum dose of boron concentration was 85 ppm. Quality attributes, viz. TSS (6.23 °Brix), Vitamin C (22.7 mg/100g and b carotene (25.2 µg/100 g) were also found highest at 100 ppm B. The maximum boron uptake both by fruits (0.07 kg/ha) and plants (0.06 kg/ha) was recorded at 100 ppm B. Therefore, it is concluded that 85 ppm boron (500 ppm boric acid) as foliar application along with other soil applied fertilizers @ 116-32-70-13-2 kg/ha of N-P-K-S-Zn can be recommended for higher yield and quality of *Bt* begun production.

Keywords: Boron, Yield, *Bt* eggplant, Vitamin-C, β- carotene, Transgenic brinjal

### Introduction

Brinjal or eggplant (*Solanum melongena* L.), a member of Solanaceae family, is a very important vegetable in Bangladesh. It is popularly known as 'begun' grown throughout the country. It is low in calories (24 kcal/100g) but high in folate, calcium, vitamin B & C, fiber and water content. It is also used in ayurvedic medicine for curing diabetics, hypertension and obesity. Brinjal is the second most important vegetable crop in Bangladesh in terms of production area as well as yield and it is cultivated all over the country in *rabi* and *kharif* seasons. In 2018-19, it is cultivated in 19114.5 hectares of land with an annual production of 170189 metric tons in *kharif* and 33281.8 hectares of land with an annual production of 360421 metric tons in *rabi* season. (Anon., 2020). However, the average brinjal yield in

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<sup>1,2&3</sup>Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

Bangladesh is relatively low compared to other advanced countries of the world. The low yield of brinjal in Bangladesh is primarily due to the lack of high yielding varieties, inadequate, imbalanced use of manure and fertilizers lacking in micronutrients especially boron.

Brinjal suffers regular and heavy losses from a very destructive insect-pest called the fruit and shoot borer which cannot be controlled effectively by conventional insecticides. *Bt* begun is the genetically modified (transgenic) version of regular brinjal. In common brinjal variety CryI-AC gene isolated from the soil bacterium, *Bacillus thuringiensis* (*Bt*) is inserted to develop *Bt* brinjal. The special gene, CryI-AC makes the brinjal poisonous to the pest brinjal fruit and shoot borer by the synthesis of insecticidal proteins, which are effective against pest but do not cause any harm to other organisms. Micronutrients such as boron had a great influence on plant growth and development. The essential physiological activities of boron linked to strength of cell wall and development, RNA metabolism, sugar transport, hormones development, respiration, cell division, Indole acetic acid (IAA) metabolism and as part of the cell membranes (Marchner, 1995). Boron deficiency causes delay in pollen germination and pollen tube development and ultimately it halts flowering and fruit setting (Halfacre, and Barden, 1979). Further, macronutrients are quickly absorbed and utilized by the tissues of the plants by the catalyzing effect of micronutrients (Phillips, 2004).

Foliar spray of micronutrients is the common practice to overcome the deficiencies in order to improve the quality of fruit. Nutrients are generally quickly available to the plants by the foliar application than the soil application (Phillips *et al.*, 2004 and Silberbush, 2002). Boron also plays an important role in flowering and fruit formation (Nonnecke, 1989). Several studies have been conducted on effect of boron on flowering and fruit setting in tomato, chilli and potato which belong to the same family Solanaceae (Ali *et al.*, 2015; Basavarajeswari *et al.*, 2008; Lenka and Das, 2019; Mondal *et al.*, 2023). In Bangladesh foliar application of boron on brinjal has not yet been reported. Therefore, the present study was conducted to investigate the effect of boron on flowering, fruit setting and yield of *Bt* brinjal and find out the optimum dose of boron for maximizing the yield of *Bt* brinjal.

### **Materials and Methods**

A field experiment was conducted at the Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Gazipur on 03 December, 2018 to study the effect of boron on flowering, fruit set and yield of *Bt* brinjal (transgenic brinjal) (var. BARI *Bt* Begun-2). The experiment was laid out in a randomized block design with three replications. The unit plot size was 3 m × 3 m. Fertilizers were applied @ 116-32-70-13-2 kg/ha of N-P-K-S-Zn in the form of urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate respectively. Equal size healthy 35 day-old seedlings of brinjal were transplanted on 03 December, 2018 with a spacing of 100 cm from row to row and 75 cm from plant to plant. Non-*Bt*

begun seedlings were planted as resistant varieties. Intercultural operations were done as and when necessary.

### Methods of chemical analysis of soil

Initial soil samples collected from 0-15 cm depth prior to fertilizer application, were analyzed for all important soil parameters using standard procedures (Table 1). Soil pH was measured by a combined glass calomel electrode (Jackson, 1958). Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934). Total N was determined by a modified Kjeldahl method. Calcium (Ca), magnesium (Mg) and K were determined by  $\text{NH}_4\text{OAc}$  extractable method, copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were determined by DTPA extraction followed by AAS reading. Boron (B) was determined by  $\text{CaCl}_2$  extraction method. Available P was determined by the Bray and Kurtz method while S was determined using the turbidimetric method with  $\text{BaCl}_2$ .

**Table 1. Initial properties of the soil samples of experimental field**

Soil Properties	Texture	pH	OM (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Zn
				meq 100g <sup>-1</sup>				μg g <sup>-1</sup>					
Result	Clay loam	5.77	0.97	5.33	1.83	0.18	0.051	8.5	13.2	0.19	2.1	66	0.96
Critical level	-	Acidic	Low	2.0	0.5	0.12	Very low	7.0	10	0.2	0.2	4.0	0.6

### Foliar application

Boric acid ( $\text{H}_3\text{BO}_3$ ) having 18% boron were applied at different concentrations as per imposed treatments. Sprays were done three times at full bloom stage and the other two sprays were given at an interval of 10 days. The treatment combinations of foliar spray of boron were 0.0 (control), 50, 100 and 150 ppm B. Foliar sprays were applied using a hand sprayer. All treatments were applied as a foliar spray on plants using hand operated compressed air sprayer at the rate of 9 liter/plot. Boron @ 100 ppm (100 mg/L) solution was prepared by dissolving 0.572 g boric acid ( $\text{H}_3\text{BO}_3$ ) in 1000 mL of deionized water. Similarly, 50 and 150 ppm were prepared with 0.286 and 0.858 g of boric acid dissolving in 1000 mL deionized water, respectively. The time of foliar spray was 8:00 A.M. Young fruits were harvested time to time at edible stage. Five plants were randomly selected from each and every treatment for recording necessary yield data such as plant height (cm), fruit length (cm), number of fruits per plant, fruit weight (g) and yield (t ha<sup>-1</sup>). Fruit quality data were total soluble solid (TSS) and vitamin C. The ANOVA was prepared on yield attributes, quality and yield data. When F was significant at the  $p < 0.05$  level, the means were compared by Tukey's W test using Excel version 4.0 (Esumi Co. Ltd., Tokyo, Japan).

**Total soluble solid, ascorbic acid content and carotenoids:**

Brinjal fruit from each treatment were cut into small slices and pooled. Samples were homogenized in a blender and portion of the homogenate were taken to determine the fruit quality. Total soluble solids content (TSS) was determined at 20°C with a refractometer and reported as °Brix. Ascorbic acid content (vitamin C) was measured by classical titration method using 2, 6-dichlorophenol indophenols solution and express as mg 100 g<sup>-1</sup> of fresh weight (Miller, 1998). Total carotenoid (µg 100 g<sup>-1</sup>) was measured by spectrophotometer (T-40, PG Instrument Ltd.UK) at 451nm (Alasalvar *et al.*, 2005).

**Results and Discussion**

Yield and yield contributing parameters of *Bt* begun were significantly influenced by foliar spray of boron (Table-2). The highest plant height (70.5 cm) was recorded in 150 ppm B, which was statistically identical to 50 ppm B and 100 ppm B but higher than the control. The lowest (67.8 cm) plant height was recorded in the control. In general, the vegetative growth of brinjal responded positively to foliar application of boric acid. Boron is vital to plant health, due to its role in forming and strengthening cell walls (Broadly *et al.*, 2012). The highest number of fruits per plant (30.4) was recorded at 100 ppm B which was identical with 50 ppm B but significantly higher than 150 ppm B and control treatments. This attributed to the accessibility of boron by foliar feeding and the key role of boron on cell integrity, sugar transport, RNA metabolism and enhancing respiration rate, increasing uptake of certain nutrients and metabolic activities. Ali *et al.* (2013) reported that boron increased the number of fruits in tomato (30 fruits at 5x 10<sup>6</sup> ppm). Similar results were also observed by Shnain *et al.* (2014) where 1250 ppm boron was applied as foliar spray in tomato. The maximum length of fruit (13.4 cm) was found in T<sub>2</sub> which was significantly higher than the other treatments. The lowest fruit length (10.7cm) was noticed in the control.

Individual fruit weight was significantly variable among the treatments (Table 3). The maximum individual fruit weight (79.0 g) was obtained from the plants receiving 100 ppm boron which was significantly higher than the other treatments and the minimum fruit weight was obtained from the control treatment. Foliar application of boron (100 ppm) increased weight of fruits that may be due to greater photosynthetic activity, resulting the increased production and accumulation of carbohydrates and favorable effect on vegetative growth and retention of flowers and fruits, which might have increased number and weight of fruits. The results agree with the findings of Davis *et al.* (2003); Bhatt *et al.* (2004); Naga *et al.* (2013) and Basavarajeswari *et al.* (2008).

The fruit yield per plot and per hectare was significantly influenced by the different levels of boron (Table 2). The maximum fruit yield/plot (9.0 m<sup>2</sup>) was obtained

from the spray of 100 ppm B (2433 g) closely followed by 50 ppm B spray (2166 g) and its minimum value was obtained from the control. The highest yield (24.3 t/ha) was noted at 100 ppm boron spray which was statistically similar to 50 ppm B spray (21.6 t/ha) and significantly higher than the 150 ppm B and control. This resulted due to production of fertile flowers and better pollen germination which is an essential phenomenon of reproduction process. The productive flowers are directly linked with the content of phenolic compounds. B has also an important role in phenol metabolism (Gupta *et al.*, 2012). Meena *et al.* (2015) showed that foliar application of boron and zinc either solely or in combination is quite beneficial for vegetative growth, flowering and fruiting as well as quality improvement of tomato fruits.

**Table 2. Effect of boron on yield and yield contributing character of *Bt* brinjal**

Treatment (Born conc. in ppm)	Plant height (cm)	Number of fruits/plants	Length of fruit (cm)	Individual fruit weight (g)	Fruit weight/plot (g)	Yield (t/ha)
50	69.5a	26.3ab	12.1b	73.4b	2166ab	21.6ab
100	70.5a	30.4a	13.4a	79.0a	2433a	24.3a
150	68.1a	22.3b	11.2c	71.3b	1966b	19.6b
0 (Control)	67.8b	16.4c	10.7d	63.6c	1766b	17.6b
CV (%)	6.48	1.65	7.07	2.46	7.71	7.70

Plot area: 3 m x 3 m (9.0 m<sup>2</sup>)

It was observed that the fruit yield was increased with the increase in boron concentration up to 100 ppm beyond that yield decreased. The percent increase in fruit yield over control was 22.7, 38.1 and 11.4% for 50, 100 and 150 ppm B, respectively (Table 3). As a micronutrient B requirement is very low (concentration) for plant growth and development (Abd El-Gawad *et al.*, 2014). There is a very thin margin between the level of B deficiency and toxicity. An optimum concentration of B for a plant can be toxic for another plant. Plant growth can be affected very badly due to the higher concentration of B (Miwa *et al.*, 2007).

### **Economic performance**

The economic performance of different treatments is presented in Table 3. The highest gross return (972000 Tk/ha) and maximum marginal benefit-cost ratio (MBCR) (28) were found from 100 ppm B spray. The lowest MBCR (8) with 784000 Tk/ha was obtained from 150 ppm B spray.

**Table 3. Yield comparison between different levels of foliar application of B and their economics**

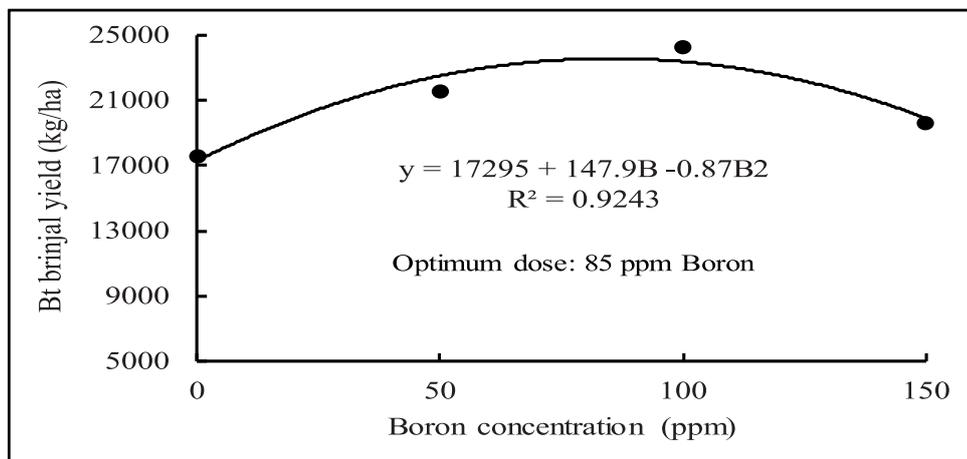
Treatment (Born conc. in ppm)	Fruit yield (t ha <sup>-1</sup> )	Yield increased (%) Over control	Variable cost <sup>§</sup> (Tk ha <sup>-1</sup> )	Gross return (Tk ha <sup>-1</sup> )	MBCR over control
50	21.6	22.7	32308	864000	17
100	24.3	38.1	32357	972000	28
150	19.6	11.4	32407	784000	8
0 (Control)	17.6	–	22808	704000	–

<sup>§</sup> Variable cost considering only fertilizer, wage rate, seed and land preparation only.

Input prices (Tk kg<sup>-1</sup>): Urea: 16; TSP: 25; MoP: 15; Gypsum: 15; Zinc sulphate: 140; Boric acid: 240. Wage rate: 450 Tk., Seed: 500 kg<sup>-1</sup>, Land preparation: 9880 Tk ha<sup>-1</sup>.

### Response function between boron and yield

A positive but quadratic relationship was observed between yield of *Bt* brinjal and B application (Fig. 1). To build a response function, boron levels were plotted in X axis and yield levels were plotted in Y axis. The obtained regression equation was  $y = 17295 + 147.9 B - 0.87 B^2$  and the coefficient of determination ( $R^2$ ) was 0.9243. The  $R^2$  value 0.9243 indicates that 92.43% yield was due to B application and the rest 7.57% yield was due to other factors. Thereby the optimum dose of B was 85 ppm and estimated maximum yield was 23.5 t/ha.



**Fig. 1. Response of *Bt* brinjal yield to boron application.**

### Boron concentration and uptake of *Bt* brinjal

Boron concentration and uptake by *Bt* brinjal fruit and plants are presented in Tables 4 and 5. The maximum boron concentration and uptake were found in 100

ppm foliar spray of B followed by 50 ppm B and 150 ppm B. It was observed that boron uptake increased with increase in boron concentration. Similar result was also reported by Haribhushan *et al.* (2008) where B availability increased in soil after application of optimum dose of borax.

**Table 4. Boron concentration and uptake of *Bt* brinjal fruit in different treatments**

Treatment (Born conc. in ppm)	B content (ppm)	B conc. (%)	B uptake by <i>Bt</i> brinjal fruits (kg/ha)
50	27	0.0027	0.06
100	29	0.0029	0.07
150	25	0.0025	0.05
0 (Control)	21	0.0021	0.04

**Table 5. Boron concentration and uptake of *Bt* brinjal plant in different treatments**

Treatment (Born conc. in ppm)	B content (ppm)	B conc. (%)	B uptake by <i>Bt</i> brinjal plants (kg/ha)
50	22	0.0022	0.05
100	24	0.0024	0.06
150	20	0.0020	0.04
0 (Control)	19	0.0019	0.03

#### TSS, Vitamin C content and $\beta$ - carotene content in *Bt* brinjal fruit

TSS and vitamin C content are presented in Table 6. Higher TSS (6.23<sup>0</sup>Brix) was found in 100 ppm and the lowest value (5.40<sup>0</sup>Brix) was noted in the control. The increase in TSS might be due to the more nutrients were available by foliar sprays which may enhance the synthesis of carbohydrate and other quality characters. These results are in conformity with findings of Fagaria *et al.* (2009). The maximum vitamin C (22.7 mg 100g<sup>-1</sup>) was found in 100 ppm foliar spray of B and minimum value (17.7 mg 100 g<sup>-1</sup>) was in the control. Similarly, the highest  $\beta$ -carotene (25.2 $\mu$ g 100 g<sup>-1</sup>) was found in 100 ppm B followed 50 ppm B and 150 ppm B.

**Table 6. Quality characters of *Bt* brinjal as affected by foliar application of boron**

Treatment (Born conc. in ppm)	TSS ( <sup>0</sup> Brix)	Vitamin-C (mg/100 g)	$\beta$ - carotene ( $\mu$ g/100 g)
50	5.70	21.1	23.4
100	6.23	22.7	25.2
150	5.56	20.3	20.4
0 (Control)	5.40	17.7	18.8

## Conclusion

Foliar application of boron enhanced number of fruits/plants, individual fruit weight and fruit yield of *Bt* brinjal. The highest fruit yield, Vit-C and  $\beta$ -carotene content were recorded in 100 ppm boron treatment. From the quadratic response function, the optimum dose of B was recorded as 85 ppm boron. Therefore, it may be concluded that 85 ppm boron (500 ppm boric acid) as foliar application along with other soil applied fertilizers @ 116-32-70-13-2 kg/ha of N-P-K-S-Zn may be recommended for producing good quality of *Bt* brinjal in Grey Terrace Soil of Joydebpur.

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## EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON LEAF YIELD AND QUALITY OF BAY LEAF

M. N. YOUSUF<sup>1\*</sup>, A. J. M. SIRAJUL KARIM<sup>2</sup>, S. BRAHMA<sup>3</sup>  
M. I. HAQUE<sup>3</sup> AND M. M. KAMAL<sup>1</sup>

### Abstract

Two field experiments were conducted during two successive years of 2019-20 and 2020-21, to study the response of integrated nutrient management (INM) on leaf quality and yield of bay leaf at experimental bay leaf garden of Regional Spices Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur. The experiment comprised five nutrient management packages following the INM principle. They are T<sub>1</sub>= 220-70-150-40-5-3 g tree<sup>-1</sup> year<sup>-1</sup> of N-P-K-S-Zn-B, T<sub>2</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 7 kg cowdung tree<sup>-1</sup> year<sup>-1</sup>, T<sub>3</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg vermicompost tree<sup>-1</sup> year<sup>-1</sup>, T<sub>4</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup> and T<sub>5</sub>= Control (native fertility). The growth parameters of bay leaf were significantly affected by the different integrated nutrient management packages. The maximum annual increment of plant height (23.0 and 25.88 cm), the tallest plant (3.99 and 4.63 m), annual shoot growth (15.16 and 21.0 cm), leaf area (19.23 and 31.33 cm<sup>2</sup>), number of leaves per feet of shoot (18.17 and 19.33), leaf dry weight (1.47 and 1.73 g) and leaf yield (7.70 and 8.53 kg tree<sup>-1</sup>) in 2019-2020 and 2020-2021, respectively, were recorded from the application of nutrients @ 165-70-150-40-5-3g N-P-K-S-Zn-B with 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>. The application of nutrients @ 165-70-150-40-5-3g N-P-K-S-Zn-B with 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup> might be recommended as the best suitable nutrient management packages for bay leaf cultivation in Grey Terrace Soil of Madhupur tract (AEZ-28).

**Keywords:** Bay leaf quality, organic manures, chemical fertilizers, integrated nutrient management, leaf yield

### Introduction

Bay leaf (*Cinnamomum tamala* Nees and Eberm), a member of the Lauraceae family, is an evergreen perennial shrub originated in Bangladesh and south-east Asia and is widely distributed in the tropical and sub-tropical areas (Khanal, 2021; Kuna *et al.*, 2020). Around 350 species of *Cinnamomum* are grown in worldwide. It is locally called *Tejpata*, commercially known as Indian cassia, an important cash crop in Bangladesh. Its leaves are used for flavoring and seasoning of foods as spices as fodder and leaves oils are used as medicine and perfumery over the

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<sup>1</sup>Senior Scientific Officer and <sup>3</sup>Principal Scientific Officer, Regional Spices Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, <sup>2</sup>Professor, College of Agricultural Sciences, International University of Business Agriculture and Technology (IUBAT), <sup>4</sup>Embankment Drive Road, Sector-10, Uttara Model Town, Dhaka-1230, Bangladesh.

world since ancient times (Raman *et al.*, 2017; Parthasarathy *et al.*, 2008; Dighe *et al.*, 2005). Some times its bark is also used as substitute for cinnamon (*Cinnamomum zeylenicum*) in many parts of the world (Jakhetia *et al.*, 2010). In Bangladesh, bay leaf is grown on an area of 563.56 ha with annual production of 1814 metric tons with annual productivity of 3.22 t ha<sup>-1</sup> (Anon., 2021). The annual increment of leaf production and use is increasing day by day due to changing food habits of peoples. The fresh and processing of this crop facilitate opportunities for establishment of small industries at the local and regional levels. There are many production constraints for up scaling the leaf yield of bay leaf, viz. lack of modern cultivars, lack of processing technologies with value addition, lack of technical knowledge for spalling production, lack of improved production technologies, marketing facilities etc. Among the production technologies, nutrient management is one of the key yield limiting factors. Application of nutrient elements are ever ending input for growth and yield of crops. Continuous use of chemical fertilizers has degraded the soil health in terms of fertility and has also caused soil pollution. The reduction in the soil fertility has resulted in low productivity of the crop. Besides, the increasing cost of fertilizers and their negative effect on soil health has led to intensified attempts to the use of organic matter along with inorganic fertilizers. The supplying of NPK, farm yard manure improves the physical, chemical and biological status of soil; apart from this, it needs also to supply N, P, and K to soil. Due to these essential nutrients' deficiencies, bay leaf gardens are producing low- and poor-quality leaf. There are reports that lower yield and poor-quality leaves are associated with macro and micro-nutrients' unavailability from soils. Moreover, bay leaf is a nutrient loving plant, but growers of this region are not using balanced fertilizers that causes serious nutritional disorders in bay leaf. The investigation was conducted to develop a suitable nutrient management package for yield maximization of bay leaf.

### Materials and Methods

The present investigation was carried out at the experimental bay leaf garden of Regional Spices Research Centre, Bangladesh agricultural Research Institute (BARI), Gazipur during 2019-20 and 2020-21. The geographic coordination of the experimental location was 24<sup>09</sup>' North Latitude and 90<sup>26</sup>' East Longitude with elevation of 8.2 m from mean sea level. The soil of the experimental site belongs to Chhiata Soil series and has been classified as Grey Terrace Soil, which falls under Inceptisol in Soil Taxonomy under the AEZ-28 (Madhupur Tract). The experimental field soil was sandy clay loam in texture, non-saline, low in organic carbon (0.88%), low in available nitrogen (0.009%), medium in available phosphorus (6.89 ppm) and low in available potassium (0.07 meq 100 g<sup>-1</sup> soil). The experiment was laid out in randomized complete block design with three replications. The experiment comprised five treatment combinations which were: T<sub>1</sub>= 220-70-150-40-5-3 g tree<sup>-1</sup> year<sup>-1</sup> of N-P-K-S-Zn-B, T<sub>2</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 7 kg cowdung tree<sup>-1</sup> year<sup>-1</sup>, T<sub>3</sub>= 165-70-150-40-5-3 g N-P-K-S-

Zn-B + 4 kg vermicompost tree<sup>-1</sup> year<sup>-1</sup>, T<sub>4</sub> = 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup> and T<sub>5</sub> = Control (native fertility). The chemical properties of the organic manures used in the experiment are stated in Table 1.

**Table 1. Nutrient status of organic manure used in the experiment**

Organic manure	pH	OC	N	K	P	S
		(% )				
Cowdung	7.3	10.6	1.1	0.6	0.5	0.06
Vermicompost	7.6	10.7	1.7	0.9	1.1	0.03
Mustard oil cake	6.6	35.6	4.3	1.3	1.9	0.41

The experiment consisted of uniformly grown ten trees of eight-year-old, spaced at 3 m were selected randomly where all the agronomic practices were carried out as per package of practices. The various growth parameters like, plant height, increase in plant height, annual shoots growth and leaf area was recorded by using standard methods. For annual shoot growth, ten annual shoots were randomly selected from all over the periphery of the tree and their length was measured with the measuring tape at the end of growing period and expressed in centimetre. The leaf area (cm<sup>2</sup>) was recorded by randomly collecting twenty-five fully developed leaves from all directions of the tree periphery, measured with the help of Automatic Leaf Area Meter and expressed in square centimetre. The weight of ten leaves was recorded on electronic balance and the results were expressed in grams. The leaves of small branches were harvested on 01 October during both the years and dried in the shade for four days. The recorded data were statistically analyzed by using R version 3.5.0 software to find out the significance of variation between treatments. The difference between treatment means were judged by Least Significant Difference (LSD) test at 5% level of significance.

## Results and Discussion

### Effect of INM practices on growth parameters of bay leaf

Nutrient elements play an important role in plant growth and development, the excess and too low application may hinder growth and yield of bay leaf. So, by reducing the synthetic dose and applied in the form of organic and or integrated forms help to restore nutrient element and make it for available form. The Table 2 showed that the maximum plant height (3.9 m and 4.63 m in 2019-20 and 2020-21, respectively), annual increment of plant height (23.0 and 25.88 cm in 2019-20 and 2020-21, respectively) by the application of the treatment T<sub>4</sub> (165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>) followed by T<sub>3</sub> with (19.67 and 21.7 cm in 2019-20 and 2020-21, respectively), and the minimum increment in plant height (12.0 and 12.66 cm in 2019-20 and 2020-21, respectively) were reported in treatment T<sub>5</sub> (Control). The maximum number of primary and secondary branches per plant (5.4 & 5.6 and 15.5 & 15.1 in 2019-20

and 2020-21, respectively) were recorded in T<sub>4</sub> treatment (165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>) and the minimum (2.3 & 2.9 and 11.5 & 11.3 in 2019-20 and 2020-21, respectively) was noted in T<sub>5</sub> treatment (control). Hence, the present findings exposed that the integrated application of organic and chemical fertilizers was the best treatment for better tree growth. INM based nutrient management supplied all the essential nutrients and also improved soil physical, chemical and microbial properties of soil which enable the crop to utilize nutrients and water more efficiently. The application of recommended dose of N, P, K and S through chemical fertilizers enhanced the availability of nutrients, which resulted in increased photosynthetic activities and translocation of photosynthates from source to sink and resulted in increased plant growth.

**Table 2. Effect of integrated nutrient management on vegetative growth parameters of bay leaf**

Treatment	Plant height (m)		Annual Increment in plant height (cm)		No. of primary branches plant <sup>-1</sup>		No. of secondary branches plant <sup>-1</sup>	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T <sub>1</sub>	3.47a	4.23a	15.0cd	16.7bc	3.9ab	4.3ab	12.4b	12.9c
T <sub>2</sub>	3.74a	4.17a	16.7bc	17.5cd	4.8ab	5.2ab	14.7a	14.3ab
T <sub>3</sub>	3.67a	4.27a	19.7ab	21.7ab	4.7ab	5.0ab	13.3b	13.0bc
T <sub>4</sub>	3.99a	4.63a	23.0a	25.88a	5.4a	5.6a	15.5a	15.1a
T <sub>5</sub>	3.27b	3.37b	12.0d	12.66d	2.3b	2.9b	11.5c	11.3c
CV (%)	5.44	7.84	10.60	9.64	9.03	8.56	3.33	4.59

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

T<sub>1</sub>= 220-70-150-40-5-3 g N-P-K-S-Zn-B tree<sup>-1</sup> year<sup>-1</sup>

T<sub>2</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 7 kg cowdung tree<sup>-1</sup> year<sup>-1</sup>

T<sub>3</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg vermicompost tree<sup>-1</sup> year<sup>-1</sup>

T<sub>4</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>

T<sub>5</sub>= Control

### Effect integrated nutrient management on shoot growth, leaf size and leaf number

Annual increment of shoot, leaf size and number of leaves per feet of shoot were significantly differed by integrated nutrient management practices in bay leaf (Table 3). The maximum annual shoot growth (15.1 and 21.0 cm in 2019-20 and 2020-21, respectively), leaf area (19.23 and 31.33 cm<sup>2</sup> in 2019-20 and 2020-21, respectively) and number of leaves per feet of shoot (18.17 and 19.33 in in 2019-20 and 2020-21, respectively) were recorded T<sub>4</sub> treatment (165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>) and the minimum annual shoot

growth (11.83 and 14.67 cm in 2019-20 and 2020-21, respectively), leaf area (15.87 and 22.83 cm<sup>2</sup> in 2019-20 and 2020-21, respectively) and number of leaves per feet of shoot (11.13 and 13.0 in 2019-20 and 2020-21, respectively) were obtained in T<sub>5</sub> (control). This increase in shoot growth, leaf size and number of leaves might be due to increase in uptake of nutrients and increased release of growth factors (*viz.*, auxins, gibberellins and cytokinins) and essential nutrient availability in root zone. Moreover, the release of nutrients might be considered with the physiological stage which resulted in proper root growth and enhanced nutrient uptake which was reflected in all growth parameters (Musmade *et al.*, 2010). This might be due to the increased photosynthetic rate and carbohydrate accumulation as a result of multifarious role of vermicompost and FYM to allow most favourable conditions of soil with increased availability of plant nutrients responsible for better plant growth (Dutta *et al.*, 2009). Application INM based fertilizer management packages had maintained the sustainable soil fertility in soil thus, improved in growth, leaf size and leaf number over control (Naik and Babu, 2007). The similar finding was also reported by Thakur and Thakur (2014).

**Table 3. Effect integrated nutrient management on shoot growth, leaf size and leaf number of bay leaf**

Treatment	Annual shoot growth (cm)		Leaf area (cm <sup>2</sup> )		No. of leaves feet shoot <sup>-1</sup>	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T <sub>1</sub>	13.50ab	18.33b	18.07a	28.67a	16.10a	19.33a
T <sub>2</sub>	14.90a	18.0b	18.37a	29.0a	16.73a	17.0a
T <sub>3</sub>	13.77a	18.67b	18.53a	29.67a	17.63a	18.33a
T <sub>4</sub>	15.16a	21.0a	19.23a	31.33a	18.17a	19.33a
T <sub>5</sub>	11.83b	14.67c	15.87b	22.33b	11.13b	13.0b
CV (%)	6.75	6.49	5.05	8.03	7.47	10.60

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

T<sub>1</sub>= 220-70-150-40-5-3 g N-P-K-S-Zn-B tree<sup>-1</sup> year<sup>-1</sup>

T<sub>2</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 7 kg cowdung tree<sup>-1</sup> year<sup>-1</sup>

T<sub>3</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg vermicompost tree<sup>-1</sup> year<sup>-1</sup>

T<sub>4</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>

T<sub>5</sub>= Control

### **Effect of integrated nutrient management on leaf weight and leaf yield of bay leaf**

The data presented in Table 4 revealed that integrated nutrient based nutrient management packages influenced the leaf weight and leaf yield of bay leaf. The highest leaf fresh weight (2.40 and 2.53 g in 2019-20 and 2020-21, respectively), leaf dry weight (1.47 and 1.73 g in 2019-20 and 2020-21, respectively) and leaf

yield per plant (7.70 and 8.53 kg in 2019-20 and 2020-21, respectively) were obtained by the application of 165-70-150-40-5-3 g N-PK-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup> while the lowest leaf fresh weight (1.73 and 1.83 g in 2019-20 and 2020-21, respectively), leaf dry weight (0.60 and 0.73 g in 2019-20 and 2020-21, respectively) and leaf yield per plant (5.87 and 6.53 kg in 2019-20 and 2020-21, respectively) were noted in the treatment T<sub>5</sub> (control). This might be attributed to enhancement of nutrient status of the tree. Yield is a complex character which involves the interaction of several intrinsic and external factors. It largely depends upon the production and mobilization of carbohydrates, uptake of nutrients and water from the soil and the hormonal balance, in addition to several environmental factors to which tree is exposed during the growing period. These findings are in accordance with the results of Soni *et al.* (2018). The effectiveness of chemical fertilizers was greatly enhanced, when it was applied along with organic fertilizer, this might have resulted due to better retention of N in root zone and better availability of potash and phosphate to the plants by applying organic matter.

**Table 4. Effect of nutrient management on various leaf yield and yield contributing attributes in bay leaf**

Treatment	Individual leaf fresh weight (g)		Individual leaf dry weight (g)		Leaf yield (kg plant <sup>-1</sup> )	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T <sub>1</sub>	2.23a	2.37a	1.43a	1.47a	7.00a	7.67ab
T <sub>2</sub>	2.37a	2.30a	1.39a	1.66a	7.53a	8.33a
T <sub>3</sub>	2.37a	2.50a	1.43a	1.62a	7.67a	8.37a
T <sub>4</sub>	2.40a	2.53a	1.47a	1.73a	7.70a	8.53a
T <sub>5</sub>	1.73b	1.83b	0.60b	0.73b	5.87b	6.53b
CV (%)	8.76	8.76	18.43	10.68	7.81	8.82

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

T<sub>1</sub>= 220-70-150-40-5-3 g N-P-K-S-Zn-B tree<sup>-1</sup> year<sup>-1</sup>

T<sub>2</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 7 kg cowdung tree<sup>-1</sup> year<sup>-1</sup>

T<sub>3</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg vermicompost tree<sup>-1</sup> year<sup>-1</sup>

T<sub>4</sub>= 165-70-150-40-5-3 g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>

T<sub>5</sub>= Control

## Conclusion

From this study it may be concluded that integrated nutrient management packages had beneficial effect in achieving higher leaf yield of bay leaf. The maximum leaf yield of bay leaf of 7.7 and 8.53 kg plant<sup>-1</sup> in in 2019-20 and 2020-21, respectively was obtained from the fertilization @ 165-70-150-40-5-3g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup>. The overall results indicate that the fertilizer dose @ 165-70-150-40-5-3g N-P-K-S-Zn-B + 4 kg mustard oil cake tree<sup>-1</sup> year<sup>-1</sup> appears to

be the best suitable nutrient management package for achieving higher leaf yield of bay leaf in Grey Terrace Soil of Madhupur tract (AEZ-28).

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**BIOLOGY, MORPHOMETRY AND DAMAGE ASSESSMENT OF  
PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS* WILLIAMS AND  
GRANARA DE WILLINK (HEMIPTERA: PSEUDOCOCCIDAE)**

M. AFROZE<sup>1</sup>, M. A. LATIF<sup>2</sup>, N. AKHTER<sup>3</sup>  
M. D. H. PRODHAN<sup>4</sup> AND S. JAHAN<sup>5</sup>

**Abstract**

Two experiments were conducted to study the biology and damage assessment of papaya mealybug in Sher-e- Bangla Agricultural University. In Biology study, each adult female laid one egg sack and per egg sack contained  $123 \pm 19.52$  eggs in average. The female had three instars' nymphs and male had four. Average duration of female and male was  $22.4 \pm 3.7$  and  $17.2 \pm 2.86$  days, respectively. At 1<sup>st</sup> instar male and female could not be distinguished, average length and breadth was  $0.41 \pm 0.08$  and  $0.25 \pm 0.03$  mm, respectively. Average length and breadth of 2<sup>nd</sup>, 3<sup>rd</sup> instar nymph and adult female were  $0.69 \pm 0.03$ ,  $0.44 \pm 0.02$ ;  $1 \pm 0.14$ ,  $0.72 \pm 0.05$  and  $1.94 \pm 0.27$ ,  $1.38 \pm 0.05$  mm, respectively. The average length and breadth of 2<sup>nd</sup>, 3<sup>rd</sup> instar, pupa and adult male were  $0.70 \pm 0.06$ ,  $0.38 \pm 0.04$ ;  $0.85 \pm 0.02$ ,  $0.41 \pm 0.02$ ;  $0.94 \pm 0.04$ ,  $0.26 \pm 0.03$  and  $0.98 \pm 0.03$ ,  $0.26 \pm 0.01$  mm, respectively. In damage assessment study, papaya plant was covered with fine net and imidacloprid (Admire) 200 SL @ 1ml/L of water was sprayed at 7 days interval and plants also artificially infested by papaya mealybug (100 papaya mealybugs per plant. Mealybug infestation reduced plant height (34.35%), number of leaves per plant (86.08%), petiole length (53.31%), number of flowers per plant (86.23%), number of fruits per plant (89.43%), individual fruit weight (88.01%) as well as total fruit yield per plant (98%). However, some plants showed a total loss in yield, indicating that 100% damage occurred for those plants.

Keywords: Biology, Papaya Mealybug, Damage Assessment, *Paracoccus marginatus*,

**Introduction**

Papaya (*Carica papaya* L.), a member of the Caricaceae family, is an important fruit crop in Bangladesh. Locally, it is popularly known as 'pepe' cultivated all over the country. Now a days papaya is severely damaged by a pest known as papaya mealybug (*Paracoccus marginatus*) Williams and Granara de Willink (Hemiptera: Pseudococcidae). The papaya mealybug, *P. marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) is native to Mexico and/or Central America (Miller *et al.*, 1999). It was first described in 1992 (Williams and Willink, 1992) and re-described by Miller and Miller (2002). Papaya mealybug is

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<sup>1&5</sup>Scientific Officer, Entomology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, <sup>4</sup>Senior Scientific Officer, Entomology Division, BARI, Gazipur, <sup>2&3</sup>Professor, Entomology Department, Sher-E-Bangla Agricultural University, Bangladesh.

a polyphagous insect. The adult female is yellowish color, and is covered with a white waxy coating. Adult male has well developed wings (Miller and Miller, 2002). The Papaya mealybug has been recorded on over 55 species from 25 families, including a variety of economically important crops (Walker *et al.*, 2003). Economically important crop hosts and weed hosts include papaya, hibiscus, avocado, citrus, cotton, tomato, eggplant, peppers, beans, peas, sweet potato, mango, cherry and pomegranate. The specimens of the pest were collected first in 1992 from the Neotropical region in Belize, Costa Rica, Guatemala, and Mexico. Papaya mealybug became a pest when it invaded the Caribbean region. Since 1994 it has been recorded in 14 Caribbean countries. Both Nymph and adult damage the plant. Papaya mealybug infestation appears on above ground parts on leaves, stem and fruits as clusters of cotton-like masses. The insect sucks the sap by inserting its stylets into the epidermis of the leaf, fruit and stem. While feeding, it injects a toxic substance into the leaves, resulting in chlorosis, plant stunting, leaf deformation or crinkling, early leaf and fruit drop, and death of plants. The honeydew excreted by the bug results in the formation of black sooty mould which interferes in the photosynthesis process and causes further damage to the crops. Heavy infestations are capable of rendering fruit inedible due to the buildup of thick white waxy coating. Honeydew attracted the ant which helps in transfer the mealybug one plant to another (Tanwar *et al.*, 2010). The papaya mealybug has been identified firstly in Bangladesh in the year 2009 (Muniappan *et al.*, 2011). Within the last few years this insect pest spreads many parts of the country very rapidly and has become major concern to papaya growers in Bangladesh (Karim *et al.*, 2012). A significant reduction in papaya production in Bangladesh is recorded in the recent years, and among other factors, it is assumed that mainly infestation of this nonindigenous pest is responsible and causing huge economic losses to farmers (Helemul, 2013). The infestation also depends on the atmospheric condition like temperature, rainfall, humidity. Heavy rainfall reduces the population and damage severity (Galanihe *et al.*, 2010). Sometimes it occurs to assume the status of a major pest and it causes severe damage to economically important crops and huge losses to farmers. A survey on the host range and damage assessment of mealybugs in Bangladesh revealed that, according to farmers, papaya had the highest level of infestation which is 95.5% (Mahmud, 2017). Keeping the above facts in view, the experiment was conducted to study biology and damage assessment of papaya mealybug that can further assist to device appropriate management tactics.

### **Materials and Methods**

The experiment was conducted during the period from June, 2017 to December, 2018 to study the biology and damage assessment of papaya mealybug. The study on biology of *P. marginatus* was carried out in Entomology laboratory, Sher-e-Bangla Agricultural University. Adult of papaya mealybug used in this study were confirmed to be *P. marginatus* by the insect identification keys provided by Miller

and Miller (2002). The host plants used in this study was papaya. The individual leaves of host plants with petioles were removed and kept in Petri dish lined with moist cotton to prevent desiccation of leaf. Hence, the whole plant with intact root system was used in the study. Three months old seedlings were planted in the pot and fully an expanded young leaf was preferably at the top most position selected for this experiment. Each plant was inoculated with eggs of *P. marginatus* using a camel hair brush. All plants were observed daily for egg hatching. The interval between each moulting was checked by examining exuviae on the leaves using a hand lens (10X magnification) and the exuviae were removed after each moulting. Morphological determination of all the instars was done under a stereo microscope in the laboratory. The number of days to egg hatch, emergence of first instars, duration of second instar males and females, duration of third instar males and females and duration of fourth instar males (pupa) were recorded. The adult female mealybugs were individually transferred to new leaf (leaves of plant lined with moistened cotton) for monitoring the reproductive period (oviposition and incubation). Adult longevity of five male and female mealybugs was observed.

The damage assessment experiment was conducted at agronomy farm of Sher-e-Bangla Agricultural University. The papaya variety used in the experiment was 'Red Lady'. The experiment consisted of two treatments and 10 replications. The two treatments were: T<sub>1</sub>= papaya plant covered with fine net and imidacloprid (Admire) 200 SL @ 1ml/L of water was sprayed at 7 days interval and T<sub>2</sub> =Artificially infested by papaya mealybug (100 papaya mealybugs per plant)

The experiment was laid out in Randomized Complete Block Design (RCBD) with ten replications. Data on plant height, leaf number, petiole length, number of inflorescences, fruits per cluster, fruit weight were recorded from the sample plants during the course of experiment. Percent damage due to infestation of mealybug calculated by following formula: Percent damage =  $\frac{T_1 - T_2}{T_1} \times 100$ ; [T<sub>1</sub>=Papaya plant covered Papaya plant with fine net and imidacloprid (Admire) 200SL@ 1ml/L of water was sprayed at 7 days interval; T<sub>2</sub>= Artificially infested by papaya mealybug (100 papaya mealybugs per plant)]

The recorded data on various parameters were statistically analyzed using SPSS statistical package program. The mean for all the treatments was calculated and analysis of variance (ANOVA) for all the characters were performed by paired t test.

## Results and Discussions

### Biology and Morphometry of Papaya Mealybug

**Egg sack:** The papaya mealybug (*Paracoccus marginatus*) laid eggs in an egg sack. Each female lays one egg sack (Table 1) after laying the eggs female was died. Egg sack was made of whitish cottony layer (Fig.1).

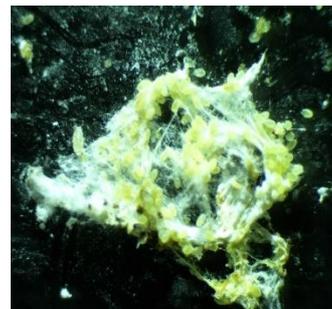


**Fig. 1. Egg Sack.**

**Egg:** Adult female lays (97-150) eggs per sac (Table 1). Eggs were yellowish color and oval shape (Fig.2). The length of egg was  $0.35\pm 0.01$  mm (Table 3) and the breadth was  $0.14\pm 0.008$  mm (Table 3). The average incubation period of the eggs was 4-7 days (Table 2). The oviposition period of a female was 5-8 days (Table 2). Chellappan *et al.* (2013) reported that the length of egg was  $0.34\pm 0.01$  mm and the breadth was  $0.15\pm 0.01$  mm which is also confirmed the present study. They also reported that incubation period was  $8.5\pm 0.85$  days and oviposition period  $7.8\pm 0.63$  days is also close to the present study. Females usually lay 150- 600 eggs in an ovisac. The results of the present study are lying between the ranges of these findings. Egg laying usually occurs over the period of 3-4 days, which is lower than the present study. Egg hatch in about ten days which is lower than the present study. However, this variation might be due to the environmental condition (Jithu *et al.*, 2016). The adult female of *P. marginatus* laid about 150 to 200 eggs inside the ovisacs (Al-Hilal *et al.*, 2012) which are close to the present study. Suganthi *et al.* (2011) reported that the period of egg was  $6.33\pm 0.58$  days and this finding is lying between the present studies. Females usually lay 100 to 600 eggs. Eggs are greenish yellow and are laid in an ovisac and these findings are similar to the present study but they also reported that egg laying usually continues over a period of one to two weeks and eggs hatch in about 10 days, these results are somewhat different to the present study. This variation might be occurred due to environmental condition or host species (Tanwar *et al.*, 2010).



A



B

**Fig. 2. A. Egg, B. A mass of egg.**

**Table 1. Number of eggs per sack, egg sack laid per female during May 2018**

Observations	Egg number
1	97.0
2	120.0
3	118.0
4	130.0
5	150.0
Mean± SD	123±19.52

**Nymph:** Females have three instars' nymphs whereas males have four instars (Table 2). Al-Hilal *et al.* (2012) observed that in case of *P. marginatus*, generally three and four nymphal instars took place in case of female and male mealybug, respectively, this finding is same as the present result.

**First instar nymph:** At this stage male and female could not be distinguished (Fig. 3). First instar nymph was very active. The length of the nymph was  $0.41 \pm 0.08$  mm (Table 3) and the breadth was  $0.25 \pm 0.03$  mm (Table 3). The average duration of 1<sup>st</sup> instar nymph was 4-6 days (Table 2). The first instar nymph is yellowish color (Fig. 3). Miller and Miller (2002) reported that in 1<sup>st</sup> instar gender could not be determined and nymph is yellow color which is similar to the present findings. They also reported that the length and breadth of nymph were 0.4 mm and 0.2 mm which is close to the present findings. 1<sup>st</sup> instar nymph was  $4.6 \pm 0.52$  days this result is accordance with the present result (Chellappan *et al.*, 2013). Seni and Sahoo (2014) studied the biology of *P. marginatus* on sprouted potato throughout the year revealed that the duration of first instar nymphs ranged from 3-17 days and the present study finding is also lying between the ranges of this findings. The sexes of which could not be distinguished and this finding is same as the present result. The length of first instar nymph were  $0.42 \pm 0.074$  mm and  $0.024 \pm 0.27$  mm in width. This instar appears yellowish in color which is similar to the present findings (Al-Hilal *et al.*, 2012). Suganthy *et al.* (2011) reported that the period of first instar nymph was  $4.00 \pm 1.00$  days and this finding is lying between the present studies.



A



B

**Fig. 3. A. A mass of 1<sup>st</sup> Instar Nymph, B. 1<sup>st</sup> instar nymph**

**Second Instar Nymph:** The 1<sup>st</sup> instar nymph was moulted to 2<sup>nd</sup> instar nymph and casted their exuvae. The 2<sup>nd</sup> instar female was yellowish color (Fig.4) and male was pink color (Fig.4) Female length was  $0.69\pm 0.03$  mm and breadth was  $0.44\pm 0.02$  mm and the male was  $0.70\pm 0.065$  mm long and  $0.38\pm 0.04$  mm wide (Table 3). Average duration of 2<sup>nd</sup> instar female nymph was 3-5 days and the 2<sup>nd</sup> instar male nymph was 3-4 days (Table 2). Miller and Miller (2002) reported that the 2<sup>nd</sup> instar female was yellowish color and male was pink color which is similar to the present study. They also reported that 2<sup>nd</sup> instar female length and breadth was 0.7 mm and 0.04 mm which is close to the present study. But the 2<sup>nd</sup> instar male nymph 0.4 mm long and 0.02 mm wide which is somewhat different to the result. Chellappan *et al.* (2013) find that 2<sup>nd</sup> instar male nymph was  $0.75\pm 0.02$  mm long and  $0.44\pm 0.02$  mm wide, which is similar to this study. They also observed that 2<sup>nd</sup> instar female nymph average duration was  $4.2\pm 0.63$  days and 2<sup>nd</sup> instar male nymph average duration was  $4.3\pm 0.67$  days. Al-Hilal *et al.* (2012) observed that the length of second instar female nymph was  $0.6\pm 0.054$  mm and  $0.089\pm 0.4$  mm in width. Body color appeared yellow in field conditions. Length of second instar male nymph was  $0.62\pm 0.044$  mm and  $0.09\pm 0.3$  mm in width. Body looks like yellow in color during field observation. The length of second instar male and female is close to the present result but the width showed different result and this might be due to the environmental condition or host species. The period of second instar nymph was  $3.67\pm 0.58$  days (Suganthi *et al.*, 2011) and this finding is lying between the present studies.

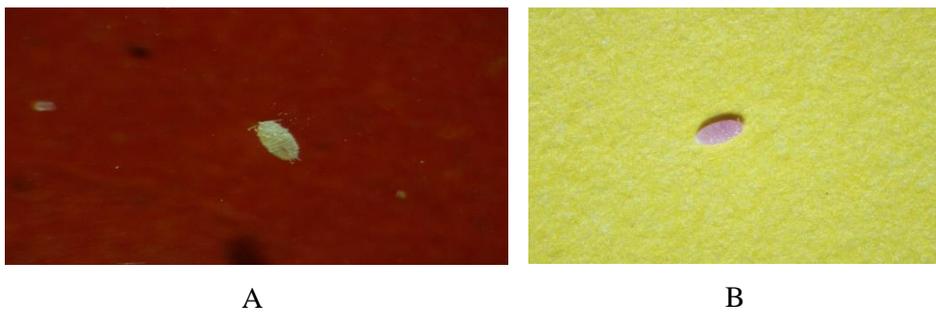
**Table 2. Duration of different life stages of *Paracoccus marginatus* during May 2018**

Life stage	Observation	Period in Days Average $\pm$ SD	Temperature (°C)	Relative Humidity (%)
Oviposition	5	$6.00\pm 1.22$		
Incubation period	5	$5.80\pm 1.09$		
1 <sup>st</sup> instar gender is not identified	5	$4.80\pm 0.83$	21-36	45-97
2 <sup>nd</sup> instar female	5	$4.20\pm 0.83$		
3 <sup>rd</sup> instar female	5	$3.40\pm 0.54$		
Adult female	5	$10.0\pm 2.00$		
2 <sup>nd</sup> instar male	5	$3.60\pm 0.54$		
3 <sup>rd</sup> instar male	5	$2.80\pm 0.83$		
Pupa	5	$3.60\pm 0.54$		
Adult male	5	$2.40\pm 0.54$		
Total lifespan male	5	$17.2\pm 2.86$		
Total lifespan female	5	$22.4\pm 3.70$		



**Fig. 4. A. 2<sup>nd</sup> Instar nymph female B. 2<sup>nd</sup> Instar nymph male.**

**Third instar nymph:** The 2<sup>nd</sup> instar female moulted after 3-4 days and male was moulted after 2-4 days into 3<sup>rd</sup> instar nymph (Table 2). The 3<sup>rd</sup> instar male was pink color (Fig.5) and the female was yellowish color (Fig.5). Female length was  $1 \pm 0.14$  mm and breadth was  $0.72 \pm 0.05$  mm and male 3<sup>rd</sup> instar nymph was  $0.85 \pm 0.02$  mm long and  $0.41 \pm 0.02$  mm wide (Table 3). Miller and Miller (2002) reported that the 3<sup>rd</sup> instar female was yellowish color and male was pink color which is confirmed the present study. They also reported that 3<sup>rd</sup> instar female length and breadth were 1.1 mm and 0.7 mm and male were 0.9 mm and 0.4 mm which is similar to the present result. Studies made by Chellappan *et al.* (2013) observed that 3<sup>rd</sup> instar female and male average duration were  $5.1 \pm 0.32$  days and  $2.6 \pm 0.52$  days, which also confirmed the present study. Al-Hilal *et al.* (2012) observed that the length of third instar nymph was  $0.89 \pm 0.11$  mm and it was  $0.12 \pm 0.51$  mm in width. Body appears yellow in color during field observation. Length of third instar male nymph was  $1.05 \pm 0.23$  mm and  $0.156 \pm 0.59$  mm in width. Body looks like yellow in color during field observation. This is result somewhat different from the present result and this might be due to the environmental condition or host species. The period of third instar nymph was  $5.00 \pm 1.00$  days (Suganthi *et al.*, 2011). and this finding is higher than the present study. This variation might be due to the environmental condition or host species.



**Fig 5. A. 3<sup>rd</sup> Instar nymph female, B. 3<sup>rd</sup> Instar nymph male**

**Table 3. Measurement of different stages of *Paracoccus marginatus***

Stage	Length (mm) Average $\pm$ SD	Breadth (mm) Average $\pm$ SD
Egg	0.35 $\pm$ 0.03	0.14 $\pm$ 0.01
1 <sup>st</sup> instar (gender not identified)	0.41 $\pm$ 0.08	0.25 $\pm$ 0.03
2 <sup>nd</sup> instar female	0.69 $\pm$ 0.03	0.44 $\pm$ 0.02
3 <sup>rd</sup> instar female	1 $\pm$ 0.14	0.72 $\pm$ 0.05
Adult female	1.94 $\pm$ 0.27	1.38 $\pm$ 0.05
2 <sup>nd</sup> instar male	0.7 $\pm$ 0.06	0.38 $\pm$ 0.04
3 <sup>rd</sup> instar male	0.85 $\pm$ 0.02	0.41 $\pm$ .02
Pupa	0.94 $\pm$ .04	0.26 $\pm$ 0.03
Adult male	0.98 $\pm$ .03	0.26 $\pm$ 0.01

**Pupa:** The 4<sup>th</sup> instar nymph occurred only in case of male *P. marginatus*. It is the pupal stage. The duration of this stage was 3-4 days (Table 2). The length of pupa was 0.94  $\pm$ .04 mm and breadth were 0.26 $\pm$ .03 mm (Table 3). Pupal stage occurred in a cocoon. The cocoon was made of whitish cotton like thread. The color of pupa was pink (Fig. 6). The pupa was pink color and length and breadth of pupa were 1.0 mm and 0.03 mm (Miller and Miller, 2002) which also supported the present result. Average duration of pupa was 4.2 $\pm$ 0.63 days, almost similar to that determined by Chellappan *et al.* (2013). Al-Hilal *et al.* (2012) observed that the length of fourth instar nymph was 0.98 $\pm$ 0.075 mm and 0.02 $\pm$ 0.49 mm in width. Body color appeared pink but occasionally yellowish. Only width is different from the present result but length and color support the current finding.

**Fig. 6. Pupa.**

**Adult female:** Body is yellowish color, dusted with mealy wax not thick enough to hide body color (Fig.7) without discrete bare areas on dorsum, with many short waxy filaments around body margin. Body was 1.94 $\pm$ 0.27 mm long and 1.38 $\pm$ 0.05 mm wide (Table 3). The antennal segment of this adult female was 8. The average duration of adult female was 8-13 days (Table 2). The adult female was yellow color and 2.2 mm long and 1.4 mm wide (Miller and Miller, 2002), and the present findings close to that. Chellappan *et al.* (2013a) studied that the average duration

of adult female was  $22.4 \pm 1.35$  days somewhat different to the current result. The length of adult female was  $2.08 \pm 0.354$  mm and it was  $1 \pm 0.063$  mm in width. Body was yellow in color during field observation (Al-Hilal *et al.*, 2012). The length of this finding also supports the present finding but the width is less than the present finding. Suganthy *et al.* (2011) reported that adult longevity of females was  $20.33 \pm 1.53$  days, which is higher than the present finding as their host species was different which was sunflower and their temperature and relative humidity were also different that was 25-30 °C and 75-80%. On the other hand, during this experiment temperature range was 21-36°C and relative humidity was 45-95%.



**Fig. 7. Adult female.**

**Adult male:** Adult male was winged (Fig.8). Antennae 10 segmented. The length of the adult male was  $0.98 \pm 0.03$  mm and the breadth were  $0.26 \pm 0.01$  mm (Table 3). The wings are white color. The longevity of adult male was 2-3 days (Table 2).

According to Miller and Miller (2002), the adult male had wings and measured 1.0 mm in length and 0.03 mm in width. These measurements are similar to the current findings.

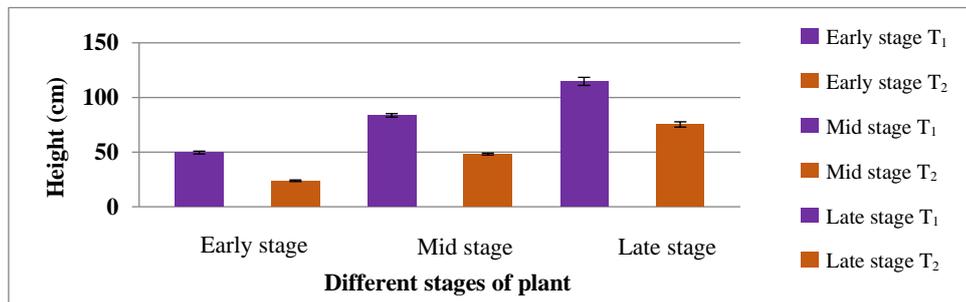
Chellappan *et al.* (2013) observed that the average duration of adult male was  $2.7 \pm 0.48$  days which is accordance with the present result. The length of adult male was 1.5 mm and was 0.5 mm in width. Body color appeared pink, but occasionally yellowish; these findings different from the present findings. This variation might be due to the environmental condition or host species (Al-Hilal *et al.*, 2012). Suganthy *et al.* (2011) reported adult longevity of males was  $1.67 \pm 1.15$  days and this finding supports the present investigation.



**Fig. 8. Adult male.**

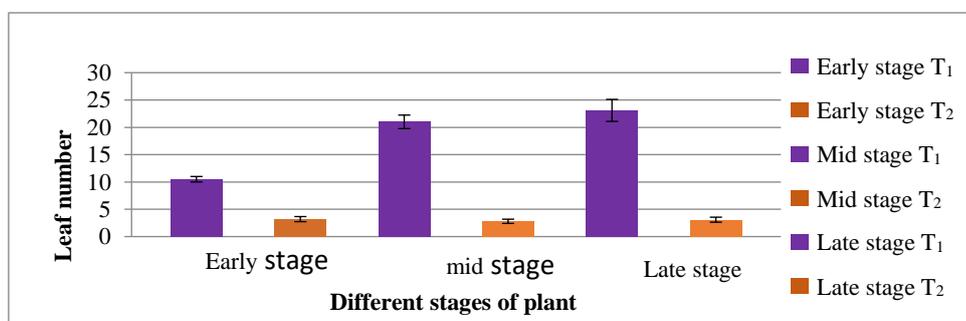
### Damage Assessment of papaya field after infestation papaya mealybug

**Plant Height:** The result indicated that papaya plant height increased progressively with the advancement of time and growth stages. At early stage, average plant height was 49.6cm in T<sub>1</sub> and 23.80cm in T<sub>2</sub>. At middle stage the plant height in T<sub>1</sub> was 83.6cm per plant and in case of T<sub>2</sub> that was 48.20cm per plant. At later stage, average height of plant in T<sub>1</sub> was 114.70cm per plant and average height of plant in T<sub>2</sub> was 75.30cm per plant. The result indicated that T<sub>1</sub> showed the higher plant height and T<sub>2</sub> became stunted. This finding reveals that in early, mid and late-stage infested plant (T<sub>2</sub>) height was reduced 52.01%, 42.6%, 52.25% respectively comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.9).



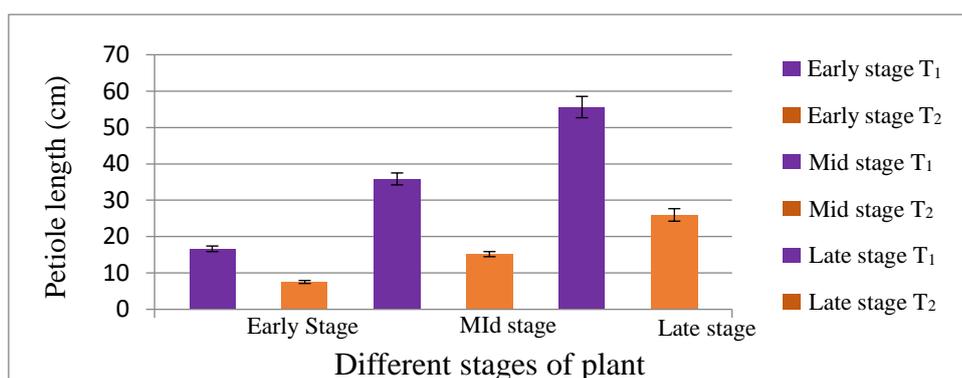
**Fig. 9.** Effect of papaya mealybug infestation on plant height of papaya plant at different stages of plant.

**Leaf number:** In early stage, the leaf number of plant in case of T<sub>1</sub> was 10.5 and in case of T<sub>2</sub> plant which was infested with mealybug showed lower number of leaves that was 3.2. In mid stage, the leaf number of plant in T<sub>1</sub> treatment was increasing rapidly and that was 21 but in the case of T<sub>2</sub> plant showed very poor number of leaves that was 2.8. In late stage, the leaf number of plant in T<sub>1</sub> also had leaf number increasing that was 23 on the other hand leaf number of T<sub>2</sub> plant was 3.1 which was very lower than that of T<sub>1</sub> plant. This result indicated that in early, mid and late-stage leaf number reduced 69.5%, 86.6%, 86.08% respectively due to infestation of papaya mealybug (Fig.10)



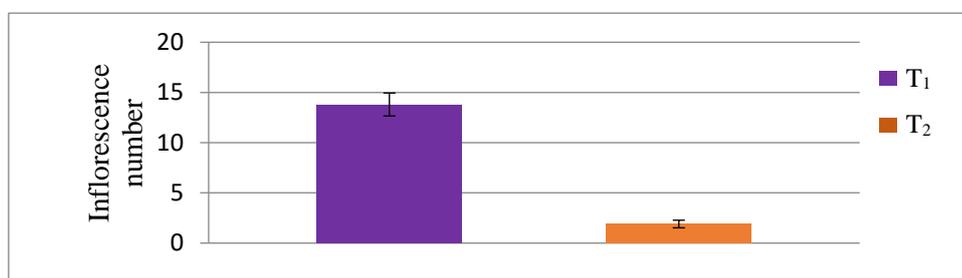
**Fig. 10.** Effect of papaya mealybug infestation on average leaf number of papaya plant at different stages of plant.

**Petiole Length:** At early stage, average petiole length of T<sub>1</sub> was 16.65 cm and the average petiole length of T<sub>2</sub> was 7.52 cm. At middle stage, petiole length in T<sub>1</sub> was 35.85 cm and 15.17 cm in T<sub>2</sub>. At later stage, average petiole length of T<sub>1</sub> was 55.61 cm and average petiole length of T<sub>2</sub> was 25.96 cm. The result indicated that T<sub>1</sub> showed longer petiole length than T<sub>2</sub>. This result indicated that in early, mid and late-stage petiole length reduced 54.83%, 57.68%, 53.31% respectively comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.11).



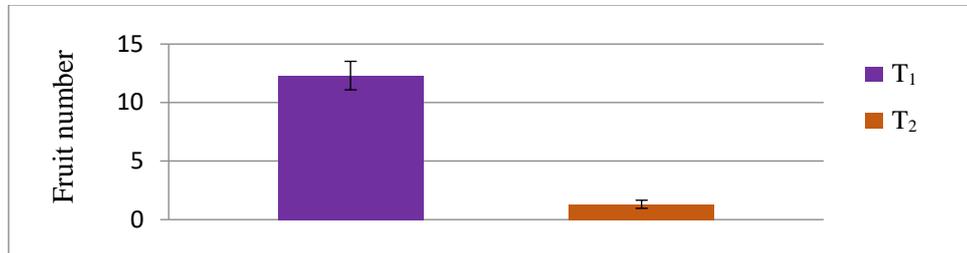
**Fig. 11. Effect of papaya mealybug infestation on average petiole length of papaya plant at different stages of plant.**

**Inflorescence Number:** No of inflorescence in T<sub>1</sub> was 13.80 but T<sub>2</sub> showed very lower number of inflorescences. Average inflorescence number for T<sub>2</sub> was 1.90. This result indicated that in reproductive stage inflorescence number reduced 86.23% comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.12).



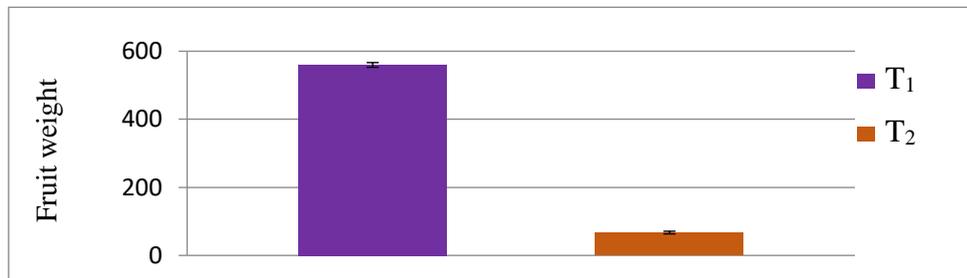
**Fig. 12. Effect of papaya mealybug infestation on average inflorescence number of papaya plant.**

**Fruit Number:** In the case of T<sub>1</sub> average number of fruits per plant recorded was 12.30. On the other hand, the average number of fruits in T<sub>2</sub> recorded was 1.30. This result indicated that in reproductive stage fruit number reduced 89.43% comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.13).



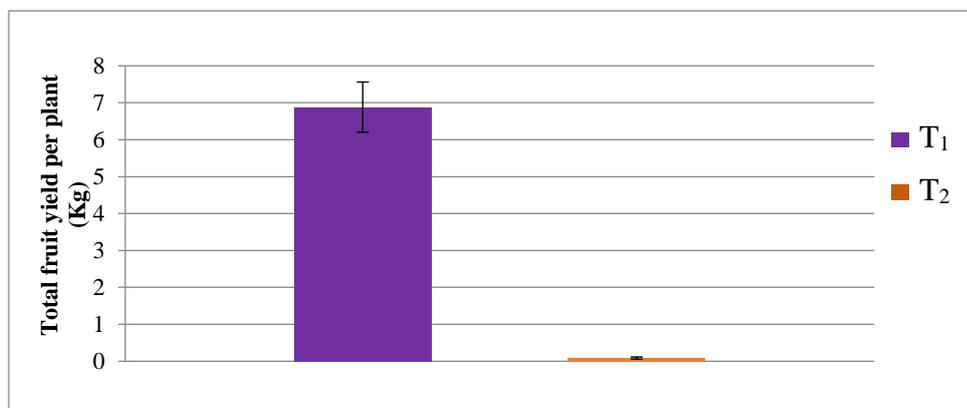
**Fig. 13. Effect of papaya mealybug infestation on average fruit number of papaya plant.**

**Average Fruit Weight:** Average weight of fruit in T<sub>1</sub> was 559.7gm on the contrary average weight fruit was 67.1gm in T<sub>2</sub>. This result indicated that fruit weight reduced 88.01% comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.14).



**Fig. 14. Effect of papaya mealybug infestation on average fruit weight (g) of papaya plant.**

**Total fruit yield per plant:** Total fruit yield per plant in T<sub>1</sub> was 6.88 kg on the contrary total fruit yield 0.087 kg in T<sub>2</sub>. This result indicated that total fruit yield per plant reduced comparing with the healthy plant (T<sub>1</sub>) 98% comparing with the healthy plant (T<sub>1</sub>) due to infestation of papaya mealybug (Fig.15).



**Fig. 15. Total fruit yield per plant (Kg).**

## Conclusion

In this experiment the characteristics of eggs, larvae, pupae and adult were studied. This information will be very helpful in predicting its development, emergence, distribution and abundance, which will also help in developing effective management strategies. Moreover, damage assessment revealed that due to infestation of papaya mealybug, papaya field was severely damaged. The damage percent was more than 80%, and thus it caused great losses in papaya production in Bangladesh.

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## EFFECT OF NITROGEN REGIMES ON THE YIELD AND QUALITY OF ONION (*Allium cepa* L.) THROUGH SET TO BULB METHOD

M. A. KHAN<sup>1</sup>, M. M. RAHMAN<sup>2</sup>, R. SARKER<sup>3</sup>  
M. A. ALAM<sup>4</sup> AND N. S. BRISTY<sup>5</sup>

### Abstract

The experiment was conducted at the Spices Research Sub-Centre (SRSC), Bangladesh Agricultural Research Institute (BARI), Faridpur during winter season of 2023-2024 from October to January to find out the optimum dose of nitrogen for higher yield and quality of onion (var. BARI Piaz-4) through set to bulb method. The experiment comprised 7 levels of nitrogen, viz. T<sub>1</sub>: 0 kg N/ha, T<sub>2</sub>: 30 kg N/ha, T<sub>3</sub>: 60 kg N/ha, T<sub>4</sub>: 90 kg N/ha, T<sub>5</sub>: 120 kg N/ha, T<sub>6</sub>: 150 kg N/ha and T<sub>7</sub>: 180 kg N/ha. The experiment was laid out in the Randomized Complete Block Design with three replications. The results revealed that characteristics studied were influenced by N regimes. Growing onion without N exhibited yellowing in colour on the leaves of plants under the score 5 significantly followed by 30 kg N/ha (score 3). While, onion plants receiving N @ 60-180 kg/ha had no sign of yellowing on the plant. Instead of yellowing, plants with higher doses of N showed dark green colour. Days to maturity were increased with increasing N up to 150 kg N/ha ranging from 75.33 to 82.33 days. And then it was decreased to 81.07 days at 180 kg N/ha. Incorporation of 150 kg N/ha produced the highest bulb yield (22.15 t/ha) closely followed by 180 kg N/ha (21.08 t/ha), 120 kg N/ha (20.74 t/ha) and 90 kg N/ha (17.32 t/ha). Plants with 120 kg N/ha gave 16.43% split bulb which was statistically similar to the 90 kg N/ha (14.96%) and 150 kg N/ha (18.22%). Incidence of bolting gradually decreased with the increase in N rates. In the economic point of view, the highest gross return (Tk. 890295), net return (Tk. 624968) and benefit-cost ratio (3.36) were observed at 150 kg N/ha. It is concluded that 150 kg N/ha was optimum for the production of onion (var. BARI Piaz-4) through set to bulb method.

Keywords: Onion, *Allium cepa*, Nitrogen, Set to Bulb Method, Yield and Quality.

### Introduction

Onion (*Allium cepa* L.) is a member of the family Alliaceae grown throughout the world including Bangladesh. It is one of the most important spice crops popularly known as 'piaz' in Bangladesh. Among the spice crops, onion ranks first in Bangladesh based on the daily intake (35 g/day/person) and production as well. The total area for onion production in the country is about 2.04 lakh hectare, which produces about 25.47 lakh metric tons per annum and the average yield is very low, being 12.51 t/ha (Anon.,2024) as compared to Indian onion yield, being 16.80

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<sup>1,2&3</sup>Principal Scientific Officer & <sup>2</sup>Scientific Officer, Spices Research Sub-Centre, Bangladesh Agricultural Research Institute (BARI), Faridpur; <sup>4</sup>Scientific Officer, Spices Research Centre, BARI, Bogura and <sup>5</sup>BSAg, College of Agricultural Science, International University of Business Agriculture and Technology, Dhaka, Bangladesh.

t/ha. The production of the country does not fulfill country's demand and to fulfill this demand, the government of Bangladesh imports around 9 lakh metric tons onions and shallots per year by expending hard earned foreign currency about 4 lakh crore Tk (Anon., 2024). Farmers in Bangladesh grow their onion following three methods: a) transplanting of seedlings, b) direct seeding in line or broadcast and c) through set to bulb method. Around 25-30% of total annual onions are produced through set to bulb method. In many countries, onions are largely grown through set to bulb method (Khokhar *et al.*, 2002). The sets (small bulbs) are produced in previous season by seeding thickly @ 4-6 g seeds/m<sup>2</sup>. The crops grown by set to bulb method can come into the market quite early in the season and meets market demand for several months. However, early harvesting during the season compensates for the additional price cost required for sets by high price received for the crops. The bulbs produced in this method are entirely fresh (green onion) and these bulbs are immediately consumed but not suitable for store purpose. Onion production is greatly influenced by different factors including cultural practices. Among the cultural practices, fertilizer especially nitrogen (N) plays an important role for producing onion. Islam *et al.* (1999) observed that the growth, yield and quality of onion produced through set to bulb method were greatly influenced by N doses. Both insufficient and excessive addition of N reduce yield and quality of onion. In Bangladesh, farmers grow their onion through set to bulb method by using different doses of nitrogen according to their willingness. Several studies have done with nitrogen on the growth, yield, quality of transplanting onion (Nasreen *et al.*, 2007), but so far, research work on nitrogen doses for onion production through set to bulb method in the country is scanty. Therefore, it is very essential to determine optimum N dose for higher bulb yield of onion. The aforesaid reasons deserve the study on nitrogen fertilization for growing onion in set to bulb method. The present experiment was, therefore, undertaken to find out the optimum dose of nitrogen for higher yield and quality of onion (var. BARI Piaz-4) through set to bulb method.

### **Materials and Methods**

The experiment was conducted at the Spices Research Sub-Centre (SRSC), Bangladesh Agricultural Research Institute (BARI) Faridpur during *rabi* season of 2023-2024 from October to January to find out the optimum N dose for higher yield and quality of onion (var. BARI Piaz-4) through set to bulb method. The experiment consisted of seven levels of nitrogen doses viz. T<sub>2</sub>: 0 kg N/ha, T<sub>2</sub>: 30 kg N/ha, T<sub>3</sub>: 60 kg N/ha, T<sub>4</sub>: 90 kg N/ha, T<sub>5</sub>: 120 kg N/ha, T<sub>6</sub>: 150 kg N/ha and T<sub>7</sub>: 180 kg N/ha. A 3.5-6.5g size of disease free and healthy individual onion sets was used in the study. These sets were produced at Spice Research Sub Centre (SRSC), Bangladesh Agricultural Research Institute (BARI), Faridpur in previous season (2021-2022) by seeding thickly @ 4-6 g/m<sup>2</sup> in well prepared land like nursery bed. The field trial was laid out in randomized complete block design (RCBD) with three replications. The produced onion sets were planted in raised bed on 23 October 2023 with the spacing of 15 cm x 10 cm. Bulbs were placed keeping

upright at a depth of 2.5 cm. Sets were also planted at the border of the experiment field separately for reuse when required. Rotten bulbs of the experimental plots were replaced by healthy ones from the border within 7 days of planting. The unit plot size was 2.00 m x 1.50 m having 200 plants. The experimental site belongs to Agro Ecological Zone-12 (Low Ganges River Floodplain). Soil samples were randomly collected at 0-30 cm soil depth for physical and chemical analysis before the commencement of the experiment. The physico-chemical properties of the field experimental plot are summarized in the Table 1. The soil was texturally clay loam and alkaline in reaction with the pH of 8.10. The presence of organic matter content in the trial field soil was very low (1.43%) against optimum requirement of 5%, as described by Khan (2018). The total available N content in the experimental soils was 0.08% which was within the range of low. The other nutrients, namely P, K, S, B and Zn were above the critical level. Rice (var. BRR1 dhan57) was grown in the field before the experiment conducted. The experimental field was fertilized with 3000 kg well-decomposed cow dung, 0-180 kg N (as per treatment), 50 kg P, 85 kg K and 40 kg S per hectare. Cow dung was applied before ploughing the land. The entire quantity of triple super phosphate (TSP) for P, muriate of potash (MOP) for K, gypsum for S and one third of urea for N were applied as basal dose during final land preparation. The remaining urea was incorporated as top dress in two equal splits at 25 and 45 days after set planting. Two irrigations were applied in the field. First and second irrigation were done on 14 November 2023 and on 03 December 03, 2023, respectively. Preventing measure was taken by spraying Rovral 50 WP (500 g iprodione/kg Rovral) @ 3 g/litre of water at 35 days after planting (DAP) to keep the crops free from diseases. Second spraying was done with Nativo 75 WG (trifloxystrobin 25% and tebuconazole 50%) @ 0.6 g/litre of water at 45 DAP. Third spraying was done with Rovral at 55 DAP using the above rate to keep the diseases under control. Last spraying was done with Nativo using the above rate at 65 DAP. Bulbs were harvested at maturity when the pseudostem of non-bolted plants becomes flaccid and unable to support the leaf blades. Under the study harvesting of bulb was done at different dates according treatments. The leaves of harvested onion were removed by cutting 2.0-2.5 cm above the bulb. Ten plants were randomly selected from each plot for recoding data and averaging it. Flower stalks were taken on 29 December 2023, 02 January 2024 and 06 January 2024 from each treatment. Data was recorded on plant height (cm), number of leaves per plant (no.), percent bolting (%), yellowing of leaves (%), maturity of bulbs (days), polar and equatorial diameter of bulb (cm), individual bulb weight (g), multiplier (split) bulbs (%), dry matter content of bulbs (%), total soluble solid content (°brix or %), weight of flower stalks per plot (g) and days to maturity. Flower stalk weight per plot and bulb weight per plot were converted to per hectare yield as kg/ha and t/ha, respectively. Plant height and number of leaves were recorded at harvest. The number of bolting plants (undesirable flowering stalk) was visually counted in each plot, recorded and expressed in percent in relation to the total number of plants. The yellowing severity of leaf caused by nitrogen deficiency was scored by following 0-5 scale. The details of scales are as follows:

0- no yellowing symptoms, 1- yellowing covering 10% leaf area, 2- yellowing covering 20% leaf area, 3- yellowing covering 40% leaf area, 4- yellowing covering 75% leaf area and 5- complete yellowing of the leaves. Observations were made at the first appearance of yellowing symptoms on leaves, till the harvest at weekly intervals. The yellowing severity of leaf was presented with bar graph. The number of multiplier (split) bulbs was visually counted in each plot, recorded and expressed in percent in relation to the total number of bulbs per plot. The percent dry matter content of bulbs was calculated by dry weight basis as per procedure of Walle *et al.* (2018). Percentage data of bolting, split bulb, single bulb and dry matter of bulb were converted into Arcsine transformation values. The Arcsine transformation values were shown in parenthesis. The total soluble solid (TSS) content of bulbs was recorded by hand held refractometer (ATAGO, Master-53M, Japan) with a range of 0-53 °brix. The recorded data were analyzed with the help of Statistical Software 'R' and the means were compared by the least significant difference (LSD) test.

Profitability analysis was done. Based on the market price of all the applied inputs and wholesale price of the produce; cost, return and benefit ratio (BCR) were calculated.

**Table 1. Physico-chemical properties of initial soil at the experimental plot of SRSC, BARI, Faridpur in 2021-2022**

Soil texture	Soil pH	OM (%)	K	Ca	Mg	Total N (%)	P	S	B	Zn	Fe	Cu	Mn
			meq/100 g				µg/g soil						
Clay loam	8.10	1.43	0.57	27.96	4.3	0.08	21.7	18.6	0.67	2.76	33.92	0.53	11.9
Critical level			0.12	2.0	0.5	0.15	7.0	10.0	0.2	0.6	4.0	0.2	1.0

## Results and Discussion

### Plant height

Plant height was significantly influenced by various nitrogen (N) doses (Table 2). Plant height was increased with the increase of nitrogen doses up to 150 kg/ha and then it was decreased. The tallest plant was recorded at 150 kg N/ha (43.93 cm) closely followed by 120 kg N/ha (42.85 cm). Growing onion through set to bulb method without N gave the shortest plant (30.92 cm). Nitrogen application @ 180 kg/ha produced 43.80 cm tall plant height. The shortest plant height from without nitrogen might be due to growing onion under deficient of N in the soil (Table 1). Rice *et al.* (1990) recorded stunted onion plant with a lower level of N in soil. The increase in plant height with the addition of higher N fertilizer could be due to the increased availability of N for vegetative growth because of protein synthesis and the accumulation of carbohydrates. This finding agrees with the result of Tiffin and Boxworth (2005) who disclosed that onion plants that were deficient in

nitrogen had stunted growth depending on the severity of the deficiency. The lowest plant height from zero kg N/ha or lower dose of N might be due to N deficiency, which limits chloroplast development, chlorophyll concentration and enzyme activity (Soleymani and Shahrajabian, 2012). Islam *et al.* (1999) registered increasing plant height with the increase in N rates (0, 60, 120 & 180 kg N/ha) in set to bulb method. On the other hand, Nasreen *et al.* (2007) reported that plant height increased with the increase in N rates (0, 80, 120 & 160 kg N/ha) up to 120 kg N/ha and then it was tended to decrease with further increase in N rates in transplanting onion. The decreasing plant height from 180 kg N/ha might be due to over dose of nitrogen. Excessive use of N fertilizers is a concern, since large amounts of N can remain in the soil after crop harvest (Fageria and Baligar, 2005). They also stated that usually 50% of N applied is effectively used by plants. Excess nitrogen increases plant height.

**Table 2. Effects of nitrogen regimes on plant height, number of leaves/plants, incidence of bolting, equatorial and polar diameter of onion in set bulb method**

Nitrogen rate (kg/ha)	Plant height (cm)	Number of leaves/plant	Bolting (%)	Bulb equatorial diameter (cm)	Bulb polar diameter (cm)
0	30.92	3.87	8.17 (16.61)	2.95	3.86
30	36.19	3.99	12.67 (20.85)	3.76	4.57
60	38.94	4.52	12.17 (20.42)	3.97	4.86
90	41.71	4.73	11.33 (19.67)	4.27	5.72
120	42.85	4.89	10.83 (19.21)	4.51	5.99
150	43.93	5.65	10.59 (18.99)	4.79	6.10
180	41.80	5.33	9.83 (18.27)	4.53	5.91
CV%	7.85	8.16	11.93	9.78	10.48
LSD (0.05)	4.265	0.716	3.516	0.694	1.173
Level of sig.	**	*	*	**	**

Foot note: \*\* Significant at the 1% level of significance and \* Significant at the 5% level of significance. <sup>+</sup>Arcsine transformed values were shown in the parenthesis.

### Number of leaves per plant

Number of leaves per plant was significantly influenced by various N doses (Table 1). The maximum number of leaves per plant was observed at 150 kg N/ha (5.65) closely followed by 120 kg N/ha (4.89), 90 kg N/ha (4.73) but significantly followed by 60 kg N/ha (4.52). However, the lowest number of leaves per plant was noted with nourishing onion field @ zero (0) kg N/ha (3.87). The lowest number of leaves per plant from zero kg N/ha or lower dose of N might be due to N deficiency, which limits chloroplast development, chlorophyll concentration and enzyme activity (Soleymani and Shahrajabian, 2012). At the maximum dose @ 180 kg N/ha, number of leaves per plant tended to reduce. Increased leaf number

per plants with increase in the rate of N dose might be due to reasons mentioned above in the case of plant height. The current result was supported by the earlier findings of Dinega *et al.* (2023), who observed that increasing N from 50 to 150 kg/ha increased leaf number. Beyond 150 kg/ha, the number of leaves decreased. Islam *et al.* (1999) depicted that number of leaves/plants increased with the increase in N rates (0, 60, 120 & 180 kg/ha) in set to bulb method, while, in transplanting method Nasreen *et al.* (2007) recorded gradual increase in number of leaves per plant with the increase in N rates (0, 80, 120 & 160 kg N/ha) up to 120 kg N/ha and then it was tended to decline with further increase in N rates.

### **Bolting percentage**

The first highest and second highest percentage of bolting were observed from the application of 30 and 60 kg N/ha (12.67%, 12.17%), respectively, beyond which it was gradually and insignificantly decreased with the increase in N rates. Plants receiving zero (0) kg N/ha produced the lowest bolting percentage (8.17%). When onion plants experienced a mild nutrient stress, such as reduced nitrogen, they may accelerate their reproductive cycle. This stress responsible causes the plant to shift from vegetative to reproductive growth as a survival mechanism, leading to more abundant flowering. Hence, nitrogen deficient onion plants with 30-60 kg N/ha resultant in more flowers. Low C/N ratio (@ higher N rates favours vegetative growth and high C/N ratio (@ lower N rates favours reproductive growth in horticultural plants. They further stated that bulb N content increased with increasing N fertilizer and bolting decreased steadily with increasing bulb and shoot N contents. The present result is in agreement with the findings of Geisseler *et al.* (2022) and Abdissa *et al.* (2011) who stated that increasing N availability generally decreased incidence of bolting. On the other hand, onion plants without receiving nitrogen would be unable to carry out efficient photosynthesis, leading to reduced energy production and stunted growth, which would hinder both vegetative and reproductive development.

### **Diameter of bulb**

The equatorial diameter of bulb was increased with the increase of N doses up to 150 kg N/ha ranging from 2.95 to 4.79 cm, beyond which the equatorial diameter was decreased (4.53 cm) and the lowest from control (3.86 cm). The similar results were also found for polar diameter of bulb. Application of N @ 150 kg/ha gave the maximum polar diameter (6.10 cm) closely followed by 90 kg N/ha (5.72 cm), 120 kg N/ha (5.99 cm) and 180 kg N/ha (5.91 cm). While the minimum polar diameter of bulb (3.86 cm) was recorded when no nitrogen was applied. Polar and equatorial diameter of bulbs were increased by 43.66% with the increase in N rate from 50 to 150 kg/ha (Dinega *et al.*, 2023). They further stated that increasing the N rate beyond 150 kg/ha did not increase bulb diameter. Dinega *et al.* (2023) reported that development of wider bulbs with increasing rate of N fertilizer up to 150 kg/ha could be associated with the availability of more growth resources due to efficient N use as bulbs develop. On the other hand, lower bulb growth beyond

150 kg/ha could be due to excessive growth of above-ground biomass resulting from the application of excess N. In set to bulb method Islam *et al.* (1999) revealed that both polar and equatorial diameter of bulb were increased with the increase of N dose (0, 60, 120 & 180 kg N/ha) up to 120 kg/ha and then it was decreased with 180 kg N/ha. Nevertheless, in transplanting onion Nasreen *et al.* (2007) found increasing equatorial diameter with the increase in N rates (0, 80, 120 & 160 kg N/ha) up to 120 kg N/ha and the diameter was decreased at higher N rates. The reduced bulb growth due to application of excess N was also reported by Aregay *et al.* (2009) and Abdissa *et al.* (2011).

### Individual bulb weight

Nitrogen application had significant effect on individual bulb weight (Table 3). Plants receiving no nitrogen produced the lowest weight of individual bulb (17.32 g). After that it was increased with the increase in the N doses up to 150 kg N/ha (34.22 g) and then it was decreased at 180 kg N/ha. Application of 150 kg N/ha produced the highest individual bulb weight which was identical with 90 kg N/ha (28.83 g), 120 kg N/ha (32.75 g) and 180 kg N/ha (33.94 g). Dinega *et al.* (2023) stated that the increase in fresh bulb weight with an increase in N fertilizer rate might be due to a sufficient supply of N that enhances chloroplast development resulting in chlorophyll synthesis, and enzyme activity that increased photosynthates. The present result is consistent with the findings of Dinega *et al.* (2023) who found decreased bulb weight with the over dose of 180 kg N/ha. Islam *et al.* (1999) found gradual increase in bulb weight from 0 to 120 kg/ha N and then it was declined at 180 kg N/ha. Nasreen *et al.* (2007) opined that individual bulb weight increased with the increased in N rates (0, 80, 120 & 160 kg N/ha) and thereafter it was decreased with further increase in N rates. Khan *et al.* (2021) found the maximum bulb weight at 180 kg N/ha in set to bulb method.

**Table 3. Effects of nitrogen regimes on individual bulb weight, yield of bulb and flower stalk onion in set to bulb method**

Nitrogen rates (Kg/ha)	Individual bulb weight (g)	Bulb yield/plot (3.0 m <sup>2</sup> ) (kg)	Yield of bulbs (t/ha)	Yield of flower stalks (kg/ha)
0	17.32	3.02	10.05	514.20
30	22.93	3.68	12.27	1186.23
60	26.86	4.77	15.90	1109.60
90	28.83	5.20	17.32	984.70
120	32.75	6.22	20.74	903.72
150	34.22	6.65	22.15	859.13
180	33.94	5.90	21.08	778.83
CV%	10.28	9.52	19.68	21.86
LSD (0.05)	5.457	0.697	3.402	89.916
Level of sig.	**	**	**	**

Foot note: \*\* Significant at the 1% level of significance

### **Bulb yield per plot**

Application of N had significantly changed the bulb yield/plot (Table 3). The highest bulb yield/plot was recorded at 150 N kg/ha (6.65 kg) closely followed by 120 kg N/ha N (6.22 kg). The lowest bulb yield/plot was observed at zero kg N/ha (3.02 kg).

### **Yield of bulbs**

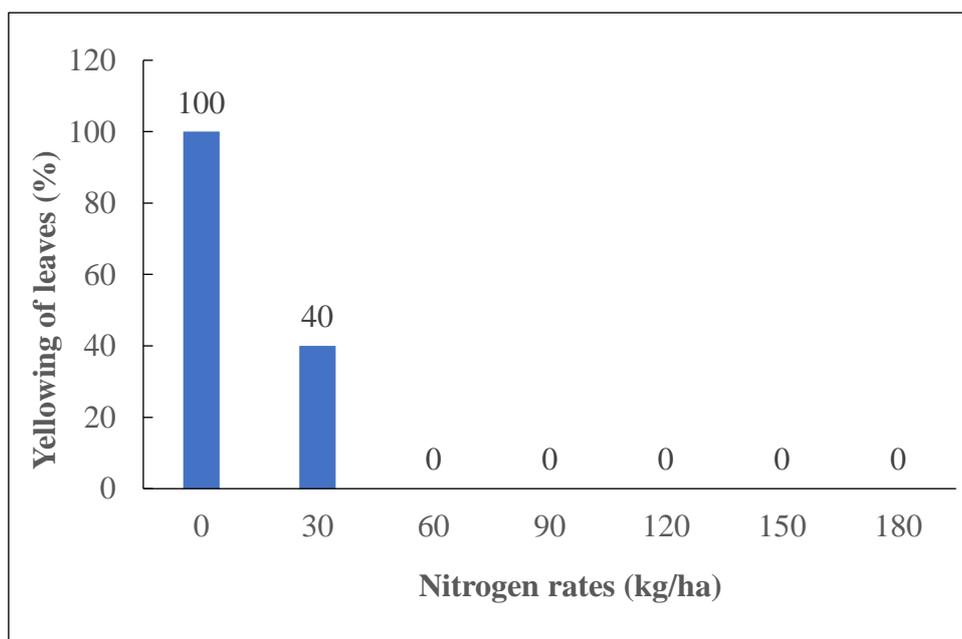
An increase in bulb yield was observed at the increased doses of N up to 150 kg N/ha and then the bulb yield was decreased. The maximum bulb yield was obtained at 150 kg N/ha (22.15 t/ha), which was statistically similar to 180 kg N/ha (21.08 t/ha), 120 kg N/ha (20.15 t/ha) but statistically dissimilar to 90 kg N/ha (17.32 t/ha). However, fertilizing the onion field with zero (0) kg N/ha gave the lowest yield of bulbs (10.05 t/ha). The current finding is in agreement with the results of Dinega *et al.* (2023), who stated that the bulb yield increased in response to increasing N rates up to 150 kg/ha and the over dose beyond 150 kg/ha declined the bulb yields. They further opined that the increased bulb yield in response to 150 kg/ha might be due to plants receiving sufficient N. Geisseler *et al.* (2022) reported that enhanced leaf number and length may lead to increased photo-assimilate production resulting in increased bulb yield. Mahdiah *et al.* (2012) depicted that the decrease in total bulb yield with application of N beyond 150 kg/ha might be due to luxury consumption of N that affected onion plant metabolism by decreasing the ability of the root surface to absorb phosphorus and decreasing the assimilate preparation. Islam *et al.* (1999) obtained a gradual increase of yield through set to bulb method from 0-120 kg N/ha and then the yield was decreased at 180 kg N/ha. Dhital *et al.* (2017) also found the highest yield from 120 kg N/ha and further increase in N rates decreased yield. In set to bulb method Khan *et al.* (2021) obtained the highest yield from 180 kg N/ha among five rates of N (0, 60, 120, 180 and 240 kg N/ha). Working with transplanting onion Nasreen *et al.* (2007) stated that increasing N levels from 0 to 120 kg/ha resulted in progressive increase in bulb yield and further increase in N (160 kg/ha) tended to depress bulb yield. The highest bulb yield of onion was observed at 150 kg N/ha and the lowest from 50 kg and 100 kg N/ha through set to bulb method (Biesiada and Kolota, 2009).

### **Yield of flower stalks**

The highest yield of flower stalks was found from the incorporation of N at 30 kg N/ha (1186.23 kg/ha) closely followed by 60 kg N/ha (1109.60 kg/ha). But the highest yield was significantly followed by the values of other treatments. However, the lowest yield of flower stalks was noted in the treatment of zero (0) kg N/ha (514.20 kg/ha). The highest yield of flower stalks at 30 kg N/ha might be happened due to maximum incidence of bolting in this treatment.

### Yellowing of leaves

The extent of variation was more pronounced in the yellowing of onion leaves among the nitrogen regimes (Fig. 1). Growing onion in set to bulb method without N exhibited yellowing in colour on the plants under the score 5 (100% of leaves) significantly followed by 30 kg N/ha (score 3: 40% of leaves). On the other hand, onion plants receiving N @ 60-180 kg/ha had no sign of yellowing on the plant. Instead of yellowing, plants with receiving higher doses of N showed dark green in colour. Probable cause of yellowing in growing onion without nitrogen might be due to the deficient of nitrogen. This result is in line with the findings of Geisseler *et al.* (2022) who narrated that increasing N rate is associated with promoting above-ground vegetative growth and the synthesis of chlorophyll, resulting in dark green leaves. The total N content in the experimental soils was 0.08%, which is far below than critical level (Table 1). The total N content of the soil under present experiment was within the range of low. According to Havlin *et al.* (2021), soil total available N contents of less than 0.15, 0.15-0.25 and >0.25% are categorized as low, medium and high, respectively. The present result is in consonance with the finding of Tiffin and Boxworth (2005), who stated that onion plants that are deficient in nitrogen exhibits yellowing in colour.



**Fig. 1. Incidence of yellowing (%) on onion leaves according to nitrogen rates.**

### Maturity of bulbs

Days to maturity were increased with the increased N up to 150 kg N/ha ranging from 75.33 to 82.33 days. And then it was decreased to 81.07 days at 180 kg N/ha.

Plants grown at 150 kg and 120 kg N/ha got matured 7.0 and 5.67 days later than that of no N fertilization, respectively. Delayed maturity with receiving higher doses of N might be due to excessive vegetative growth. The present result supports the findings of Abdissa *et al.* (2011) who reported that N fertilization significantly extended 5 days of physiological maturity at 115-138 kg N/ha over the unfertilized treatment. Islam *et al.* (1999) reported that the highest dose of N (0, 60, 120 & 180 kg N/ha) prolonged the growing period in set to bulb method. On the contrary, Dhital *et al.* (2017) described that onion matured about 7 days earlier at 120 kg N/ha than those grown with no N fertilizer and further increase in N had no significant effect on maturity.

**Table 4. Effects of nitrogen regimes on maturity of bulbs, percent of split & single bulb, bulb dry matter and total soluble solid of onion in set to bulb method**

Nitrogen rates (kg/ha)	Maturity of bulbs (Days)	Split bulbs (%)	Single bulb (%)	Bulb dry matter (%)	Total soluble solid (°brix)
0	75.33	10.63 (19.03)	89.37 (70.97)	15.65 (23.30)	17.11
30	76.67	12.40 (20.62)	87.60 (69.38)	16.40 (23.89)	17.55
60	77.67	14.47 (22.36)	85.53 (67.64)	17.09 (24.42)	17.78
90	79.00	14.96 (22.75)	85.04 (67.25)	17.43 (24.68)	17.99
120	81.00	16.43 (23.91)	83.57 (66.09)	17.69 (24.87)	18.11
150	82.33	18.22 (25.27)	81.78 (64.73)	17.93 (25.05)	18.44
180	81.67	19.82 (26.44)	80.18 (63.56)	16.75 (24.16)	17.77
CV%	10.56	15.83	4.87	7.77	6.95
LSD (0.05)	2.635	2.052	3.164	1.751	1.406
Level of sig.	*	**	**	*	NS

\*\* Significant at the 1% level of significance, \* Significant at the 5% level of significance and NS=Not significant; Arcsine transformed values were shown in the parenthesis.

### Splitting of bulbs

A considerable variation in the split bulb (%) was caused by the levels of N (Table 4). The percent split bulb increased with the increasing levels of N. A dose of 180 kg N/ha produced the highest percent of split bulbs (19.82%), whilst the lowest split bulbs (10.63%) was registered from the control (0 kg N/ha). The present result corroborates the finding of Islam *et al.* (1999) who stated that maximum split bulb percent was recorded from higher rates of N (0, 60, 120 & 180 kg/ha) through set to bulb method. They further explained as higher N enhanced vegetative growth along with much tittering that resulted in a greater number of splitted bulbs. Among three rates of N (0, 40, 80, 120 & 160 kg N/ha), incidence of doubles was significantly increased by nitrogen application (Dhital *et al.*, 2017). Growing onion in set to bulb method Khan *et al.* (2021) also recorded the maximum split bulbs (%) at 180 kg N/ha among five doses of N (0, 60, 120, 180 & 240 kg/ha).

### Single bulbs

The single bulbs percent was significantly influenced by N fertilization (Table 4). The percentage of single bulb was decreased with the increase of N dose ranging from 89.37% to 80.18%. Higher percent of single bulb from zero kg N/ha or lower dose of N/ha might be due to lower incidence of split bulbs. The present finding corroborates the result of Islam *et al.* (1999) who opined that the application of higher N doses (0, 60, 120 & 180 kg/ha) caused the gradually increase of single bulb in set to bulb method.

### Dry matter content of bulbs

The bulb dry matter content gradually increased with the increase in N up to 150 kg N/ha and varied from 15.65 to 17.93% (Table 4). After that it was decreased to 16.75% at 180 kg N/ha. The increased bulb dry weight from 150 kg/ha might be due to enough N supply for photosynthesis and photo-assimilate production (Geisseler *et al.*, 2022). Nevertheless, Aregay *et al.* (2009) and Abdissa *et al.* (2011) found the lower bulb dry weight at over doses (from 200 to 250 kg N/ha) which might be because of excessive growth of above-ground biomass and low bulb growth performance resulting from the application of excess N. Islam *et al.* (1999) stated that dry matter of bulbs increased with the increase in N rates up to 120 kg N/ha and then it was decreased with further increase of N at 180kg N/ha in set to bulb method. Dhital *et al.* (2017) also reported that dry matter of bulb increased with the increase in N rates up to 120 kg N/ha and thereafter it was decreased at 160 kg N/ha. However, the maximum percent of bulb dry matter was recorded from addition of 100 kg N/ha and the minimum from 50 kg and 150 kg N/ha in growing onion from sets (Biesiada and Kolota, 2009).

### Total soluble solid content:

Total soluble solid content (TSS) was not significantly influenced by N fertilization (Table 4). The results of TSS were in the similar direction to those of bulb dry matter content. However, the maximum TSS content was recorded at 150 kg N/ha (18.44°brix) and the lowest TSS content was observed at zero (0) kg N/ha (17.11°brix). The possible reason for increasing total soluble solids with a higher application rate of N might be due to increased chlorophyll content and dry weight plant. The result is in conformity with those of Dinega *et al.* (2023) who noted that the TSS content increased with increasing N rates.

### Profitability analysis

The profitability analysis showed (Table 5) that application of 180 kg N/ha had the highest cost of production (Tk. 267060) and the lowest at zero kg N/ha (Tk. 256660). Highest cost of production was due to maximum use of N fertilizers. Maximum gross return (Tk. 890295), net return (Tk. 624968) and benefit-cost ratio (BCR, 3.36) were calculated at 150 kg N/ha as compared to other treatments.

Applying zero kg N/ha gave the lowest gross return (Tk. 404571), net return (Tk. 147911) and BCR (1.58). The highest gross return, net return and BCR at 150 kg N/ha might be due to obtaining maximum yield from this treatment.

**Table 5. Profitability analysis of onion production through set to bulb method as per N rates (Tk./ha)**

Nitrogen rates (kg/ha)	Yield (kg/ha)		Cost of production (A)	Gross returns (B)	Net returns (B-A)	BCR (B/A)
	Bulb	Flower stalks				
0	10050	514.20	256660	404571	147911	1.58
30	12270	1186.23	258393	496731	238338	1.92
60	15900	1109.60	260126	641548	381422	2.47
90	17320	984.70	261860	697723	435863	2.66
120	20740	903.72	263593	834118	570525	3.16
150	22150	859.13	265327	890295	624968	3.36
180	21080	778.83	267060	847094	580034	3.17

Wholesale price of onion bulbs and flower stalks 40 and 5 Tk./kg, respectively

### Conclusion

Based on the result of the present study, in the economic point of view it might be concluded that application of 150 kg N/ha was optimum for onion production (var. BARI Piaz-4) through set to bulb method.

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**EXTRACTION AND ANALYSIS OF INDIGENOUS SPICE *Cinnamomum zeylanicum* WIDELY CONSUMED IN BANGLADESH: AN ASSESSMENT TO EXPLORE ITS BIOACTIVE AND ANTIOXIDANT ACTIVITIES**

M. S. HOSSAIN<sup>1</sup>, M. M. ISLAM<sup>2</sup>, M. M. AKAND<sup>3</sup>  
M. Z. RAHMAN<sup>4</sup> AND M. A. HOQUE<sup>5</sup>

Keywords: Antioxidants, Bioactive compounds, Cinnamon, *Cinnamomum zeylanicum*, Cinnamaldehyde, Minerals, Phenolic compounds.

Cinnamon (*Cinnamomum zeylanicum*) or true cinnamon is the most well-known spice and condiment. It is widely grown and consumed in many countries around the world, such as Srilanka, China, Vietnam, India, and Bangladesh (Unlu *et al.*, 2010). It is also commonly known as the Bangladeshi word 'Daruchini'. The bark is sold in scrap or powder form and is widely used in many food dishes due to its strong pleasing aromatic taste. The flavoring bark powder is mixed in the preparation of many kinds of desserts, spicy candies, in tea for flavor, and also used in the kitchen and cooking with it makes food a whole lot tastier. In addition, it's used in dentifrices, confectionery, perfumes, liqueurs, pharmaceuticals, and alternatives to traditional food preservatives (Paliwal *et al.*, 2018). Cinnamon primarily contains bioactive components, such as cinnamaldehyde, cinnamylacetate, cinnamic acid, phenylpropyl acetate, eugenol, linalool,  $\alpha$ -pinene, terpineol etc. The major bioactive component of cinnamon is cinnamaldehyde, which is widely used in the flavorings or aroma, food processing, cosmetics, confectionaries and pharmaceuticals (Abdelwahab *et al.*, 2017). Moreover, it helps people with type-II diabetes and improves their ability to respond to insulin, thus normalizing their blood sugar levels (Khan *et al.*, 2003). In addition, cinnamaldehyde has health protecting effect that helps to prevent unwanted clumping of blood platelets (Abdelwahab *et al.*, 2017). Cinnamon bark contains high-value protein, fibre, vitamins, and minerals that are acknowledged to promote health facilities and prevent disease (Gul and Safdar, 2009). The antioxidant activity of cinnamon species has been extensively investigated. In recent years, during the COVID-19 pandemic, the use of cinnamon bark has increased noticeably in Bangladesh to boost immunity. However, only a few scientific or in our countries first report about the bioactive compounds, phytochemicals, and antioxidant compounds and their activities have been reported. Hence, this investigation aimed to estimate the major constituents' such as bioactive (cinnamaldehyde for aroma), phytochemicals, and antioxidant composition of indigenous cinnamon variety which can give more comprehensive information.

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<sup>1</sup>Senior Scientific Officer, Central Laboratory, Research Wing, Bangladesh Agricultural Research Institute (BARI), Gazipur, <sup>2</sup>Principal Scientific Officer, Plant Pathology Division, BARI, Gazipur, <sup>3</sup>Senior Scientific Officer, Spices Research Centre, BARI, Gazipur, <sup>4</sup>Senior Scientific Officer, Pulse Research Sub-station, BARI, Gazipur, <sup>5</sup>Scientific Officer, Horticulture Division, BARI, Gazipur, Bangladesh.

The experiment was implemented at the Central Laboratory, Research Wing, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. A cinnamon sample was collected from the Spices Research Centre, BARI, Gazipur. Among them, the Cinamon var. BARI Daruchini-1 was considered in the present study. Fresh cinnamon barks were cleaned, washed, and dried at room temperature and ground to powder by using a grinder. Finally, sieves with a 60 micron opening were used to pass the powder, and stored in sealed containers for further research. The extracted essential oil from cinnamon bark to measure of bioactive elements from samples according to the following protocol with some modifications describe by Hossain *et al.*, (2023). The powdered sample (250 g) was added ethanol (750 ml) which was connected to the condenser in a heating mantle. Initially, the contents were heated 60°C to 100°C for 12 h and the essential oil content of each sample was determined on a dry weight basis and stored in glass vials at 4°C until analysis. The bioactive compound of essential oils of cinnamon was estimated by gas chromatography. Cinnamon essential oil sample (200 ul) was treated with 5 ml of ethylate reagent and vortex and put in overnight at normal temperature. Then, 5 ml salt solution was added and shaken. The upper oily layer was collected and injected with a Gas Chromatograph (Shimadzu, GC-2010, Japan). The proximate composition (protein, fibre, fat, and carbohydrate) of dry powder of cinnamon bark samples was determined using the standard Association of Official Analytical Chemists (AOAC, 2000) method. The contents of minerals in cinnamon powder samples were estimated according to the method Petersen *et al.*, (2002) with slight modification. The total phenolic and flavonoid content were determined spectrophotometrically using the folin-ciocalteau and aluminum chloride colourimetric assay method John *et al.*, (2014). The 2, 2-diphenyl-1-picrylhydrazyl (DPPH) and ferric-reducing antioxidant power (FRAP) assay were determined according to a method suggested by Brand-Williams *et al.*, (1995). Data obtained for each analysis were expressed in triplicate. Mean values and standard deviation (SD) were used .

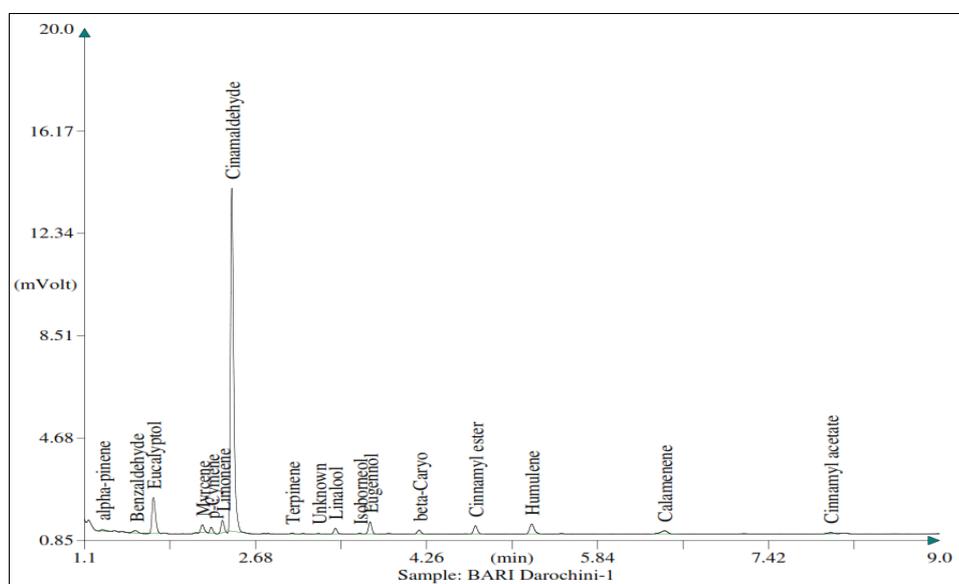
### **Bioactive composition of cinnamon bark oil**

Essential oils and their bioactive constituents of cinnamon have out-standing antioxidant properties. The present study has therefore evaluated the chemical constituents of cinnamon bark oil by using gas chromatography (GC). BARI Daruchini-1 bark oil obtained or identified 15 bioactive compounds (Table 1). The most abundant components were *trans*-cinnamaldehyde (72.91%), eugenol (2.73%), eucalyptol (8.17%), limonene (2.42%), cinnamyl ester (2.07%), and  $\alpha$ -Humulene (3.22%). The other important components were *p*-cymene (1.10%), myrcene (1.51%), linalool (1.17%),  $\beta$ -Caryophyllene (1.04%), and cinnamyl acetate (1.65%) (Table 1). The present result revealed that BARI Daruchini-1 contained a high amount of *trans*-cinnamaldehyde (72.91 %). The spicy and fragrance or aroma characteristics of cinnamon are mainly due to cinnamaldehyde. It is used traditionally to provide aroma, medicinal purposes, and essence compounds (Rao and Gan, 2014). In addition, its active constituents and other

related this phenylpropanoid compound enhance defense against ROS contributed hyperglycemia and protect cells by reducing lipid peroxidation (Zhao *et al.*, 2021). Another is eugenol (4-allyl-2-methoxy phenol) prevents ROS formation under conditions related to cancer, diabetes, inflammation diseases by breaking peroxidation cascade and scavenging radicals (Aminzare *et al.*, 2018). In accordance with results, several studies have reported that cinnamaldehyde is the major chemical compound of *C. zeylanicum* bark essential oil (Unlu *et al.*, 2010; Behbahani *et al.*, 2020).

**Table 1. Chemical constituents of BARI Daruchini-1 bark essential oil.**

Name of compounds	Retention time (min)	Content (%)
		BARI Daruchini-1
$\alpha$ - pinene	1.265	0.39 $\pm$ 0.09
Benzaldehyde	1.575	0.71 $\pm$ 0.03
Eucalyptol	1.737	8.26 $\pm$ 0.70
Myrcene	2.187	1.51 $\pm$ 0.20
<i>p</i> -Cymene	2.272	1.17 $\pm$ 0.21
Limonene	2.375	2.41 $\pm$ 0.19
<i>trans</i> -cinaamaldehyde	2.460	72.64 $\pm$ 0.74
Terpinene	3.017	0.17 $\pm$ 0.02
Linalool	3.417	1.18 $\pm$ 0.02
Isoborneol	3.642	0.16 $\pm$ 0.03
Eugenol	3.738	2.74 $\pm$ 0.06
$\beta$ - Caryophyllene	4.193	1.07 $\pm$ 0.11
Cinnamyl ester	4.712	2.09 $\pm$ 0.04
$\alpha$ -Humulene	5.230	3.22 $\pm$ 0.09
Cinnamyl acetate	6.457	1.63 $\pm$ 0.09



**Fig. 1. Chromatogram of the chemical composition of BARI Darochini-1 bark oil.**

### Proximate and mineral composition of cinnamon bark

The nutrient content of cinnamon bark is shown in Table 2. The crude fibre, crude fat, crude protein, and total carbohydrate content of BARI Daruchini-1 are 24.76, 4.17, 5.02, and 58.73%, respectively. The present study observed that carbohydrate and fiber content represent the major nutrients constituent in Bangladeshi cinnamon, which is almost like the fiber and carbohydrate values of cinnamon reported by Lartey *et al.*, (2023) and Sana *et al.*, (2019). The protein composition of cinnamon (5.02%) in this study compares with that similar by Sana *et al.*, (2019). Furthermore, the cinnamon lipid or fat or oil result was higher than most of the values from previous studies (Gul and Safdar, 2009). Indeed, dietary fat is established to be very important in ensuring the absorption and retention of aroma or flavour, thereby increasing the palatability of food (Lartey *et al.*, 2023). The differences seen in the percentage composition of the parameters between different studies are suspected to be due to the length of drying time, the variation due to differences in varieties, growth conditions, harvesting times, soil properties, climate, origin, environmental conditions, and geographic parameters. Minerals are inorganic chemicals that are required in specific amounts for human cells to operate correctly. The composition of minerals in cinnamon is presented in Table 2. The average results indicated that 100 g of cinnamon bark powder contains calcium (661.19 mg), potassium (777.20 mg), phosphorus (195.27 mg), iron (11.06 mg), and zinc (8.79 mg), respectively. The results from the mineral analysis revealed potassium and calcium as the most predominant inorganic constituents in cinnamon, while lowest values in iron and zinc composition. This agrees with the findings of Sana *et al.*, (2019) in which potassium and calcium constituted the majority of the mineral composition of cinnamon. Another highest occurring mineral component in cinnamon is phosphorus which was corroborative by Goel and Mishra, (2020). Its occurrence in such a quantity makes cinnamon a good addition to food for the maintenance of regular heart contraction, osteosynthesis, general body cell growth, and regulation of blood sugar levels as indicated by the role of phosphorus (Indrayan *et al.*, 2005). The nutritional composition of plant materials varied across geographical locations due to the differences in climate and growth conditions.

**Table 2. Nutrient compositions of cinamon var. BARI Daruchini-1 bark**

Nutrients	BARI Daruchini-1	Nutrients	BARI Daruchini-1
	Content (%)		Amount in "mg/100g"
Crude Fibre	24.76 ± 1.76	Calcium	661.19 ± 3.17
Crude Fat	4.17 ± 0.25	Potassium	777.20 ± 3.05
Crude Protein	5.02 ± 0.61	Phosphorus	195.27 ± 2.64
Carbohydrate	58.73 ± 0.81	Iron	13.06 ± 0.54
		Zinc	8.79 ± 0.24

Values are expressed as %, mean of three replicates ± standard deviation.

### Total phenolic (TPC) content and total flavonoid (TFC) content of *C. zeylanicum*

Plant secondary metabolites, such as phenolic compounds, as a major group of phytochemicals, play an important role in plant protection, and these are responsible for antioxidant activity. Phenolic compounds and their activities are defined by their structure (reactive benzene rings), which is directly linked with quenching radicals in biological systems. The amounts of TPC in extracts of cinnamon bark are shown in Table 3. The TPC of BARI Daruchini-1 was 163.62 mg GAE/100g DW. The total phenolics might be the main substances that contribute the antioxidant activities for cinnamon. Besides, the total flavonoids have been reported to have multiple biological effects, including antioxidant activity. The capacity of flavonoids to act as antioxidants depends upon their molecular structure. The position of hydroxyl groups and other features in the chemical structure of flavonoids are important for their antioxidant and free radical scavenging activities. As shown in the Table 3, the TFC of bark extract is 97.83 mg QE/100g DW. This result agrees with the findings of Paliwal *et al.*, 2018. Phenolic and flavonoid compounds in plants characterize as a reducing agents by the ability to donate electrons to oxidant species, scavenge free radicals, and chelate metal ions (Khan *et al.*, 2003; Zhao *et al.*, 2021).

**Table 3. Phytochemicals and antioxidants content in cinamon var. BARI Daruchini-1 bark**

Compounds	BARI Daruchini-1
<b>Phenolic compounds</b>	
Total phenolic (mg GAE/100g DW)	163.62 ± 0.72
Total flavonoids (mg QE/100g DW)	97.83 ± 0.26
<b>Antioxidant capacity</b>	
DPPH radical activity inhibition (%)	57.29 ± 1.67
FRAP (mg GAE/100g)	39.35 ± 1.75

Values are expressed as %, mean of three replicates ± standard deviation.

### Antioxidant Activities of cinnamon bark

The 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity assay was performed on the cinnamon sample and is given in Table 3. The DPPH content of BARI Daruchini-1 is 57.29%. DPPH free radicals react with antioxidant compounds and are inhibited. The reduction of DPPH molecules is directly related to the number of hydroxyl groups. Hydroxyl groups by denoting H into free DPPH radicals converts them from purple diphenyl pyrylyl-hydrazine to colorless compound; thus, the discoloration degree indicates the free radical scavenging activity of the antioxidant agent (Aminzare *et al.*, 2018), and finally, the results are expressed as the percentages of a reduction in the adsorption of DPPH solutions in the presence of essential oils. Our results indicate that DPPH activity of the essential oil of BARI Daruchini-1 was found to be 57.29%, indicating the strong

ability of the oil to neutralize DPPH free radicals *via* either hydrogen atom or electron donation mechanisms (Aminzare *et al.*, 2018).

The ferric-reducing antioxidant power (FRAP) activity of cinnamon oil is measured by the reduction of Fe<sup>3+</sup> TPTZ complex to ferrous (Fe<sup>2+</sup>) form (intense blue colour) using electron-donating antioxidants at low pH, measuring FRAP values by absorbance change with the increase in absorbance of blue Fe<sup>3+</sup> concentrations, which forms an important mechanism for antioxidant action. Increasing the optical absorption in the mixture caused by the intensity of the green color produced by the production of iron II (ferruginum) will mean increasing the reducing (antioxidant) power. The present results of the reducing power test are shown in Table 3. The FRAP content of BARI Daruchini-1 is 39.35 mg GAE/100g. According to the amount of reported absorption if the concentration of oils is increased, the reducing power is increased; as well as the reported values (39.35 mg GAE/100g) indicate that the reducing activity of cinnamon was higher. Indeed, it has been proven that antioxidant power is directly related to the percentage of phenolic compounds in essential oils (Abdelwahab *et al.*, 2017).

*C. zeylanicum* is used worldwide as a spice in daily life with a positive impact on human health. The major bioactive constituents of BARI Daruchini-1 were found to be *trans*-cinnamaldehyde (72.91%), eugenol (2.73%), eucalyptol (8.17%), limonene (2.42%), cinnamyl ester (2.07%), and  $\alpha$ -Humulene (3.22%). These compounds can affect the human body in many different ways and can be applied to treat a wide range of diseases and metabolic disorders. Among the most valuable bioactive element is cinnamaldehyde, which is widely used in the aroma or flavorings, food processing, cosmetics, confectionaries and pharmaceuticals. The nutrient analysis revealed cinnamon as a rich sources of fibre (24.76%), carbohydrate (58.73%), and lipid (4.17%) and mineral content also revealed calcium (661.19 mg/100g), potassium (777.20 mg/100g), phosphorus (195.27 mg/100mg), and iron (11.06 mg/100g) of BARI Daruchini-1 variety. The cinnamon oil contained remarkable levels of phytochemicals such as phenolic (163.62 mg GAE/100g), flavonoid (97.83 mg QE/100g), and antioxidants, DPPH radical scavenging activities (57.29%), and FRAP activities (39.35 mg GAE/100g). Due to their antioxidant properties these compounds indirectly affect the receptor-mediated mechanism. Overall, nutritional, chemical profiles and antioxidants could be effectively applied for monitoring cinnamon which plays significant roles in human body.

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