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EXOGENOUS TREHALOSE BOOSTED DROUGHT TOLERANCE IN WHEAT SEEDLINGS (*TRITICUM AESTIVUM* L.) BY ENHANCING GLYOXALASE SYSTEM

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Abstract

The present experiment was conducted at the Molecular Breeding Laboratory of Bangladesh Agricultural Research Institute (BARI), Gazipur during 2016-2017, to investigate the potential of trehalose (Tre) as a protective agent against drought stress in wheat seedlings. Two genotypes, viz. CSISA DR 30 (drought-tolerant) and BAW 1163 (drought-sensitive), were subjected to varying levels of polyethylene glycol (PEG)-induced drought stress, with and without the addition of trehalose (Tre). Eight-day-old seedlings were subjected to drought stress for 2, 4, and 6 days. Results revealed that drought stress at various durations increased proline, lipid peroxidation (MDA) and methylglyoxal (MG) contents, but decreased relative water content (RWC) and reduced glutathione (GSH) compared to control in both genotypes at seedling stage. It was also observed that the activities of glyoxalase I (Gly I) and glyoxalase II (Gly II) enzymes were increased in CSISA DR 30 genotype, but decreased in BAW 1163 genotype under drought stress of different durations. However, the application of trehalose (10 mM) under drought stress led to a decrease in MG, MDA and proline levels. At the same time, this osmolyte increased RWC, activities of Gly I and Gly II enzymes, as well as GSH contents in both genotypes. Notable, the MDA and MG accumulation was found remarkably lower in CSISA DR 30 genotype than in BAW 1163 wheat genotype under control, drought (15% PEG) and drought with 10 mM trehalose condition. The results also suggested that the genotype CSISA DR 30 is drought tolerant and moreover, its capability is further enhanced by exogenous trehalose application.

Keywords: Trehalose, methylglyoxal, glyoxalase system, PEG, drought, wheat genotype.

Introduction

Wheat (*Triticum estivum* L.), a member of the family ‘Poaceae’ is one of the major cereal crops ranked second after rice mainly cultivated in the north and north-west region of Bangladesh. Wheat has an annual production of 778 million metric tons with a 10% value addition in agriculture (Kamal *et al*., 2020). It provides 1.8% fiber, 9.4% protein, 69% carbohydrates, and 2.5% fat (Ahmad *et al*., 2021). In recent years, due to climate change several periodic natural calamities of which drought is the most prominent and prevalent limiting factors of wheat production.

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Drought employs expressively adverse effects on production of wheat in northern and central part of Bangladesh and around 3.5 million ha land are vulnerable to crop production specially wheat due to drought (Alam, 2014). Therefore, the cultivation of wheat faces soil moisture stress due to inadequate and erratic rainfall and limited irrigation facilities. The area under wheat cultivation is gradually decreasing and its production has increased a little bit but not significantly due to temperature rise and changing in precipitation pattern after 2018-19.

Under water deficit conditions, plants experience oxidative stress, leading to increased accumulation of reactive oxygen species (ROS) (Rohman *et al*., 2016; Hasanuzzaman *et al*., 2014). These ROS act as major toxic radicals capable of damaging essential biomolecules such as proteins, lipids, and DNA (Rohman *et al*., 2016). Additionally, the generation of cytotoxic methylglyoxal (MG) under drought stress, induces similar damaging effects to those caused by ROS (Rohman *et al*., 2016; Alam *et al*., 2014). However, ROS and MG homeostasis in plant cells is very important to exert its physiological function. It is reported that enzymes of glyoxalase system, Gly I and Gly II effectively detoxify MG. In two step reaction, Gly I converts MG to S-D-lactoylglutathione (SLG) by using GSH as co-factor and second step converts SLG to D-lactate where GSH is recycled back (Yadav *et al*., 2005b).

Over the past few decades, the application of exogenous osmoprotectants, such as glycine betaine, proline, trehalose, and salicylic acid, has proven effective in mitigating the detrimental impacts of drought stress on plant growth (Ali, 2011; Alam *et al*., 2014). Trehalose, a non-reducing disaccharide of glucose, exists in plants in modest quantities, nearly at the detection limit. Yet it demonstrates the ability to reduce oxidative stress and enhance plant tolerance to abiotic stresses, including drought stress (Ali and Ashraf, 2011; Ma *et al*., 2013).

Extensive studies have explored the impact of trehalose on diverse crops facing drought conditions globally, encompassing growth, photosynthetic attributes, and ROS scavenging antioxidant defense (Ma *et al.*, 2013; Ali and Ashraf, 2011). Despite a number of research conducted on mitigation of drought stress and scavenging ROS, there is a notable scarcity of research on the effects of trehalose in MG detoxification system under drought stress. Specifically, the investigation into the strategies employed by wheat seedlings to endure drought conditions remains limited. This research aimed to fill this gap by examining the potential effects of trehalose in detoxifying MG with facilitating adaptive strategies in the leaves of wheat seedlings under drought stress induced by PEG. The present experiment was, therefore, conducted to elucidate how trehalose may contribute and influence the survival mechanisms adopted by wheat seedlings in the face of water scarcity.

Materials and Methods

Plant Materials and Stress Treatments: The study was carried out at the Molecular Breeding Laboratory of Bangladesh Agricultural Research Institute (BARI), Gazipur during 2016-2017. The experimental treatments comprised two wheat genotypes, namely CSISA DR 30 (relatively drought-tolerant) and BAW 1163 (drought-sensitive), which were obtained from the previous research (Ahsan, 2014) and three distinct drought stress conditions, viz. 0% PEG (used as a control), 15% PEG, and 15% PEG plus 10 mM trehalose (Tre). According to Bayomi *et al.* (2008), a solution of PEG-6000 was prepared using the weight-by-volume method by dissolving 150 g of PEG in 200 mL of distilled water, and the final volume was adjusted to one liter. The experiment was conducted following completely randomized design (CRD) with three replications. Twenty-five healthy and equal-sized seeds of both genotypes were selected andseeds were surface sterilized with 70% ethanol solution for 5 min followed by washing several times with sterile distilled water. Seeds were put in sterilized 9 cm petri-dishes containing germination paper moistened with 10 ml of the deionized distilled water to provide appropriate moisture for seed germination. The petri-dishes containing seeds of wheat were then kept in an incubator (VS-1203P3V, Japan) under controlled conditions (Temp, 25±2 °C; RH, 65–70%) for germination. After 3-days, germinated seedlings with petri dishes were transferred to growth chamber with 1,000-fold diluted 20 ml Hyponex nutrient solution (Type: 5-10-5, Hyponex, Japan) under control conditions (light intensity, 100 $molm^{-2}s^{-1}$; temperature, 23 ± 2 °C; relative humidity, 60–65%) during the growing period of 8 days. Eight-day old seedlings of approximately equal sizes of two wheat genotypes were imposed to drought stress induced by 15% polyethylene glycol (PEG) with or without 10 mM trehalose and grown under the above control condition in growth chamber. Control plants were grown with Hyponex solution only. Data were taken after 2, 4 and 6 days of treatment application.

Measuring relative water content

Relative water content of the leaves was determined following the procedure of Islam *et al.* (1998). The collected leaves of wheat seedlings were excised just prior to sun set and after taking fresh weight, their base immediately placed in glass jar containing 5 to 6 cm water height. The jars were enclosed with plastic cover to maintain 100% relative humidity and the leaves were allowed to watered 24 hours in dark. The following day, the saturated leaves were removed from jars and immediately the turgid weight of leaves was recorded with the help of a precise electronic balance. Finally oven dry weights of the leaves were recorded. Relative water content of leaves was measured by the following formula-

$$RWC = \frac{Fresh\ leaf\ weight - Dry\ leaf\ weight}{Turgid\ leaf\ weight - Dry\ leaf\ weight} \times 100$$

Determination of Proline

Proline colorimetric determination according to Bates *et al.* (1973) based on proline's reaction with ninhydrin. For proline colorimetric determinations, a 1:1:1 solution of proline, ninhydrin acid and glacial acetic acid was incubated at 100º C for 1 hour. The reaction was arrested in an iced bath and the cromophore was extracted with 4 ml toluene and its absorbance at 520 nm was determined in a UV-spectrophotometer (UV-1800, Shimadzu, Japan).

Measurement of Lipid Peroxidation (MDA)

The level of lipid peroxidation was measured as malondialdehyde (MDA), a decomposition product of the peroxidized polyunsaturated fatty acid component of the membrane lipid, using thiobarbituric acid (TBA) as the reactive material following the method of Heath and Packer (1968). Briefly, the leaf tissue (0.5 g) was homogenized in 3 mL 5% (w/v) trichloroacetic acid (TCA), and the homogenate was centrifuged at 11,500×g for 10 min. The supernatant (1 mL) was mixed with 4 mL of TBA reagent (0.5% of TBA in 20% TCA). The reaction mixture was heated at 95°C for 30 min in a water bath and then quickly cooled in an ice bath and centrifuged at 11,500 × g for 15 min. The absorbance of the colored supernatant was measured at 532 nm and was corrected for non-specific absorbance at 600 nm. The concentration of MDA was calculated by using the extinction coefficient of 155 mM^{-1} cm^{-1} and expressed as nmol of MDA g^{-1} FW.

Measurement of Methylglyoxal (MG)

About 0.3 g leaf tissue was extracted in 3 mL of 0.5 M perchloric acid. After incubating for 15 min on ice, the mixture was centrifuged at 4 ℃ at 11,000 × g for 10 min. A colored supernatant was obtained in some plant extracts that was decolorized by adding charcoal (10 mg ml^{-1}), kept for 15 min at room temperature, and centrifuged at 11,000 × g for 10 min. Before using this supernatant for MG assay, it was neutralized by keeping for 15 min with saturated solution of potassium carbonate at room temperature and centrifuged again at 11,000 × g for 10 min. Neutralized supernatant was used for MG estimation following the method of Rohman *et al*. (2016). An aqueous 500mM N-acetyl-L-cysteine solution was freshly prepared. The reaction was carried out in 100 mM sodium dihydrogen phosphate buffer (adjusted to pH 7.0 with 10 M NaOH) at 25 °C. First, the MG solutions (5, 10, 15, 20 and 25 µL) equating to 0.5, 2 and 5 mM were added up to a volume of 980 µL with sodium dihydrogen phosphate buffer and the spectrophotometer was set to zero. The reaction was started by adding 20 µL of the N-acetyl-L-cysteine solution (final concentration up to 10 mM), and the formation of the product N-α-acetyl-S-(1-hydroxy-2-oxo-prop-1-yl) cysteine was recorded for 10 min at a wave length of 288 nm.

Enzyme Extraction and Assays

Using a pre-cooled mortar and pestle, 0.5 g of leaf tissue of wheat seedlings was homogenized in 1 ml of 50 mM ice-cold K-phosphate buffer (pH 7.0) containing 100 mM KCl, 1 mM ascorbate, 5 mM β-mercaptoethanol, and 10% (w/v) glycerol. The homogenates were centrifuged at 11,500 × g for 10 min, and the supernatants were used for determination of enzyme activity. All procedures were performed at 0 to 4°C.

Assay of enzymatic activities

Glyoxalase I (Gly-I, EC: 4.4.1.5) assay was carried out according to Yadav *et al*., 2005a). Briefly, the assay mixture contained 100 mM K-phosphate buffer (pH 7.0), 15 mM magnesium sulphate, 1.7 mM reduced glutathione, and 3.5 mM methylglyoxal in a final volume of 0.7 ml. The reaction was started by the addition of MG, and the increase in absorbance was recorded at 240 nm for 1 min. The activity was calculated using the extinction coefficient of 3.37 mM^{-1} cm^{-1}.

Glyoxalase II (Gly-II, EC: 3.1.2.6) activity was determined according to the method of Principato *et al.* (1987) by monitoring the formation of GSH at 412 nm for 1 min. The reaction mixture contained 100 mM Tris–HCl buffer (pH 7.2), 0.2 mM DTNB, and 1 mM S-D-lactoyl glutathione (SLG) in a final volume of 1 ml. The reaction was started by the addition of SLG, and the activity was calculated using the extinction coefficient of 13.6 mM^{-1} cm^{-1}.

Extraction and Measurement of reduced Glutathione

Wheat seedling leaves (0.5 g fresh weight) were crushed using a mortar and pestle in 3 ml of ice-cold acidic extraction buffer comprising 5% metaphosphoric acid and 1 mM EDTA. The resulting homogenates were then centrifuged at 11,500 × g for 15 minutes at 4 °C, and obtained supernatant was utilized for the analysis of glutathione, following the procedures outlined by Hasanuzzaman *et al*. (2014).

Statistical Analysis

All data obtained were analyzed with the help of STATISTIX 10 program and mean separation was done by Least Significant Difference (LSD) test at 5% significance level of probability. Values presented in figures are mean of three independent experiments (each experiment consists of three replications).

Results and Discussion

Effect of trehalose on relative water content (RWC)

Drought stress induced a significant decline in leaf relative water content (RWC) in both wheat genotypes, with the drought-sensitive BAW 1163 experiencing more substantial reduction compared to the drought-tolerant CSISA DR 30 genotype (Fig. 2). CSISA DR 30 exhibited a remarkable resistance to RWC reduction, showing declines of 10.34, 22.72, and 36.93%, while BAW 1163 recorded higher reductions at 17.08, 32.91, and 52.85% on days 2, 4, and 6 of drought stress. By the 6th day, CSISA DR 30 maintained a significantly higher RWC, emphasizing its superior drought tolerance. The addition of exogenous trehalose alleviated water loss during drought, resulting in a 13% increase in RWC for CSISA DR 30 and a 9.50% increase for BAW 1163 on the 6th day of drought stress. This indicates the significance of trehalose in mitigating water loss during drought stress. This positive impact of exogenous trehalose application on reducing the decline in RWC under drought stress, emphasizing its role in modulating leaf diffusive resistance and enhancing water retention in plant tissues was confirmed by earlier findings (Ali, 2011; Ali and Ashraf, 2011; Akram *et al*., 2016; Alam *et al*., 2014).

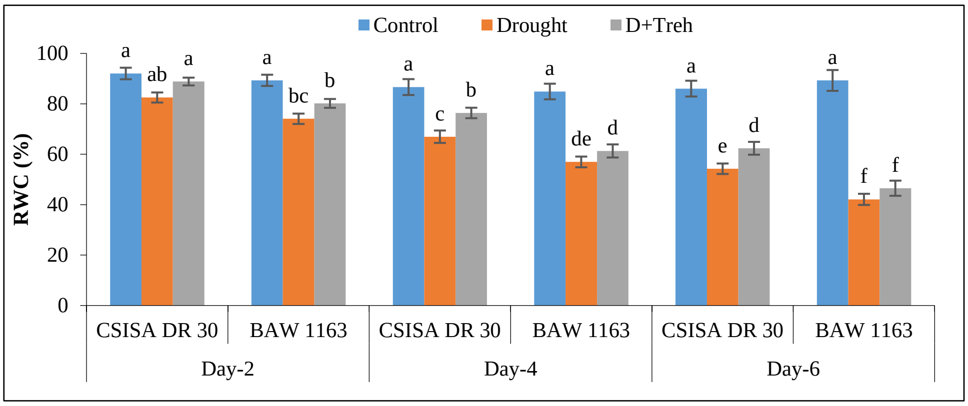

Fig. 2. Relative water content in drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stressed at different duration. Bars with the same letters are not significantly different at P≤0.05 by LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

Effect of trehalose on proline content

Drought stress caused significant increase in proline contents over time in both genotypes, with CSISA DR 30 displaying higher accumulation than BAW 1163 (Fig. 3). At 2, 4, and 6 days of drought stress, the proline content was significantly higher (84, 134 and 85%) in CSISA DR 30 than the BAW 1163 wheat genotypes. Nevertheless, the application of exogenous trehalose @ 10 mM (D + Treh) reduced proline accumulation in both the genotypes compared to their respective drought-stressed genotypes. The reduction in extra proline biosynthesis due to exogenous trehalose implies that trehalose protected wheat genotypes from the adverse effects of drought stress through alternative mechanisms, opposing the need for a further increase in proline levels. These findings corrugated the findings of Ali and Ashraf (2011), Nounjan *et al*. (2012) and Alam *et al*. (2014), contributing insights into proline dynamics in drought-tolerant and sensitive wheat genotypes while highlighting the regulatory role of trehalose in modulating proline accumulation.

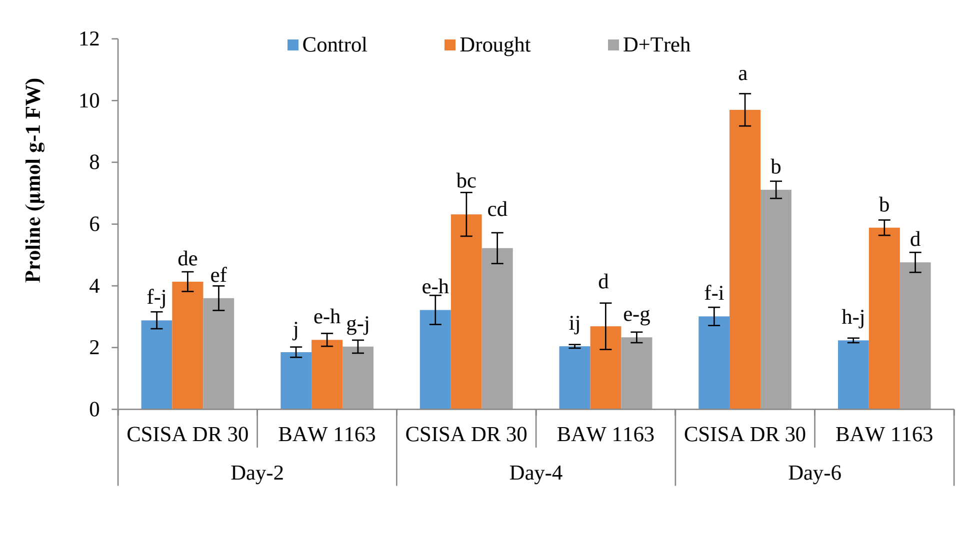

Fig. 3. Proline content in drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stressed at different duration. Bars with the same letters are not significantly different at P ≤0.05 by LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

Effect of trehalose on malondialdehyde (MDA) contents

The content of malondialdehyde (MDA) significantly increased with the duration of drought stress in both wheat genotypes. Notably, BAW 1163 exhibited higher MDA levels than CSISA DR 30 genotype (Fig. 4). Specifically, at 2, 4, and 6 days of drought stress, MDA content was 1.55, 1.71, and 1.93 times higher in CSISA DR 30 seedlings compared to their control, while BAW 1163 genotypes showed 1.73, 1.98, and 2.30 fold increases. Interestingly, treating both genotypes with 10 mM trehalose (D + Treh) reduced MDA levels compared to the content in drought stressed genotypes without trehalose. CSISA DR 30 genotypes demonstrated better MDA reduction than BAW 1163 genotypes when supplemented with exogenous trehalose during drought. Lower MDA content indicates higher antioxidative ability (Ahsan *et al.*, 2020; Ahmed *et al.*, 2021) and greater drought tolerance (Izabela *et al.*, 2013). In this study, MDA level was significantly and continuously increased in both wheat genotypes with increase drought stress intensity, while, CSISA DR 30 maintained significantly lower amount of MDA than BAW 1163 both under control and drought stress.

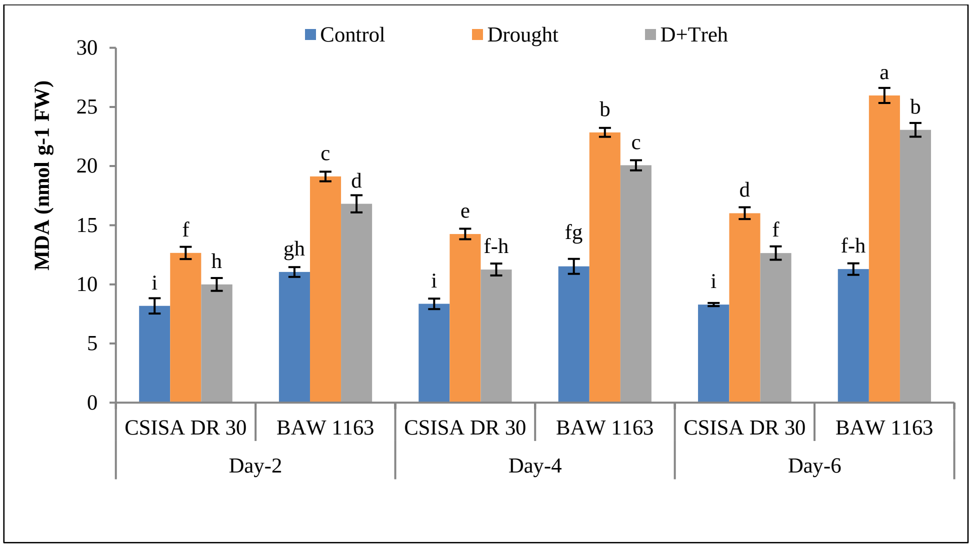

Fig. 4. MDA content in drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stressed at different duration. Bars with the same letters are not significantly different at P≤0.05 applying the LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

Effect of trehalose on methylglyoxal levels

In the presence of PEG-induced drought stress conditions, both the wheat genotypes exhibited an elevation in methylglyoxal (MG) accumulation compared to their corresponding control treatment (Fig. 5). The control conditions maintained relatively stable MG levels for both genotypes throughout the observation period. However, under drought conditions, a notable increase in MG accumulation occurred over time, with BAW 1163 consistently exhibiting higher levels (26, 29 and 32%) than CSISA DR 30 genotype. The introduction of exogenous trehalose @ 10 mM (D+Treh) demonstrated a mitigating effect on the drought-induced rise in MG levels throughout the observation periods. This indicates a potential protective role of trehalose in limiting MG accumulation under drought stress. The findings contribute valuable insights into the regulatory mechanisms by which trehalose influences methylglyoxal toxicity, enhancing our understanding of wheat responses to drought stress. Several researchers observed the reduction of MG levels under abiotic stress by exogenous osmotic protectant (Okuma *et al*., 2004; Rohman *et al*., 2016; Alam *et al*., 2014).

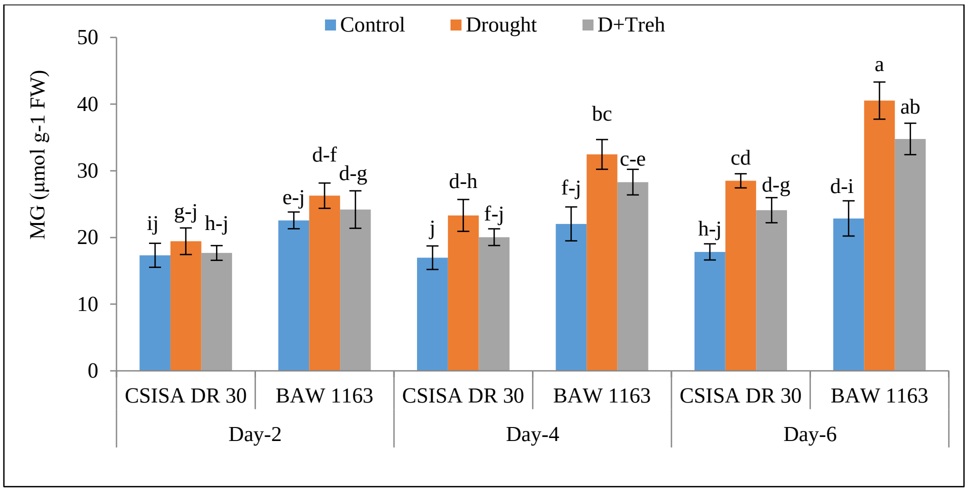

Fig. 5. Accumulation of MG in leaves of drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stress at different duration. Bars with the same letters are not significantly different at P≤0.05 applying the LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

Effect of trehalose on glyoxalase I and glyoxalase II activities

It was observed that drought stress increased Gly I and Gly II activities in drought tolerant CSISA DR 30 wheat genotypes (Fig. 6a and 6b). As compared to control, activities of Gly-I were increased by 27.87, 21.27 and 12.49% at 2, 4 and 6 days of drought stress, respectively, in CSISA DR 30 genotypes. Similarly, Gly-II activity slightly increased by 11.81, 7.14 and 2.85% at 2, 4 and 6 days of drought stress, respectively in this tolerant genotype. On the contrary in same conditions Gly I and Gly II activities were decreased in drought sensitive BAW 1163 wheat genotypes. The Gly I activity was decreased by 16.34, 34.02 and 42.03% in BAW 1163 genotypes under 2, 4 and 6 days of drought stress, respectively, compared to their control. The Corresponding values of Gly II for BAW 1163 genotypes were 10.87, 22.23 and 35.33% at 2, 4 and 6 days of drought stress, respectively. These results suggest that CSISA DR 30 wheat genotype efficiently protected the MG that was formed during oxidative stress due to its higher tolerance capacity. While, exogenous trehalose supplementation @ 10 mM in presence of PEG-induced drought stress improved Gly I and Gly II activities in two wheat genotypes in different stress duration that proved the enhanced tolerance to drought stress in wheat genotypes. Trehalose-induced upregulation of glyoxalase enzymes and subsequent abiotic stress including drought tolerance were also reported in other plants by other researchers (Hoque *et al*., 2008; Alam *et al*., 2014).

Effect of trehalose on GSH content

Although a gradual decrease was observed in GSH content with escalating drought stress severity in wheat genotypes, drought-tolerant CSISA DR 30 genotypes maintained higher GSH levels compared to the sensitive BAW 1163 genotype (Fig. 7). Under drought stress, CSISA DR 30 exhibited decreased GSH content by 4.59, 13.16, and 22.19% at 2, 4, and 6 days, respectively, while BAW 1163 experienced more substantial reductions (7.16, 37.10%, and 58.70%). Exogenous trehalose application @ 10 mM elevated GSH in both the genotypes, with CSISA DR 30 displaying higher increments (1.36, 6.33, and 10.74%) than BAW 1163 (0.74, 23.85, and 9.63%) at 2, 4, and 6 days of drought stress. The enhanced GSH content, facilitated by trehalose, may contribute to GPX-mediated ROS detoxification and GST-mediated leaf senescence, fostering stress tolerance in wheat genotypes, aligning with previous research findings (Rohman *et al*., 2016; Ma *et al*., 2013; Alam *et al*., 2014).

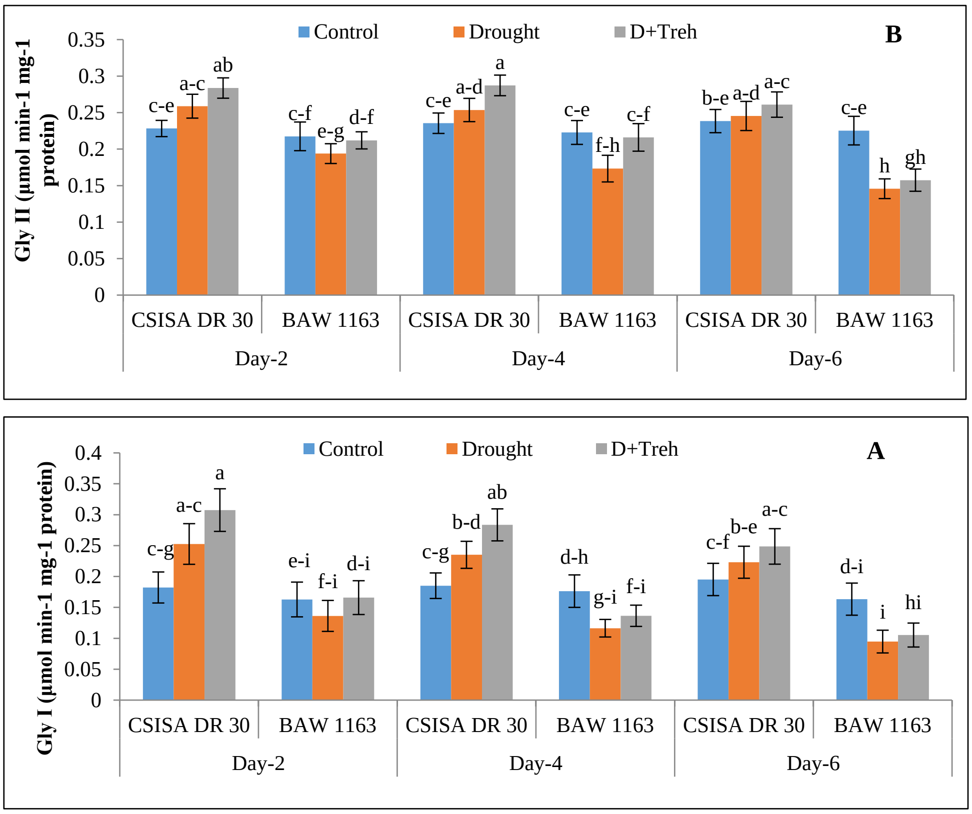

Fig. 6. Activities of Gly-I (A) and Gly-II (B) in leaves of drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stress at different duration. Bars with the same letters are not significantly different at P≤0.05 by LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

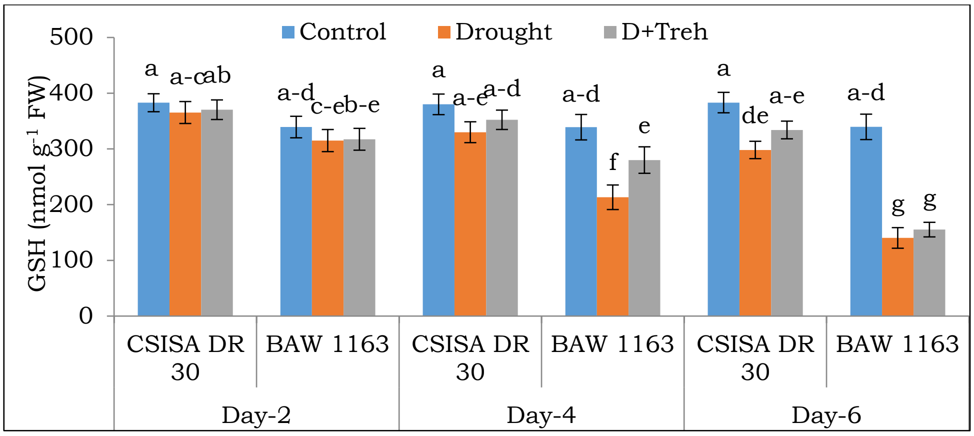

Fig. 7. Content of GSH in drought tolerant (CSISA DR 30) and drought sensitive (BAW 1163) wheat genotypes induced by exogenous trehalose under drought stress at different duration. Bars with the same letters are not significantly different at P ≤0.05 by LSD test. Control, Drought (15% PEG 6000), D + Tre (15% PEG 6000 with 10 mM Tre).

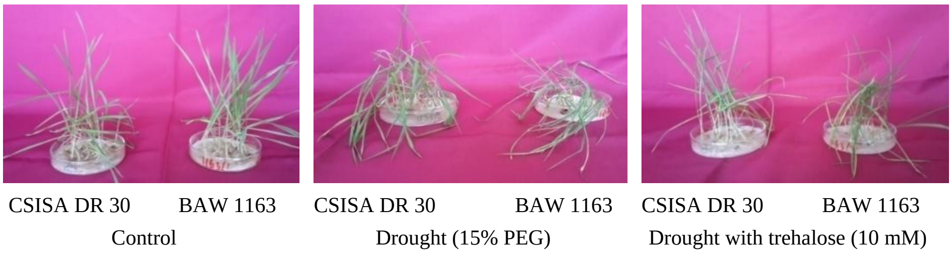

Fig. 8. Comparative tolerance to drought of two wheat genotypes (CSISA DR 30, drought tolerant and BAW 1163, drought susceptible) in presence or absence of 10 mM trehalose (Tre). Eight day-old seedlings were imposed to 15% PEG 6000 for 6 days.

Conclusion

Based on the above results under PEG-induced drought stress, the accumulation of lipid peroxidation (MDA), methylglyoxal (MG) was higher in susceptible BAW 1163 wheat genotype. Leaf relative water content (RWC%), proline, glutathione (GSH) and glyoxalase system enzymes (Gly I and Gly II) were also lower in this genotype compared to the tolerant CSISA DR 30 genotype. Trehalose (10 mM) played a significant role in MG detoxification through enhancing the glyoxalase system enzymes. Under drought stress, trehalose (10 mM) showed better maintenance of GSH as well as Gly I and Gly II activities and also regulate RWC% and proline accumulation at most favorable levels in CSISA DR 30 genotype than BAW 1163 genotype to protect cellular damage from higher MG. Trehalose maintenance of higher glyoxalase activities along with higher contents of GSH and its adjustment of the accumulated proline to an optimal level suggest the protective role of trehalose in the seedlings of two wheat genotypes under PEG-induced drought stress. The tolerant CSISA DR 30 genotype can be used as a breeding material for future breeding program for developing drought tolerant wheat varieties.

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DEVELOPMENT OF SMALL SOYMILK AND SOYA PANEER MAKERS

M. A. HOQUE[1], M. A. HOSSAIN[2], T. N. BARNA[3] AND M. M. ALI[4]

Abstract

Soybean provides a cheaper and protein rich alternative to animal protein. In Bangladesh, utilization of soybean in food items are scarce due to unavailability of suitable processing machines. Soymilk production and pasteurization machines can assist in increasing the human consumption of soybean by making soymilk and soya paneer. Thus, the experiment was conducted during 2019-21 to develop soymilk making machinery to increase consumption of soybean as human foods. Soymilk making machines consisted of a blender and a pasteurizing unit. The holding capacity of the blender and the pasteurizing units were 2 liters and 6 liters per batch, respectively. In the improved model, the operational time of the blender was 15 seconds corresponding to 83.68% blending efficiency to prepare soymilk for each batch. Time for raising the interlayer water temperature up to 100 ºC was 37.67 minutes. The soymilk was prepared within 20 minutes pasteurizing. The soya paneer was prepared and sensory evaluation was done. The panelists showed their satisfactions both on soymilk and soya paneer.

Keywords: Soymilk, Soya paneer, Small machine, Capacity, Efficiency.

Introduction

Soybean holds significant importance globally and within various industries due to its versatility and nutritional value. Soybean production in Bangladesh is relatively low compared to other crops, and the country relies heavily on import of soybean to meet her internal demand. However, during the year 2022, area under soybean production in Bangladesh was 58563 hectares with the production of 98646 metric tons (BBS, 2022). Most of the cultivable soybean varieties are 'BARI Soybean- 5', 'Sohag', 'BARI Soybean-6', and 'Davis' in Bangladesh (Islam and Khatun, 2021). Soybean provides a cheaper and high protein rich alternative substitute to animal protein. The costs and return analysis revealed that soybean production is a profitable enterprise with rate of return of 62% (Salam and Mia, 2013). Important scope for use of soybean in livestock feed has increased the production demand in Bangladesh (Islam and Khan, 2021; Jadhao *et al*., 2020). Alternate use of this nutritive soybean for human consumption could create greater market demand. The regular consumers of dairy milk and its products have reported the increased risk of certain health problems such as cow milk allergy

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which has contributed in the acceptability and popularity of soya milk (Gana and Gbabo, 2017; Gbabo *et al*., 2012; Jinapong *et al*., 2008). Soya milk has social, economic, nutritional and medicinal benefits for its consumers (Amusa *et al*., 2005). Different soya foods like soya milk, soya biscuits, soya chapatti can be prepared from soybean. It has also diabetic, medical, industrial and agricultural importance (Hossain *et al*., 1992). Soy protein directly lowers serum cholesterol levels. The soy cotyledons store proteins which are important for human nutrition. Soybean contains isoflavones having potential anticancer effects. It contains two primary isoflavones called Genistein and Daidzein and a minor one called Glycitein. They retard bone loss in premenstrual and postmenstrual women, and the soluble fiber in soy foods control blood sugar. Soy foods are quite important to human being as they reduce the risk of heart disease. Regular consumption of soya food delays the process of aging and also improves mental and physical abilities, memory power, and haemoglobin levels of children who have used soy foods, for a long time, as supplementary foods. Soymilk is an aqueous liquid obtained from the extraction of milk from soybean (Afroz *et al*., 2016). The extraction process involves grinding of soaked soybean with water to produce slurry, mixed of the slurry with water in order to separate the milk from chaffs and sieving of the milk from the paste (Gbabo *et al.,* 2012). Soya paneer is known for its extraordinary nutritional benefits, as well as its versatility. Soya paneer is a soft cheese-like food made by curdling soymilk using a coagulant (Raja *et al.,* 2014). Gana and Gbabo (2017) designed, built, and tested a mini soy milk production and pasteurization plant having a capacity of 750 liters in 8 hours of daily operation. Test results showed the blending efficiency was 88.16% and the milk yield was 98.52%. Pasteurization was done at 84 °C for 30 seconds. The machine effectively extended the shelf life of raw soya milk for 24 hours to 48 hours at room temperature and up to 144 hours when refrigerated at 4 ºC. The soya milk is coagulated either by salt or by acid followed by pressing to form soya paneer (Raja *et al*., 2014). Calcium chloride, magnesium chloride, citric acid and acetic acid are the commonly used coagulants. This product came into existence about three decades ago which could be stored up to one year (Banerjee *et al.,* 2019). Waghmare *et al.* (2022) designed and fabricated a soymilk extraction machine with 86.5% efficiency. In Bangladesh, the lack of machinery for processing soybeans into products like tofu and other soy-based foods, aside from oil extraction, presents a notable challenge. This limitation impacts the country's ability to diversify its soybean utilization beyond oil production. Without appropriate processing equipment, Bangladesh may face several implications. Hence, the design of the soymilk production and pasteurization plant would assist in increasing soyabean in human consumption. In Bangladesh, uses of soybean for these food items have limitations due to unavailability of suitable machines. Therefore, the experiment was conducted to develop soymilk and soya paneer making machineries to increase consumption of soybean as human foods.

Materials and Methods

A set of soymilk machine was designed. Some factors were taken into consideration in order to design the machines. The design parameters considered were feed rate, power requirement, shaft speed of the blender, hopper capacity etc. Small prototype of blender was targeted to develop with locally available stainless-steel materials and single- phase electric motor which seems be easily functional by the progressive farmers and small entrepreneurs. The experiment was conducted during 2019-21. A pasteurizing heater is an important part which was designed along with a blender part.

Machine components

A mini plant was constructed using stainless steel materials and it is made of the following components:

i) Blending unit: This unit was made of the sub-component parts like outer casing, hopper, delivery tube, blending chamber, blending blade, shaft, pulley, V-belt and 2200-watt electric motor as shown in Fig. 1. A blender unit were designed and developed for making soymilk. The specification of blender is shown in Table 1. The blender unit was operated with electric motor having 48000 rpm speed. The blender was designed for continuous feeding and operation. Two liters per batch was fed. The weight of the blender unit was 11 kg.

Table 1. Specification of the blender

Parameters	Measurement
Overall dimension	900 ×350 ×350 mm
Dimension of the stand	600 ×350 ×350 mm
Dimension of the blending chamber	300 × 125 × 125 mm
Dimension of the blending blade	80×60 ×30 mm
Speed of the blade	48000 rpm
Source of power	2.2 kW electric motor
Capacity of blender	2 liter/batch
Weight of the blender	11 kg

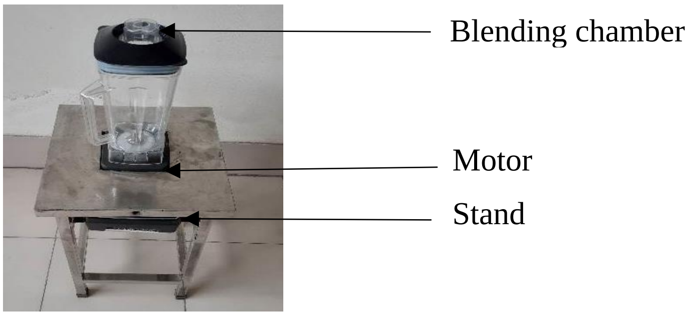

Fig 1. Blending unit for Soymilk making machine.

ii) Pasteurization unit: This unit is made of the following sub-components: inner casing, outer casing (water jacket), milk inlet and outlet valves, water inlet and draining valves, and external casing as shown in Fig. 2.

Fig 2. Pasteurization unit for Soymilk making.

The specification of pasteurizing unit of the soymilk blender is shown in Table 2. The pasteurizing unit consisted of two cylinders. The inner cylinder was used to keep soymilk and the outer cylinder for hot water. Capacity of the inner cylinder was 6 liters. The space between the cylinders was filled with water and then it was heated with a 2000-watt heater. The temperature of the water was monitored with a sensor (200±1 ºC) connected to a control box. The weight of the pasteurizing unit was 28 kg.

Table 2. Specification of the pasteurization unit

Parameters	Measurement
Overall dimension	1440 mm ×540 mm ×440 mm
Dimension of the main cylinder	300 Ø ×390 mm
Dimension of the inner cylinder	200 Ø ×230 mm
Dimension of the hopper	140 Ø ×150 mm
Dimension of the stand	600 mm ×380 mm×380 mm
Dimension of the control box	300 mm ×220mm × 180 mm
Capacity of the unit	6 liters
Sensor range	200±1 ºC
Heater load	2000 watt
Weight of the unit	28 kg

iii) **Soya paneer press:** This unit was made of stainless Steel (Fig. 3). Paneer press was made with a round cylinder of 1.6 mm thick sheet with 5 mm stainless steel (SS) plate, 25 mm threaded shaft and other parts of SS. Most of the parts being made of ss steel, the machine required less maintenance. Operation of the unit was easy to give required pressure upon soy paneer. This machine consisted of inbuilt container. It was found an amazing machine with the capacity of making paneer in large quantity. The machine maintained the hygienic condition in retaining the quality of the produced paneer.

Fig 3. Soya paneer press.

Mode of operations of the machines for soya milk

The blending blade was fixed on the vertical shaft inside the blending chamber. Soaked and dehulled grain (400 g sample) of soybean was fed inside the blending chamber. Hot water (5:1=water: soybean) was also added to the soybean (Panchal *et al*., 2014; Rahim *et al*., 2022). The machine was then switched on for blending operation. The milk was poured into the pasteurization chamber from the blending machine. This was the raw soya milk. The water tank was then mounted on the pasteurizing heating machine. The boiling tank was filled with water to the required level. The milk was fed into the machine through the hopper. The temperature of the water was monitored by the temperature gauge. The hot water was hold inside the pasteurizer for the required time (35-38 minutes). The pasteurizer outlet valve was opened for outflow of the milk. The water jacket outlet valve was open for draining of the used water. Performance test of the soymilk was done at FMP Engineering Divisional workshop, BARI, Gazipur.

Preparation of Soybean Milk

'BARI Soybean-5' was taken for this experiment. Ten kilograms of whole soybeans were washed and soaked in water (1:3) at room temperature (20±5 ºC) for 10 hours in normal water. Then the husks were separated from the beans by pressing the beans followed by washing with water. The beans were then ground in blender for different time spans. The ratio of beans to water was 1:5 (w/v) (Panchal *et al*., 2014). The resulted suspension was filtered. Then the suspension was inserted into the pasteurization unit. The outer temperature was more than 100 ºC and inner temperature was 100 ºC. The liquid was kept for 20 minutes in the pasteurization chamber (Chan, 2023; Saini and Morya, 2021; Giri and Mangaraj, 2012). Hot suspension was then allowed to drain out through the outlet and it was then cooled down to become soymilk. The process of soymilk preparation is presented in Fig. 4 through a flow chart.

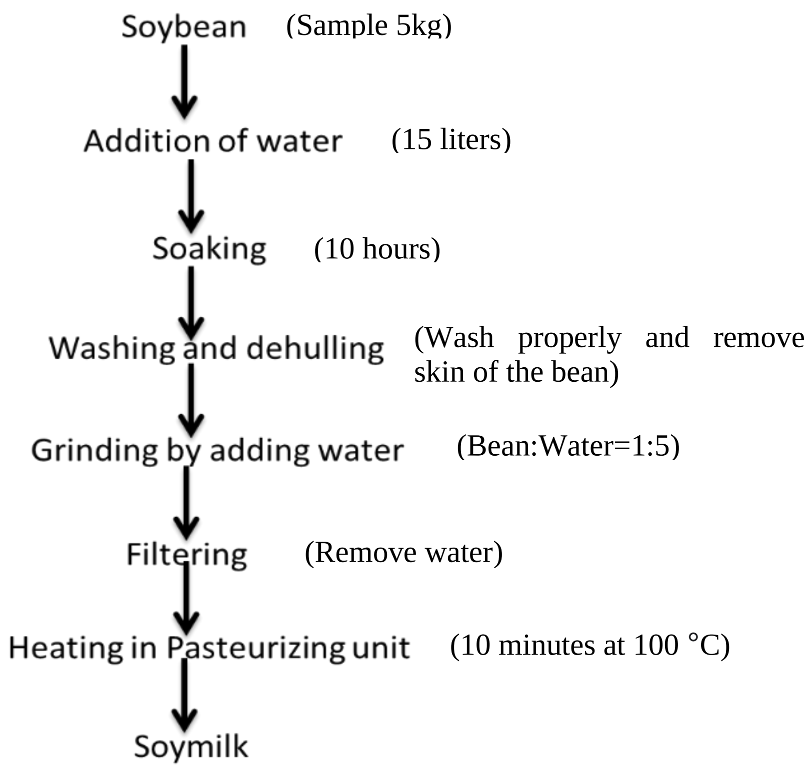

Fig 4. Flow chart for soymilk production.

Determination of machine blending efficiency

This is the measure of the degree by which the grains are reduced in size and was determined by Equation as reported by Nwaigwe *et al.* (2012).

$$E_B = \frac{A}{MT} \times 100 \quad (1)$$

where, E_B is the blending efficiency (%), *A* is the amount of the material passed through the sieve (kg) and MT is the total weight of the material fed into the machine (kg)

Preparation of Soya paneer

After preparing soymilk, when the soybean temperature of milk increased to 70-80 ºC, citric acid (1%) was mixed with soybean milk and stirred 1-2 times. The stirring operation was done continually with some intervals. Within 15-20 minutes the milk started coagulating and water became separated from it. However, in case of delayed or no coagulation, some more citric acid solution was added to speed up the action. The coagulated milk was separated instantly, else the tofu would not get soft. Once the milk and the water separated, a clean cloth was spread over a strainer and the milk was poured on it. Tofu was collected on the cloth and the water was strained down into the bowl when pressed with the soya paneer pressing device. Good quality soft tofu was found after pressing and waiting for 30-40 minutes. The tofu inside the cloth was freezed and it was then ready for use to make various dishes. The prepared soya paneer was evaluated by sensory evaluation. Ten panelists evaluated the soya paneer.

Sensory evaluation

The sensory attributes were performed based on the procedure of Joshi (2006) and Khan *et al.* (2021). It was performed using a 9- point hedonic scale, i.e. 9= Like extremely, 8= like very much, 7= Like moderately, 6= Like slightly, 5= Neither like or dislike, 4= Dislike slightly, 3= Dislike moderately, 2= Dislike very much and 1=Dislike extremely. Sensory quality attributes like colour, flavour, taste, texture, hardness and overall acceptability were evaluated by an expert sensory panelist.

Economic analysis

Economic analysis of the soymilk maker was done. Cost analysis included the operating cost of the machine. Operating cost of the machine included the fixed cost and variable cost. Fixed of the machine included capital consumption. Variable costs included labour, electricity, repair &maintenance. Three labour was required for operating the machine.

Fixed cost

Fixed cost of the machine included annual depreciation, interest on investment. Capital consumption included depreciation and interest.

i) Capital consumption (CC)

$$CC = (P - S)CRF + S \times i \quad (2)$$

Where,

P=Purchase price, Tk

S=Salvage value, Tk

CRF= Capital recovery factor

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1} \quad (3)$$

Where,

i= Rate of interest

L=Life of machine, yr

ii) Shelter, T=3.0% of purchase price of the machine, Tk (4)

iii) Repair and Maintenance cost, M= 3.5% of purchase price of the machine, Tk (5)

Total fixed cost per year

$$FC = CC + T + M \quad (6)$$

Variable Cost

In calculation of variable cost, the following relations were assumed

i) Labour cost per hour, L_b=Tk man-h^{-1}

ii) Electricity cost per hour, E=Tk h^{-1}

Total variable cost

$$VC = L_b + E \quad (7)$$

Operating cost

$$AC = FC + VC \quad (8)$$

Results and Discussion

Performance of blender for soaked soybean sample is shown in Table 3. Blending efficiency varied with the operating time. But the incremental rate of the blending efficiency was nearly static (83.68% - 83.74%) after 15-35 seconds operation. So, the operational time 15 seconds was selected with 83.68% blending efficiency to prepare soymilk for each batch. Thus, the capacity of the blender was 4 l/m considering 15 second blending time and 15 second discharge time.

Table 3. Performance of blender for soaked soybean

Operating time, Sec.	Blending efficiency (%)
10	75.29
15	83.68
20	83.68
25	83.74
30	83.74
35	83.74

Performance of pasteurizing unit for soymilk making is shown in Table 4. The average time for heating the interlayer water up to 100 ºC was 37.67 minutes. Time for raising the milk temperature up to 100 ºC was 05 minutes. Water temperature was 5-10 ºC higher than the soymilk temperature. The soymilk was prepared with 20 minutes pasteurizing. Then the same was drained out from the pasteurizing unit as shown in Fig 5. Thus, the capacity of the pasteurizing unit was 18 l/h.

Table 4. Performance of pasteurizing unit for soymilk making

Trial No.	Inter layer water volume, liter	Time for heating the interlayer water up to 100 ºC, minutes	Amount of milk, liters	Time for getting milk temperature 100 ºC, minutes	Pasteurizing time for each batch, minutes	Temperature, ºC	
						Milk	Inter layer water
01	8	38	4.5	05	20	100	108
02	8	38	4.5	05	20	100	110
03	8	37	4.5	05	20	100	110
Average	8	37.67	4.5	05	20	100	109.33

Fig 5. Prepared soymilk.

Fig 6. Pictorial flow chart of preparing soya paneer.

Soya paneer was prepared (Fig. 6) and sensory evaluation was done. The sensory evaluation results are shown in Table 5. The sensory evaluation showed encouraging feedback by the panelists. Overall acceptability was evaluated by the expert sensory panelists. The average score obtained by the panelist was indicating that the soymilk and soya paneer were liked very much.

Table 5. Sensory evaluation of soymilk and soya paneer

	Colour	Flavour	Taste	Texture	Hardness	Overall acceptability
Milk	8.14	7.43	7.86	8.71	-	Like very much (8.04)
Soy paneer	7.50	7.58	7.75	8.75	8.50	Like very much (8.02)

Financial Analysis:

Economic analysis of the soymilk making machinery is shown in Table 6. The operating cost of the machine is 499062.23 Tk/year, respectively among which fixed cost is 19787 Tk/year and variable cost is 479275 Tk/year. Net return of the soymilk maker is 1008000 Tk/year. The BCR of the machine is 2.02.

Table 6. Economic analysis of the soymilk making machinery

Price of the machine, Tk	75000
Salvage value (10% of P), Tk	7500
Bank interest, i= 10%	0.1
Life, year	5
Capital recovery factor, CRF	0.26
Fixed cost, Tk/year	19787.23
Labour required, Person/day	3
Labour charge, Tk/day	600
Labour cost, Tk/year	60000
Working days, day/year	100
Working hour, h/day	8
Electricity cost, Tk/year	14400
Repair & maintenance, Tk/year	2625
Shelter cost, Tk/year	2250
Raw Soybean price (5kg/h and 100 Tk/kg), Tk/year	400000
Variable cost, Tk/year	479275
Total operating cost, Tk/year	499062.23
Soymilk making capacity, L/h	18
Wholesale price of soymilk, Tk/L	70
Net return, soymilk, Tk/yr	1008000
Benefit-cost ratio	2.02

Conclusion

A blender was developed for making soymilk. Holding capacity of the blender and pasteurizing unit was 2 liters and 6 liters, respectively. The operational time 15 seconds was selected with 83.68% blending efficiency to prepare soymilk for each batch. The soymilk was prepared with 20 minutes pasteurizing. The soya paneer was prepared and sensory evaluation was done. The panelists showed their satisfaction on soymilk and soya paneer. The colour, flavour, taste, and texture were reported good enough for the product. The machines and the production technologies for soymilk and soya paneer preparations can be recommended for small entrepreneurs in Bangladesh.

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POPULATION DYNAMICS OF MAJOR INSECT PESTS OF FRUIT CROPS IN A ROOFTOP GARDEN AT GAZIPUR IN BANGLADESH

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S. AKTER[4] AND M. A. ISLAM[5]

Abstract

The population dynamics of the insect pests of fruit crops, namely mealybug, spiraling whitefly, leaf miner and fruit fly were studied in a rooftop garden containing guava, mango, lemon, pumelo and dragon fruits at Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh during April 2022 to March 2023. Number of insects per leaf and leaf infestation data were collected by visual observation. Fruit fly population was counted using pheromone traps. The results showed that mealybug and spiraling whitefly population were present in guava plant where mealybug population was higher than spiraling whitefly population. Mealybug population was also observed on mango plant. Leaf miner infestation was observed in lemon and pumelo plant. Percent leaf infestation was higher in pumelo plant compare to lemon plant. Mealybug population, spiraling whitefly population and leaf miner infestation were low at December-February, increased at March-April, slightly reduced at May-July and again increased at August-November. Fruit fly population found the highest at July and lowest at January. Most of the cases, weather parameter showed significant role on population abundance and infestation occurrences of insect pest at fruit crop-based rooftop garden.

Keywords: Rooftop garden, mealybug, spiraling whitefly, leaf miner, fruit fly, fruit crops.

Introduction

Rooftop gardening is the art and science of growing plants on the highest levels of industrial, commercial, and residential structures. Rooftop gardens can supplement the food of society, which contributes to food security by increasing the supply of meals to urban consumers (Bellows and Hamm, 2003). Up to 2050, the world will need 70–100% more food (World Bank, 2008). Rooftop gardeners can play an important role in supplying fruit and vegetables at urban markets and meeting the food demand of growing urban communities (FAO, 2012; Orsini *et al*., 2014).

Plants are grown on rooftop gardens for both utilitarian and non-utilitarian purposes (Sajjaduzzaman *et al*., 2005). Rooftop gardens guide social life as well

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as provide experiences of self-identification and independence, the place one can in particular acquire self-satisfaction (Rashid *et al*., 2010). With fast and unplanned urbanization, poverty and food insecurity have been growing alarmingly in Dhaka city (Choguill, 1995). Rooftop gardening can be a positive approach to ensuring meals are furnished and satisfying the dietary desires of city dwellers. It is hopeful that many people are involved in rooftop gardening, especially in urban areas of Bangladesh. Their efforts are helping to make the cities greener, despite the lack of cultivable land there. People expect chemical-free organic vegetables and fruits, but insect pest attacks occur in rooftop gardens where people apply chemical insecticides without knowing the insect pest. A total of 24 families and 46 species of insect attacks were reported at the rooftop garden (Han *et al.*, 2017). Insect pest attack and its severity may be different in roof gardens compared to field agriculture, but in Bangladesh, research work is very scanty related to insect pest attack at the rooftop gardens. Insect pest status and their population dynamics study will help develop a sustainable pest management strategy for rooftop gardens. The present study was, therefore, conducted to know the status of insect population at rooftop garden, their relationship with weather parameter and the contribution of weather parameter to build up the insect population.

Materials and Methods

Study area

The survey was conducted at rooftop garden of Horticulture Research centre (HRC), Bangladesh agricultural Research Institute (BARI), Gazipur (23.9942°N, 90.4119°E, altitude 15 meter from ground level) during April 2022 to March 2023. The rooftop garden of HRC was eastablished with fruit crops, viz. guava, mango, lemon, pumelo, dragon fruit etc. Most of the plants were 2-3 years old, moderately populated and at fruit bearing condition.

Data recorded and analysis

Data were recorded by visual observation at 30 days interval. For counting insect pest number and infested leaf, two plants were selected randomly from each crop species then four branches of selected plants were again selected randomly. Insect number and infested leaf data were recorded from upper ten leaves of selected branch and leaf infestation was calculated into percentage.

Fruit fly population was counted by using pheromone trap. Three methyl eugenol water traps were placed at HRC rooftop garden from where dead fruit flies were sorted out and counted at every seven days interval. Monthly average number of fruit fly/trap was calculated from recorded data. Weather data were collected from meteorological observatory section of Bangladesh Rice Research Station (BRRI), Gazipur. Data were analyzed by using Microsoft Excel software.

Results and Discussion

Results on population fluctuation of mealybug and spiraling whitefly on guava plants in a rooftop garden at Gazipur in Bangladesg during April, 2022 to March, 2023 are presented in Fig. 1. It was observed that the highest 8.1 mealybugs leaf^{-1} were found at September and the lowest 3.1 mealybugs leaf^{-1} were found at January during the study period. Mealybug population was higher at July to November, reduced lowest at January and after that population was gradually increased up to April. After April, with some fluctuation population reached peak at September. In case of spiraling whitefly population fluctuation, the highest population (4.25 leaf^{-1}) was found at November and the second highest population observed both at December and April (3.45 leaf^{-1}). Spiraling whitefly population was lower at May to July where the lowest population 2.15 leaf^{-1} was found at the month of June.

Monthly distribution of meteorological parameters like average temperature, rainfall and average relative humidity during April 2022 to March 2023 are presented in Table 1. During the study period, average temperature (28.90-30.93^{0}C) was high in April to October. The lowest average temperature (19.34^{0}C) was found in January followed by December (22.11^{0}C) and February (23.01^{0}C), respectively. Rainfall was high in May to October and was very low or nil in November to February. Relative humidity was comparatively higher in April to October than November to March.

The multiple linear regression analysis showed that the effect of temperature, rainfall and relative humidity on guava mealybug population was 39.7, 5.6 and 0.2%, respectively, where effect of temperature was significant. The effect of temperature and rainfall was 45.3% and the effect of temperature along with rainfall and relative humidity was 45.5% on mealybug population abundance where both equations were insignificant. On the other side, guava spiraling whitefly population was controlled 18.2% by temperature, 33% by rainfall and 11% by relative humidity. Combined effect of temperature and rainfall was 51.2%, combined effect of all three weather parameters was 62.2% and both equations were significant (Table 2).

Population dynamics of mealybug and spiraling whitefly were studied by different researchers at field condition but scanty at rooftop condition. At field condition, Abdelgayed *et al*. (2020) found two peaks population of mealybug, one in mid-August and another at end of September. They also observed that temperature had positive effect on population of mealybug. Sultana *et al.* (2015) found temperature and relative humidity had a positive correlation to mealy bug population while the rainfall had a negative correlation. Khan (2017) found the highest incidence of spiraling whitefly population in September followed by October, November and May while the lowest was in July followed by June, January and February, respectively. Chavan *et al* (2022) showed weather parameters contributed to 56.0 percent of the total variation in the population of spiraling whitefly.

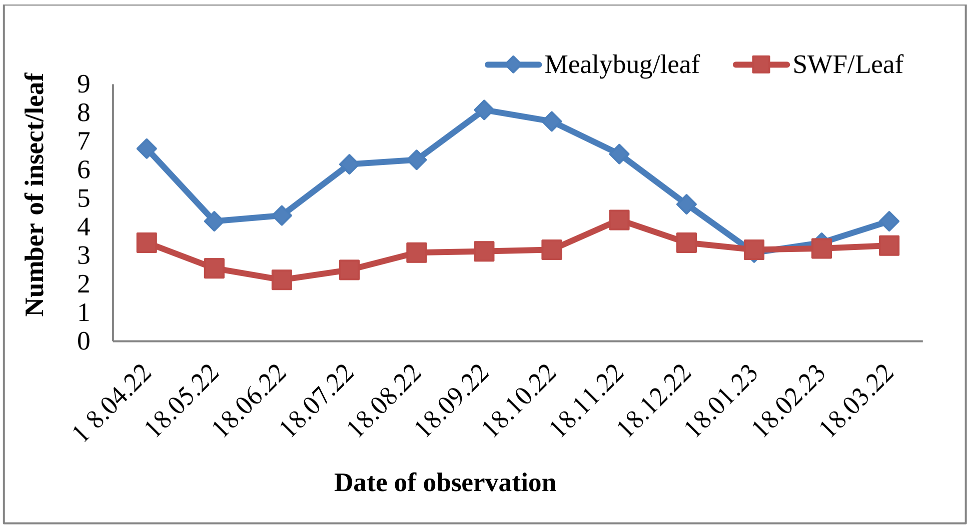

Fig.1. Population fluctuation of mealybug and spiraling whitefly on guava plants in a rooftop garden at Gazipur in Bangladesh during April, 2022 to March, 2023.

Table 1. Monthly distribution of meteorological parameters during April 2022 to March 2023

Month	Average temperature (°C)	Rainfall (mm)	Average relative humidity (%)
April 2022	30.08	58.40	70.22
May 2022	29.24	297.80	77.13
June 2022	30.18	311.00	80.17
July 2022	30.93	176.00	76.10
August 2022	30.80	110.00	74.73
September 2022	29.95	215.80	78.50
October 2022	28.90	288.20	74.02
November 2022	25.81	0.00	62.10
December 2022	22.11	2.20	68.60
January 2023	19.34	0.00	70.56
February 2023	23.01	16.40	61.10
March 2023	26.28	114.40	65.30

Source: Meteorological observatory section, Bangladesh rice research Station (BRRI), Gazipur

Table 2. Multiple regression models along with coefficients of determination (R^2) and the impact of weather parameters on the seasonal abundance of guava insects during April 2022 to March 2023

Insect name	Regression equation	R^2	100 R^2	Role of individual factor (%)	F statistic
Guava mealybug	$Y= -1.86 + 0.26 X_1$	0.397	39.7	39.7	$F_{1,10}= 6.6$ $P < 0.05$
	$Y= -3.90 + 0.366X_1-0.004X_2$	0.453	45.3	5.6	$F_{2,9}= 3.72$ $P= 0.06$
	$Y= -4.87 + 0.363X_1-0.005X_2 +0.016X_3$	0.455	45.5	0.2	$F_{3,8} = 2.22$ $P = 0.16$
Guava Spiraling Whitefly	$Y= 4.75 - 0.059 X_1$	0.182	18.2	18.2	$F_{1,10} = 2.23$ $P= 0.16$
	$Y= 3.08 + 0.019X_1-0.003X_2$	0.512	51.2	33	$F_{2,9} = 1.21$ $P= < 0.05$
	$Y= 6.06 + .031X_1-0.001X_2-0.049X_3$	0.622	62.2	11	$F_{3,8} = 5.00$ $P < 0.05$

Y = Insect population/leaf; X_1 = Average temperature (°C); X_2 = Rainfall (mm); X_3 = Relative humidity (%)

Mealybug population at mango plant

Figure 2 shows population fluctuation of mealybug at rooftop garden's mango plant. Population of mealybug at rooftop mango plant was fluctuated throughout the season but become lowest (2.10 $leaf^{-1}$) at January. After January mealybug population increased and took the highest peak (4.85 $leaf^{-1}$) at April. The second highest mango mealybug (4.75 $leaf^{-1}$) was found in the month of October.

Table 3 indicated the individual effect of temperature, rainfall and relative humidity on mango mealybug abundance was 43.3, 0.2 and 18.3%, respectively. The effect of temperature was significant. The combined effect of temperature, rainfall and relative humidity was also significant and exerted 61.8% abundance.

Mealybug population was low at mango plant compare to guava plant at rooftop garden but effect of weather parameters on mealybug population were almost similar at both host plant.

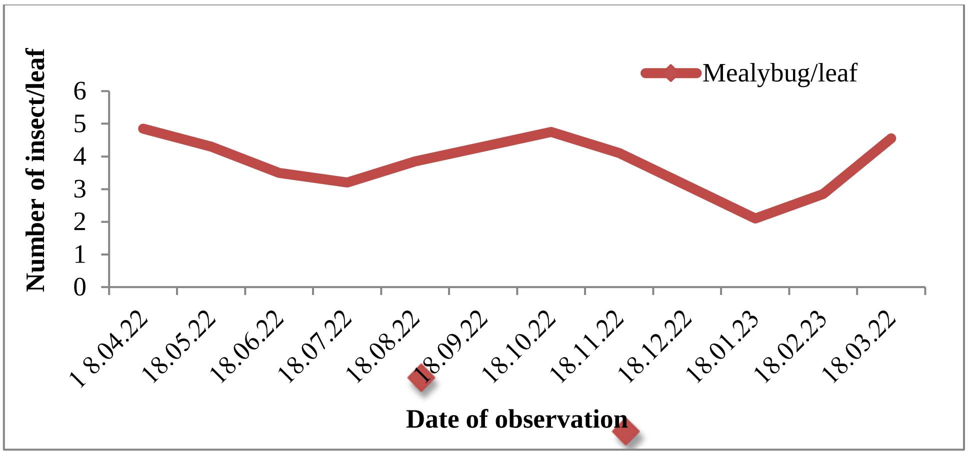

Fig. 2. Population fluctuation of mealybug mango plants in a rooftop garden at Gazipur in Bangladesh during April, 2022 to March, 2023.

Table 3. Multiple regression models along with coefficients of determination (R^2) and the impact of weather parameters on the seasonal abundance of mango mealybug during April 2022 to March 2023

Insect name	Regression equation	R^2	100 R^2	Role of individual factor (%)	F statistic
Mango mealybug	$Y = -0.11 + 0.143 X_1$	0.433	43.3	43.3	$F_{1,10} = 7.64$ $P < 0.05$
	$Y = -0.283 + 0.151X_1 - 0.0004X_2$	0.435	43.5	0.2	$F_{2,9} = 3.36$ $P = 0.07$
	$Y = 5.47 + 0.175X_1 + 0.003X_2 - 0.095X_3$	0.618	61.8	18.3	$F_{3,8} = 4.31$ $P < 0.05$

Y = Insect population/leaf; X_1 = Average temperature (°C); X_2 = Rainfall (mm); X_3 = Relative humidity (%)

Leaf miner infestation at lemon and pumelo plant

Figure 3 shows percent leaf miner infested leaf at rooftop garden's lemon and pumelo plant. Leaf miner infested leaf percentage was higher in pumelo (36.25 to 78.00%) compare to lemon (30 to 70%) at rooftop garden. In both plant species, leafminer infestation was higher at the time before and after winter. After January, leaf miner infestation was gradually increased and reached the 2nd highest peak at April (67.5% pumelo leaf infestation, 66.25% lemon leaf infestation). In May to July leaf miner infestation reduced, after that infestation increased and reached the highest peak at September.

The multiple linear regression analysis presented in Table 4 showed that the temperature individually contributed 68.2% infestation abundance of lemon leaf miner, temperature with combination of rainfall contributed 72.1% infestation abundance and combined effect of temperature, rainfall and relative humidity was 72.7% on abundance of lemon leaf miner infestation where all equations were significant. Individual effect of rainfall and relative humidity was 3.9 and 0.6, respectively.

In case of pumelo, temperature controlled 41.11% leaf infestation and its effect was significant. Individual effect of rainfall and relative humidity was 0.03 in both cases and the effect was insignificant. Combined effect of temperature, rainfall and relative humidity was 41.17 and the equation was insignificant (Table 4).

Rahman *et al.* (2005) observed that the citrus leaf miner infestation occurred throughout the year with two peak populations in the months of April and September while the minimum incidence was found in January and July which is similar to the result of present study. They also found that the temperature had positive and rainfall had negative effect on leaf miner infestation in the field.

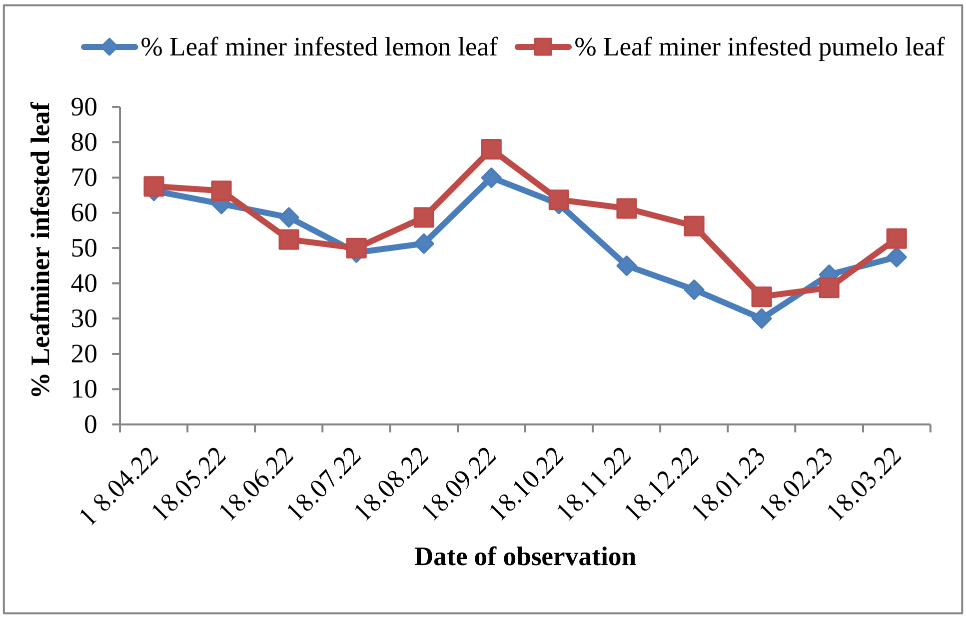

Fig.3. Infestation levels (%) of leaf miner on lemon and pumelo plants in a rooftop garden at Gazipur in Bangladesh during April, 2022 to March, 2023.

Table 4. Multiple regression models along with coefficients of determination (R^2) and the impact of weather parameters on the seasonal incidance of leafminer infestation at lemon and pumelo leaf during April 2022 to March 2023

% Leaf infestation	Regression equation	R^2	100 R^2	Role of individual factor (%)	F statistic
% Lemon leaf infestation	$Y = -18.55 + 2.59 X_1$	0.682	68.2	68.20	$F_{1,10} = 21.5$ $P < 0.01$
	$Y = -5.997 + 1.995X_1 + 0.027X_2$	0.721	72.1	3.90	$F_{2,9} = 11.67$ $P = < 0.01$
	$Y = 8.12 + 2.054X_1 + 0.035X_2 - 0.235X_3$	0.727	72.7	0.60	$F_{3,8} = 7.1$ $P < 0.05$
% Pumelo leaf infestation	$Y = 3.53 + 1.958 X_1$	0.411	41.11	41.11	$F_{1,10} = 6.98$ $P < 0.05$
	$Y = 2.39 + 2.01X_1 - 0.002X_2$	0.411	41.14	0.03	$F_{2,9} = 3.14$ $P = 0.09$
	$Y = -0.93 + 1.99X_1 - 0.004X_2 + 0.055X_3$	0.411	41.17	0.03	$F_{3,8} = 1.86$ $P = 0.21$

Y = % Leaf infestation f; X_1 = Average temperature (°C); X_2 = Rainfall (mm); X_3 = Relative humidity (%)

Fruit fly population at rooftop garden

Monthly cached fruit fly per pheromone trap is shown in Fig. 4. It was found that *B. dorsalis* population was found though out the observation period ranged from 28 to 104.67 per trap. The lowest population was found at January and the highest population was found at the month of July.

Multiple regression equation shows temperature, rainfall and relative humidity individualy controled 56.1, 0.8 and 9.3% fruitfly population abundance at rooftop garden, respectively. Temperature and rainfall controled 56.9% fruitfly population abundance and the combined effect of weather parameter exerted 66.2% population abundance where all the equations were significant (Table 5).

Uddin *et al.* (2016) observed fruit fly population using methyl eugenol water traps at mango orchard. They found the highest fruit fly population in the month of July (7236.30 ± 18.69) and the lowest from January (6.70 ± 0.70) while temperature, relative humidity, rainfall and host availability influenced the fruit fly population. At rooftop condition, fruit fly population fluctuation showed the similar trend like Uddin *et al.* (2016) study but the average fruit fly population was low at present study might be due to lower host availability.

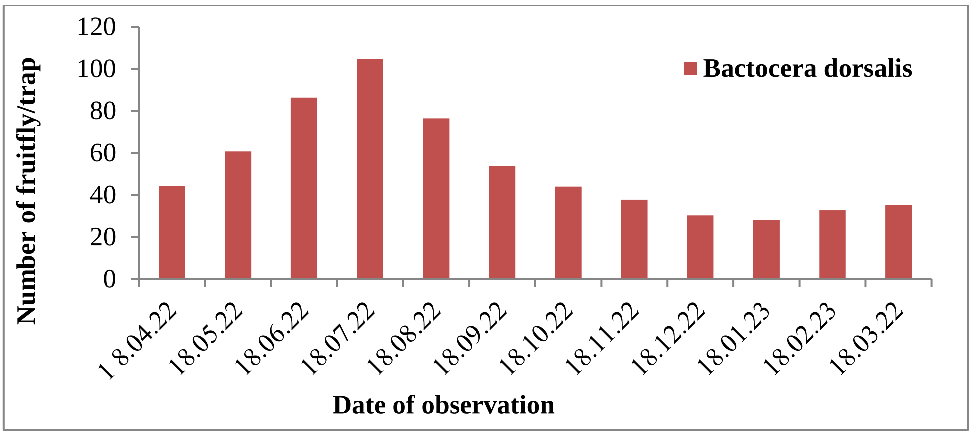

Fig. 4. Monthly catched fruit fly per pheromone trap at rooftop garden during April, 2022 to March, 2023.

Table 5. Multiple regression models along with coefficients of determination (R^2) and the impact of weather parameters on the seasonal abundance of fruit fly during April 2022 to March 2023

Insect name	Regression equation	R^2	100 R^2	Role of individual factor (%)	F statistic
Fruitfly	$Y= -75.86 + 4.72 X_1$	0.561	56.1	56.1	$F_{1,10}= 12.79$ $P < 0.01$
	$Y= -64.68 + 4.199X_1+0.024X_2$	0.569	56.9	0.8	$F_{2,9}= 5.94$ $P< 0.05$
	$Y= -183.98 + 3.703X_1-0.046X_2+1.987X_3$	0.662	66.2	9.3	$F_{3,8} = 5.23$ $P < 0.05$

Y = Fruit fly population/trap; X_1 = Average temperature (°C); X_2 = Rainfall (mm); X_3 = Relative humidity (%)

Conclusion

Both mealybug and spiraling whitefly insects were found in rooftop garden’s guava plant and it was observed that mealybug population was higher than spiraling whitefly population. Mealybug was also found in mango plant. Leaf miner infestation was found in lemon and pumelo plant. Mealybug population, spiraling whitefly population and leaf miner infestations were low at winter and monsoon but increased in summer and autumn. Fruit fly population was higher at mango during bearing season but was lower at winter. Most of the case, weather parameter had significant effect on insect population and infestation at fruit crop-based rooftop garden.

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EFFECT OF DIFFERENT CHEMICALS AND BIOLOGICAL AGENTS FOR CONTROLLING FUSARIUM BASAL ROT OF SUMMER ONION

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M. A. WADUD[4] AND S. HASAN[5]

Abstract

The experiment was conducted at the Regional Spices Research Centre, BARI, Magura during 2020-21 and 2021-22 cropping seasons to investigate the effect of different chemicals and biological agent in controlling f basal rot disease of onion caused by *Fusarium oxysporum* f. sp. *cepae*. A significant difference in yield and yield attributes was observed among different treatments. The highest bulb yield of onion (11.78 t/ha in 202-21 and 13.03 t/ha in 2021-22) was found from the treatment T_7 (*Trichoderma* mixed compost @ 500 kg/ha) followed by the treatment T4 [Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%] (12.22 t/ha in 2020-21 and 11.19 t/ha). Significantly higher plant height, number of leaves per plant, bulb diameter and individual bulb weight were recorded from T_7 treatment followed by T_5 treatment. The lowest disease incidence (6.60 % and 5.42 % in 2020-21 and 2021-22, respectively) were found in *Trichoderma* mixed compost @ 500 kg/ha treated plot followed by T_4 treated plot (8.30% in 2021-22 and 6.99% in 2021-22) while the highest disease incidence (25.78 % and 22.11% in 2020-21 and 2021-22) was observed in the control plot. Application of *Trichoderma* mixed compost @ 500 kg/ha recorded the maximum disease reduction over control (74.38% in 2020-21 and 77.90% in 2021-22) followed by T_4 (71.58% in 2021-22). It is concluded that the treatment *Trichoderma* mixed compost @ 500 kg/ha could be a better option for reducing fusarium basal rot of summer onion and increased bulb yield.

Keywords: Onion, fusarium basal rot, *Trichoderma*, yield, disease incidence.

Introduction

Onion (*Allium cepa L.*), a member of the family Amaryllidaceae, is an important spices crop which has great economic importance worldwide (Pushpalatha *et al.*, 2023; Kavitha and Rami, 2018). It is popularly called 'peyaz' which is one of the important commercial spice crops of Bangladesh. It produces 25.47 lakh metric tons of onion from 5.02 lakh acres area (Anon., 2023). In Bangladesh there is an acute shortage of onion in comparison to its total annual requirement (Ullah *et al*., 2008; Alam and Rahman, 2009). The government of Bangladesh imports around 10 lakh metric tons onions per year expending valuable foreign currency for meeting the demand of the country (Khan *et al.*, 2022). Onion is mainly produced in the winter season but cultivation in summer season is constrained due to adverse weather and

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proper cultural practices (Islam *et al*, 2008). Bangladesh Agricultural Research Institute (BARI) has already developed some onion varieties, namely 'BARI Piaj-2', 'BARI Piaj-3' and 'BARI Piaj-5' which can be grown round the year. So, summer onion cultivation can be a new way to increase the onion production in Bangladesh and make it available throughout the year. Onion production is drastically affected by several diseases throughout its developmental stages. *Fusarium oxysporum* f. sp. *cepae* (Foc) is the causal agent of fusarium basal rot (FBR) that is a major threat for onion (*Allium cepa* L.) bulb production and causes severe losses in the productivity both in the field and in storage condition (Le *et al*., 2021).

Many methods have been developed to control plant pathogens, but only few have provided satisfactory control (Behrani *et al.*, 2015). The antifungal compound isolated from *Sisymbrium irio* L. (Akhtar *et al*., 2020) and numerous fungicides such as Carbendazim and Prochloraz can reduce *Fusarium* spp. growth (Degani *et al*., 2022). Despite many attempts to control, the problem is still important throughout the world. The management practices generally employed for its control include resistant cultivars, chemical applications, cultural practices and biotechnological approaches. However, incorporation of different management provides a better opportunity to manage this disease. The experiment was, therefore, was undertaken to know the appropriate management practices for controlling fusarium basal rot of summer onion.

Materials and Methods

The field experiments were conducted at the research field of the Regional Spices Research Centre, BARI, Magura, during the years 2020-21 and 2021-22 to find out desirable different chemicals (fungicides) and biological agent for controlling fusarium basal rot disease of summer onion. The experimental site belongs to Agro-Ecological Zone (AEZ-11) (High Ganges River Floodplain) and the geographic coordinates are latitude: 23. 489877 N and longitude: 89.402456 E. The soil was moderately deep with clay loam in texture and possessed pH of 7.75. The chemical properties of the soil of experimental plot were assessed. Soil samples were randomly collected at 0-30 cm soil depth for physical and chemical analysis before the commencement of the experiment. The soil sample were air dried, grounded and sieved. The soil sample were analysed in the Regional Laboratory, Soil Resource Development Institute (SRDI), Jhenaidah using standard method to know the soil properties before setting the experiment (Table 1). The experiments were laid out in Randomized Complete Block Design (RCBD) with three replications. The variety 'BARI Piaz-5' was used in this study. Total number of treatments were nine, viz. T_1: Autostin (Carbendazim) @ 0.2%, T_2: Cabriotop (Pyraclostrobin 5%+ metiram 55% WG) @ 0.3%, T_3: Differ 300 EC (Difenoconazole 15% + propiconazole 15%) @ 0.2%, T_4: Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%, T_5: Nativo75 (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.05%, T_6: *Trichoderma* suspension @ 5ml/l, T_7: *Trichoderma* mixed compost @ 500 kg/ha, T_8: *Trichoderma* powder @ 10 kg/ha,

T_9: Control. All the treatments were applied in two times, viz. before planting and 45 days after transplanting as soil drenching.

Table 1. Chemical properties of initial soil before setting the experiment

Soil properties	Analytical Values
Soil texture	Clay loam
pH	7.75
OM (%)	1.60
K (meq/100 g soil)	0.41
Total N (%)	0.09
P (µg/g soil)	65.34
S (µg/g soil)	12.27
Z (µg/g1 soil)	0.97
B (µg.g-1soil)	0.48

N. B.: Field Soil of RSRC, Magura was analyzed by Soil Resource Development Institute (SRDI), Jhenaidah.

The unit plot size of the experiment was 3 m x 1.5 m maintaining the spacing 15 cm x 10 cm. The fertilizer was applied in the form of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum @ 120-54-75-20 kg ha^{-1} of N-P-k-S kg ha^{-1} and 10 tons well-decomposed cowdung was incorporated before ploughing the land. The entire quantity of P, K, S and one third of N were applied as basal dose during land preparation. The remaining N was used as top dress in two equal splits at 30 and 50 days after seedling transplanting.

Seeds of 'BARI Piaz-5' were sown on 3 m x 1 m nursery beds on 15 February 2021 and 20 February 2022, respectively. Forty day- old seedlings were transplanted in the experimental plot and before transplanting about 5 cm of each seedling top was trimmed out. Three weedings were done at 30, 45 and 60 days after transplanting and two irrigations were applied. Other intercultural operations were done to maintain the normal hygienic condition of crop in the field. The plots were inspected regularly to take observations on fusarium basal rot of the crop. Dead plants were counted in the field. The crop was harvested after 75 days of transplanting on 9 June 2021 and 14 June 2022, respectively.

Data on plant height (cm), number of leaves/plants, bulb diameter (cm), individual bulb weight (g), bulb yield (t/ha) and disease incidence (%) were recorded. The incidence of fusarium basal rot of onion was recorded at every alternate day. The incidence of fusarium basal rot of onion was calculated by the following formula:

$$\text{Incidence of fusarium basal rot (\%)} = \frac{Number\ of\ infected\ plants}{\text{Total number of plants}} x100$$

To determine the cost-efficiency of the treatments, the Benefit Cost Ratio (BCR) was calculated based on the local market price of onion bulbs and input costs. The BCR was measured by the following formula:

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross return}}{\text{Total cost of production}}$$

The recorded data were analyzed statistically using Statitix10 software to find out the level of significance and the variations among the treatments. Mean separation was done by Least Significant difference (LSD) test at 5% probability level.

Results and Discussion

Growth parameters and bulb yield

Growth and yield characters of onion were significantly influenced by different treatments (Table 2). The maximum plant height viz. (45.33 cm and 47.92 cm in 2020-21 and 2021-22, respectively), number of leaves per plant (7 and 9 in 2020-21 and 2021-22, respectively), bulb diameter (27.22 mm and 32.47 mm in 2020-21 and 2021-22, respectively) and individual bulb weight (35.50 g and 39.87 g in 2020-21 and 2021-22, respectively) were recorded from the treatment T_7 (Trichoderma mixed compost @ 500 kg/ha) which was followed by treatment T_4 (Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%). The minimum plant height (38.59 cm and 41.35 cm in 2020-21 and 2021-22, respectively), number of leaves per plant (6 and 8 in 2020-21 and 2021-22, respectively), bulb diameter (18.70 mm in 2020-21 and 23.99 mm in 2021-22) and individual bulb weight (22.50 g and 26.87 g in 2020-21 and 2021-22, respectively) were found from treatment T_9 (control).

Organic manure improved physical properties of the soil which increased the vegetative growth parameters significantly. According to Nahar *et al.* (2012), the chemical analysis of Tricho-compost clearly showed that it was rich in various nutrients. *Trichoderma* also produced phytohormones, vitamins and solubilize minerals which lead to increase the growth in terms of plant height (Uddin *et al.*, 2015). These results are in agreement with Alyat and Naggar (2010) who observed application of bio fertilizers with organic amendments resulted in promoting the number of leaves plant^{-1}. Kumar *et al*., (2019) concluded *Trichoderma* based compost enhancing vegetative, morphological and qualitative parameters of onion. Application of *Trichoderma* spp. biocompost had a significant effect on the plant height, number of tillers, number of bulbs per cluster wet weight and dry weight of bulb (Suparlan *et al.*, 2024).

Table 2. Effect of different treatments on growth and yield contributing character of summer onion

Treatments	Plant height (cm)		Number of leaves/plants (nos.)		Bulb diameter (mm)		Individual bulb weight (g)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
T_1	40.50	43.00	6.00	8.00	20.40	26.08	25.53	29.90
T_2	42.38	44.62	6.00	8.00	22.43	27.78	30.10	34.47
T_3	40.30	42.73	6.00	8.00	19.73	25.26	24.23	28.60
T_4	43.37	45.94	7.00	9.00	25.30	30.83	33.47	37.83
T_5	42.27	44.65	6.00	8.00	21.97	27.62	29.07	33.43
T_6	41.47	43.97	6.00	8.00	21.77	27.21	27.77	32.13
T_7	45.33	47.92	7.00	9.00	27.22	32.47	35.50	39.87
T_8	41.13	43.52	6.00	8.00	20.60	26.21	26.53	30.90
T_9	38.59	41.35	6.00	8.00	18.70	23.99	22.50	26.87
CV (%)	0.60	0.84	4.48	3.42	2.71	1.91	1.70	1.47
LSD	0.43	0.63	0.50	0.49	1.03	0.91	0.83	0.83

Y1 = 2020-21, Y_2 = 2021-22; T_1: Autostin (Carbendazim) @ 0.2%, T_2: Cabriotop (Pyraclostrobin 5%+ metiram 55% WG) @ 0.3%, T_3: Differ 300 EC (Difenoconazole 15% + propiconazole 15%) @ 0.2%, T_4: Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%, T_5: Nativo75 (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.05%, T_6: Trichoderma suspension @ 5ml/l, T_7: Trichoderma mixed compost @ 500 kg/ha, T_8: Trichoderma powder @ 10 kg/ha, T_9: Control. CV= Coefficient of variation, LSD = Least significant difference

The yields were varied significantly among the different treatment (Figure 1). The highest yield (11.78 t/ha and 13.03 t/ha in 2020-21 and 2021-22, respectively) was recorded from the treatment Trichoderma mixed compost @ 500 kg/ha followed by Eminent pro (Tetraconazole 12.5% + Carbendazimn 15%) @ 0.1%) (11.19 t/ha and 12.22 t/ha in 2020-21 and 2021-22, respectively) and the lowest bulb yield (7.85 t/ha and 9.07 t/ha in 2020-21 and 2021-22, respectively) was found from treatment T_9 (control). The weight of individual bulb was increased in tricho-compost treated plot because this compost acted as organic manure. Addition of organic manure might have improved the soil structure and enhanced the availability of macro and micro nutrients. Trichoderma solubilized insoluble minerals and captures more nutrients which plants could easily uptake (Ara *et al*., 2019). The yield and bulb weight might be increased due to the availability of many nutrients by plants i.e., nitrogen, phosphorus and potassium. The NPK enhanced the cell division of the plant tissue and hence increased the rate of photosynthesis. For this reason, *Trichoderma harzianum* significantly affected yield of onion (Ara *et al*., 2019).

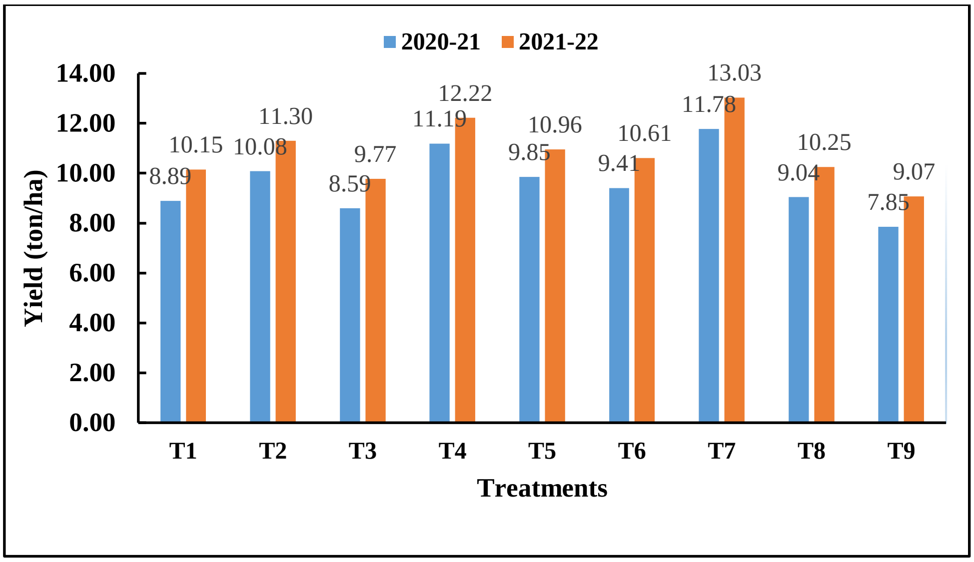

Fig. 1. Effect of different treatments with chemicals and biological agents on the yield of onion

T1: Autostin (Carbendazim) @ 0.2%, T2: Cabriotop (Pyraclostrobin 5%+ metiram 55% WG) @ 0.3%, T3: Differ 300 EC (Difenoconazole 15% + propiconazole 15%) @ 0.2%, T4: Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%, T5: Nativo75 (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.05%, T6: Trichoderma suspension @ 5ml/l, T7: Trichoderma mixed compost @ 500 kg/ha, T8: Trichoderma powder @ 10 kg/ha, T9: Control

Effect of different treatment in controlling basal rot disease of onion

The highest disease incidence (25.78% and 22.11% in 2020-21 and 2021-22, respectively) was observed in the treatment T_9 (Control) and the lowest disease incidence (6.60% and 5.42% in 2020-21 and 2021-22, respectively) from T_7 treatment which was followed by T_4 treatment (8.30% and 6.99% in 2020-21 and 2021-22, respectively) (Table 3). The maximum disease reduction over control (74.38% and 77.90 % in 2020-21 and 2021-22, respectively) was observed from the treatment T_7 (*Trichoderma* mixed compost @ 500 kg/ha) followed by T_5 (55.08%) in 2020-21 and T_4 (71.58%) in 2021-22 (Table 3). From the result it was confirmed that *T. harzianum* isolate mixed with compost was able to reduce the incidence of basal rot compared to control plot. The success of biological control of plant diseases depends on the availability of effective formulations of biocontrol agents (Kumar *et al*., 2017). According to Yagmur *et al*. (2024), *T. harzianum* with soil amendment could be used as an effective biocontrol agent against fusarium basal rot disease of onion. Ghanbarzadeh *et al*. (2016) also reported that *T. harzianum* was the best antagonists for basal rot disease of onion, caused by *Fusarium oxysporum* f. sp. *cepae,* under laboratory, pot and field conditions.

Table 3. Effect of different treatments with chemicals and biological agents for controlling basal rot disease of onion

Treatments	Disease incidence (%)		Disease reduction over control (%)	
	2020-21	2021-22	2020-21	2021-22
T_1	20.22 (4.50)	17.64 (4.20)	25.68 (5.07)	29.20 (5.40)
T_2	12.41 (3.52)	10.30 (3.21)	41.13 (6.41)	58.55 (7.65)
T_3	22.44 (4.74)	19.17 (4.38)	24.55 (4.95)	22.80 (4.77)
T_4	8.30 (2.88)	6.99 (2.64)	48.69 (6.98)	71.58 (8.46)
T_5	13.78 (3.71)	11.20 (3.35)	55.08 (7.42)	55.07 (7.42)
T_6	15.11(3.89)	12.81(3.58)	53.83 (7.34)	48.39 (6.96)
T_7	6.60 (2.57)	5.42 (2.33)	74.38 (8.62)	77.90 (8.83)
T_8	17.11 (4.14)	14.92(3.86)	36.27 (6.02)	40.01 (6.33)
T_9	25.78 (5.04)	22.11(4.70)	9.32 (3.05)	10.67 (3.27)
CV	6.6	7.93	53.01	10.97
LSD	0.50	0.31	0.65	0.50

Figures in parentheses are square root transformed values.

T_1: Autostin (Carbendazim) @ 0.2%, T_2: Cabriotop (Pyraclostrobin 5% + metiram 55% WG) @ 0.3%, T_3: Differ 300 EC (Difenoconazole 15% + propiconazole 15%) @ 0.2%, T_4: Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%, T_5: Nativo75 (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.05%, T_6: Trichoderma suspension @ 5ml/l, T_7: Trichoderma mixed compost @ 500 kg/ha, T_8: Trichoderma powder @ 10 kg/ha, T_9: Control. CV= Coefficient of variation, LSD = Least Significant Difference

Cost benefit analysis

The profitability of summer onion as influenced by different management practices are presented in Table 4. The highest Benefit Cost Ratio (BCR) was found (2.48 2020-21 and 2.74 in 2021-22) the treatment T_7 (Trichoderma mixed compost @ 500 kg/ha) followed by treatment T_4 [Eminent pro (Tetraconazole 12.5% + Carbendazimn 15%)] @ 0.1%) with BCR (2.33 in 2020-21 and 2.54 2021-22) and the lowest BCR was recorded against the treatment T_9 (control) (1.87 and 2.16). Due to the maximum marketable bulb yield with low disease incidence BCR was higher in tricho compost treated plot. Ara *et al*. (2019) also obtained the maximum BCR was noted in *Trichoderma* treated plot.

Table 4: Profitability of onion as influenced by different treatments with chemicals and biological agents

Treatments	Total cultivation cost (Tk./ha)		Gross return (Tk./ha)		Net return (Tk./ha)		BCR	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
T_1	186400	191400	355600	191400	169200	219600	1.91	2.18
T_2	188400	193400	403080	193400	214680	263480	2.14	2.39
T_3	187300	192300	343600	192300	156300	203620	1.83	2.09
T_4	192000	197000	447480	197000	255480	296800	2.33	2.54
T_5	190000	195000	394000	195000	204000	248400	2.07	2.31
T_6	187500	192500	376280	192500	188780	237020	2.01	2.26
T_7	190000	195000	471080	195000	281080	331200	2.48	2.74
T_8	190000	199000	361600	200000	166600	215000	1.90	2.06
T_9	168000	173000	314120	173000	146120	194800	1.87	2.16

Y_1 = 2020-21, Y_2 = 2021-22; Urea-Tk. 16/kg, TSP-Tk. 15/kg, MoP-Tk.15/kg, Gypsum-Tk. 10/kg, Zinc sulphate –Tk.100/kg, Boric acid-Tk. 100/kg, Labour- Tk. 400/man/day, Irrigation- 3000/ha/irrigation, Leas value- Tk. 25000/ha for 5 months, Seed-3000/kg, Sale price-Tk. 40 /kg bulb, T_1: Autostin (Carbendazim) @ 0.2%, T_2: Cabriotop (Pyraclostrobin 5%+ metiram 55% WG) @ 0.3%, T_3: Differ 300 EC (Difenoconazole 15% + propiconazole 15%) @ 0.2%, T_4: Eminent pro (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1%, T_5: Nativo75 (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.05%, T_6: Trichoderma suspension @ 5ml/l, T_7: Trichoderma mixed compost @ 500 kg/ha, T_8: Trichoderma powder @ 10 kg/ha, T_9: Control; BCR = Benefit Cost Ratio

Conclusion

Two years' experimental results revealed that application of *Trichoderma* mixed compost @ 500 kg/ha could be used for controlling fusarium basal rot disease of onion caused by *Fusarium oxysporum* f. sp. *cepae*. Vegetative growth and yield parameters of summer onion were also found maximum from this treatment. Application of this treatment would be effective for getting maximizing economic return. The fungicide 'Eminent pro' (Tetraconazole 12.5% + Carbendazim 15%) @ 0.1% applied as soil drenching twice, viz. before planting and 45 days after transplanting would also be beneficial for reducing disease incidence of fusarium basal rot of summer onion.

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EFFECT OF DROUGHT STRESS ON GROWTH AND YIELD OF BARI RELEASED TOMATO VARIETIES

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Abstract

The experiment was conducted at the Plant Physiology field of Horticulture Research Center, Bangladesh Agricultural Research Institute (BARI) during 2021-22 and 2022-23 in winter season to study the responses of BARI released open pollinated tomato varieties to drought stress. Tomato plants of eight varieties [V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20 (cherry tomato) and V_8 = BARI Tomato-21) were grown under two different conditions of water availability i.e., controlled condition (100% field capacity-FC) and drought condition (60% FC). The pooled results of two years are presented. All the parameters studied except total soluble solid (TSS) and proline content were negatively affected by drought. Fruit TSS and leaf proline content were increased at drought stress. With regard to plant height and SPAD value, the lowest reduction was noted in BARI Tomato-18 but the lowest reduction of relative water content (RWC) was observed in BARI Tomato-18 and BARI Tomato-20. In context to relative value of the characters such as number of fruits/plants, individual fruit weight, fruit set, yield/plant and yield/ha, the varieties BARI Tomato-18 and BARI Tomato-20 showed the higher relative percentage at 60% FC. Maximum TSS and proline content increase were observed in BARI Tomato-7 and BARI Tomato-18 varieties. Based on the results, it may be concluded that BARI Tomato-18 and BARI Tomato-20 perform better at drought condition (60% FC) and these two tomato varieties may be considered as medium drought tolerant.

Keywords: Tomato**,** Field capacity, Drought stress, RWC, Proline, Yield.

Introduction

Drought is one of the major limiting factors for crop expansion and it will become increasingly important due to changes in the global climate. Now-a-days, attention is focused on improving crop genotypes for drought-prone areas. It is one of the most important abiotic stresses which affect crop growth and yield (Lutts *et al.,* 2004; Mahajan and Tuteja, 2005; Castillo *et al.,* 2007; Khan *et al.,* 2010; Bakht *et al.,* 2010). The stage at which the drought stress occurs plays a major role in the final yield of the crop. Drought has become recurrent natural phenomenon of north-western part of Bangladesh.

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Tomato (*Solanum lycopersicum* L.) is one of the most important popular vegetables in the tropical and subtropical areas including Bangladesh. Now, tomato varieties are available for cultivation in both winter and summer season. Tomato is sensitive to a number of environmental stresses, especially extreme temperature, drought, salinity and inadequate moisture stress (Kalloo, 1993). Drought is an environmental stress that reduces plant growth and productivity. Generally, tomato is cultivated in winter. During winter rainfall is insufficient and during summer rainfall in not uniformly distributed all over the country. In nature, water is usually the most limiting factor for plant growth. Thus, it has become necessary and select the ones which are tolerant to drought stress. Therefore, the experiment was conducted to study the changes in morphological and physiological parameters of tomato plant under drought stress condition and observe the suitability of BARI released open pollinated tomato varieties under drought condition.

Materials and Methods

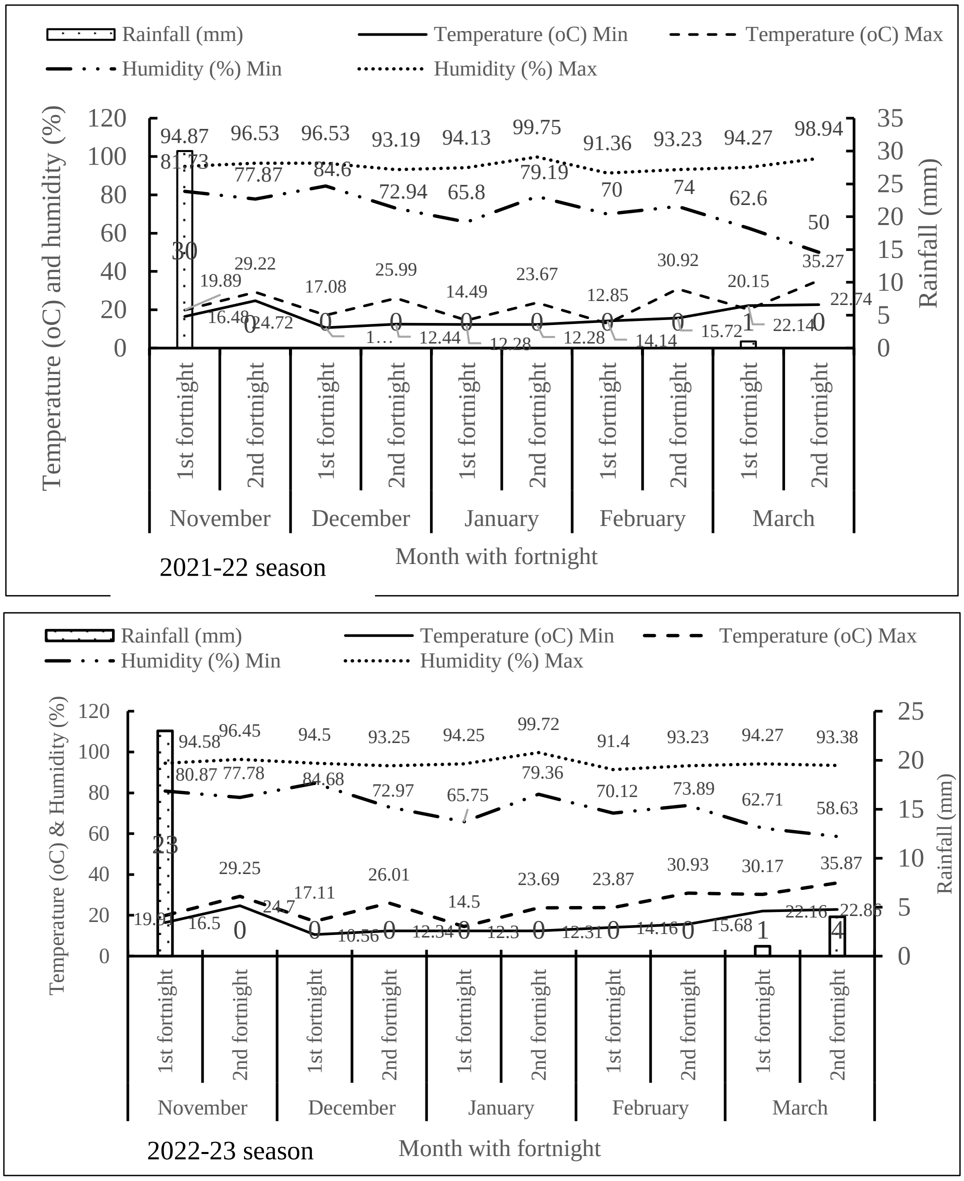
The experiment was conducted at the research field of Plant Physiology Section, Horticulture Research Center (HRC), Bangladesh Agricultural Research Institute (BARI) (23°59′34″ N latitude and 90°24′39″ E longitude) from November to March during 2021-22 and 2022-23. Eight varieties of tomato (V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20and V_8 = BARI Tomato-21) collected from the Olericulture Division of HRC, BARI, Joydebpur, Gazipur, were evaluated at two conditions of water availability (i) non stress- water applied upto 100% of field capacity (FC) and ii) drought stress-water applied up to 60% of FC (40% less than 100% FC). The moisture per cent of soil was monitored during experimental period two weeks interval in 2021-22 and 2022-23 seasons by Soil Moisture Meter (Model: PMS-714, Taiwan (Fig. 2). The weather data of two years 2021-22 and 2022-23 are presented in Fig. 1. The crop received 31.0 mm and 28.0 mm rainfall in 2021-22 and 2022-23 seasons, respectively. The experimental soil was silty clay loam in texture having the soil moisture at field capacity and bulk density of 29.5% and 1.35 g/cm^3, respectively. The study was conducted under Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 2.0 m x 2.0 m and plant spacing was 50 cm x 50 cm. Plot to plot and replication to replication distance were 60 cm and 75 cm, respectively. Twenty eight day-old seedlings were transplanted in the field on 28 November, 2021 and 26 November, 2022. Irrigation was started on 14 days after transplanting of seedlings. Measured amount of irrigation water (IW) was applied with the help of a 20 L calibrated plastic bucket. To maintain 100% FC, irrigation was done at 2-3 days interval and 60% FC, irrigation was done at 5-6 days interval. At 100 FC and 60% FC, 35 times and 18 times irrigation were applied to the plot, respectively. The required depth of irrigation was calculated using the following equation (Michael, 1978): $d = \{(M_{FC} – M_{PI}) / 100\} \times \rho b \times D$;

Where, d = depth of irrigation requirement (cm), M_{FC} = Soil moisture percentage at field capacity, M_{PI}= Soil moisture percentage in field prior to irrigation, ρb = Bulk density (g cm^{-3}), D = Rooting depth (cm) (assuming 25 cm for tomato). The formula of quantifying total volume of water required to irrigate the plot is = A x d m^3, where A = plot area and d= depth of irrigation) (Akanda *et al*., 1994). Then the measured amount of water was applied to the plot with the help of calibrated plastic bucket. The crop was fertilized with N-P-K-S-Zn-B-Mg@ 250-90-125-20-5-2-9 kg /ha, respectively (Anonymous, 2021). Cow dung was applied @10 t/ha. Half of the quantity of cow dung, entire P and half of K, entire S, Zn, B and Mg were applied during final land preparation. The rest half of cow dung was applied in the pit. The remaining K and entire N were applied at three equal installments at 15, 30 and 45 days after transplanting (Anonymous, 2021). Weeding was done as per requirements. Rovral 50 WP was sprayed @ 0.2% two times at 25 days after transplanting (DAT) and 50 DAT when symptom of early blight of tomato was seen. Ridomyl Gold was also sprayed three times at 15 days interval starting from 55 DAP for precautionary measure of late blight disease of tomato. Final harvest of tomato was done on 30 March, 2022 and 29 March 2023. Data (from 5 plants) were collected on plant height at 60 and 90 DAT, chlorophyll content (SPAD value) at 60 and 90 DAT, relative water content (RWC) at 60 and 90 DAT, no. of fruits/plant, individual fruit weight, %fruit set and fruit yield/plant. Plot yield was converted to per hectare yield. The SPAD value was taken by SPAD meter (SPAD-500 plus, Minolta Konica Inc, Japan). RWC was measured using leaves (7^{th} no. leaf from the tip of the plant) after imposing drought conditions. Immediately after cutting at the base of lamina, leaves were sealed within plastic bags and quickly transferred to the laboratory. Fresh weights were determined within 2 h after excision. Turgid weights were obtained after soaking leaves in distilled water in plastic bowls for 16 to 18 h at room temperature (about 25°C) and under the low light conditions of the laboratory. During soaking bowls were covered with polythene. After soaking, leaves were quickly and carefully blotted dry with tissue paper in preparation for determining turgid weight. Dry weights were obtained after oven drying the leaf samples for 72 h at 70°C. RWC was calculated from the equation of Schonfeld *et al*. (1988):

$$\% \text{ RWC} = \frac{\text{Fresh weight- dry weight}}{\text{Turgid weight – dry weight}} \times 100$$

TSS (%) of ripe tomato fruit was measured by a Handheld Refractometer (HRb-18 T, made in Germany). The 1-2 drops of tomato juice (after blending the fruit) were taken on the prism of refractometer and TSS data was recorded. Proline content was recorded from 5^{th} leaf of tomato plants from the apex. Proline content was estimated according to the method proposed by Bates *et al* (1973) using L-proline as standard. A one-gram sample was homogenized in 5 ml of aqueous sulfosalicylic acid (3%) and centrifuged at 14,000 g for 15 min. Two ml of supernatant was added to 2 ml of mixed acetic acid and ninhydrin, and heated for

1 h at 100^0C. The mixture was then cooled rapidly in an ice-bath, and added to 4 mL of toluene. Absorbance was recorded n a spectrophotometer (UV-200 UV Spectrophotometer, Japan) at 525 nm. Proline content was reported as µmol g^{-1} FW. The pooled data of two years were analyzed through MSTAT C software and mean separation was done by Tukey's W test at 5% probability level.



Source: Weather office, Gazipur

Fig. 1. Weather data (Temperature, rainfall and humidity) during experimentation in 2021-22 and 2022-23 seasons.

Results and Discussions

Monitoring of moister per cent

Two weeks interval moisture (%) was monitored from transplanting to last harvest (17 December to 30 March) in 2021-22 and 2022-23 seasons (Fig. 2). In 2021-22 season, soil moisture ranged from 13.25% to 15.25% and 23.42% to 25.97% at 60% FC and 100% FC, respectively. But, in 2022-23 season, soil moister ranged from 12.58% to 15.32% at 60% FC treatment, whereas, at 100% FC, soil moister ranged from 22.85% to 25.98%. At FC and wilting point, soil moisture was 29.5% and 13.42%, respectively. The Fig. 1 shows that, during growth stage the crop faced to moisture crisis under 60% FC in some days.

Requirement of Irrigation and total water

During experimental period the crop received 31 mm (effective rainfall: 31 x 0.6 = 18.6 mm) and 28 mm rainfall (effective rainfall: 28 x 0.6 = 16.8 mm) in 2021-22 and 2022-23 seasons, respectively. For tomato production, in 100% FC treatment, 584.3 mm and 560.6 mm irrigation was required in 2021-22 and 2022-23 seasons, respectively, while in 60% FC treatment, 270.04 mm and 265.2 mm irrigation was required in 1st and 2nd year, respectively. So, the actual irrigation requirement under 100% RC treatment in 1st and 2nd year was 565.7 mm and 543.8 mm, respectively, whereas, under 60% FC, the actual irrigation requirement was 251.8 mm and 248.4 mm in 1st and 2nd year respectively.

In 100% FC treatment, total amount of required water to irrigate one hectare land was 5258.6 m^3/ha, but in 60% FC treatment, the amount of required water for irrigation to one ha land was 2430.3 m^3/ha during 2021-22 season. But during 2022-23 season, in 100% FC treatment, the amount of required water was 5160.4 m^3/ha but, in 60% FC treatment the amount of required water was 2398.5 m^3/ha.

At 100% FC treatment, the average available water was 16.54% for the tomato plant in both years and 60% FC treatment, the average available water was 14.29% for both years.

Plant height

Plant height was declined due to drought stress (Table 1). At 60 days after transplanting (DAT), Plant height ranged from 73.83 cm (V_1) to 111.90 cm (V_{20}) at 100% FC (field capacity) while at 90 DAT, the range of plant height was 93.56 cm (V_8) to 160.53 cm (V_7) at 60% FC. At 60 DAT the range of plant height was 68.50 cm (V_1) to 105.80 cm (V_7) at 60% FC; whereas, at 90 DAT the plant height was in the range of 88.54 cm (V_3) to V_7 (151.60 cm). At 60% FC, the maximum reduction in plant height was observed in V_1 (7.22%) followed by V_2 (7%), V_3 (7%), V_4 (7.00%) and V_6 (7.11%) at 60 DAT, while, the lowest reduction was recorded in V_5 (4.05%) followed by V_8 (5.42%) and V_7 (5.45%). Again, at 90 DAT, the highest reduction in plant height was observed in V_3 (10.00%) followed by V_4

(9.00%) and V_1 (8.00%) and the lowest reduction was noticed in V_5 (4.00%) followed by V_8 (4.55%) at 40-50% FC. Buhroy *et al.* (2017) reported 10% decrease in plant height occurred at 50% FC in tomato.

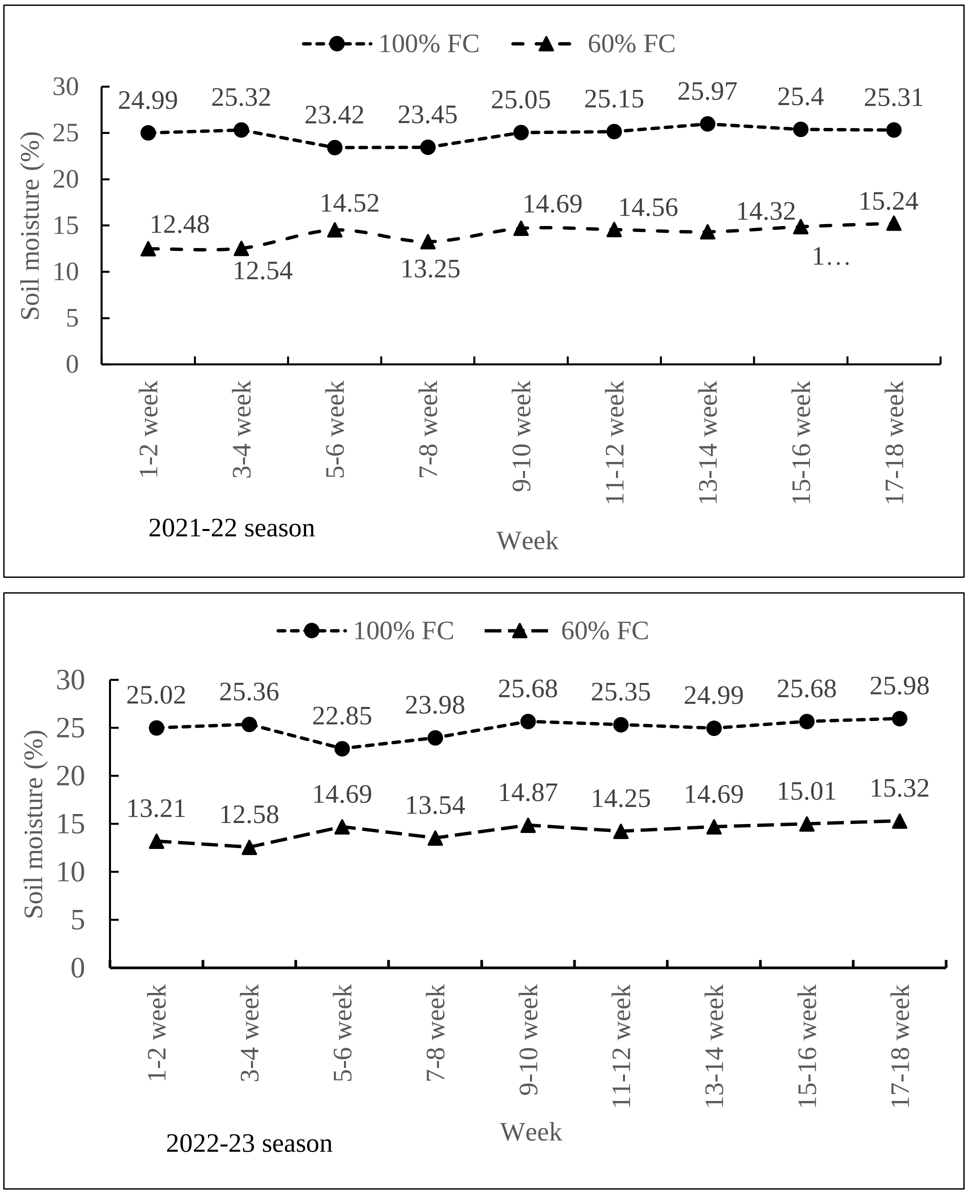


Fig. 2. Two weeks interval soil moisture (%) in tomato research field at 10 cm soil depth

Table 1. Effect of drought stress on plant height at two growth stages in tomato varieties

Variety	Plant height at					
	60 DAT			90 DAT		
	100% FC	60% FC	Reduction% at 60% FC	100% FC	60% FC	Reduction% at 60% FC
V_1	73.83f	68.50f	7.22	97.46c	89.66d	8.00
V_2	100.03b	93.03b	7.00	150.00b	137.48b	8.35
V_3	74.53f	69.31e	7.00	98.38c	88.54d	10.00
V_4	79.33ef	73.78e	7.00	95.60c	87.00d	9.00
V_5	86.07de	82.58d	4.05	94.52c	90.74d	4.00
V_6	94.37bc	87.66c	7.11	101.42c	95.33c	6.00
V_7	111.90a	105.80a	5.45	160.53a	151.60a	5.56
V_8	89.67cd	84.81cd	5.42	93.56c	89.30	4.55
Mean	88.72	83.18	6.28	111.40	10.71	6.91
CV (%)	9.21	9.21	-	8.89	8.89	-

Figures within a column having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

SPAD value

SPAD value was reduced by moisture deficit (Table 2). Variation among varieties was also presented and ranged from 41.65 (V_3) to 47.93 (V_5) (100% FC) and 33.20 (V_2) to 45.14 (V_5) (60% FC) at 60 DAT. At 60 DAT, the highest reduction in SPAD value was in V_2 (26.22%) followed by V_1 (25.76%), V_6 (25.50%), V_4 (22.32%) and the lowest reduction in from V_7 (3.58%) followed by V_5 (5.82%). At 90 DAT SPAD value ranged from 42.03 (V_8) to 48.99 (V_3) (100% FC) and 31.23 (V_1) to 44.06 (V_5) (60% FC). At this stage, the highest reduction in SPAD value was in V_1 (28.04%) followed by V_4 (27.31%), V_6 (26.07%) and V_2 (25.88%) and the lowest reduction in V_5 (4.49%).This was in agreement with the results of Gong *et al.* (2005) and Tembe *et al.* (2017) who found that reduction in chlorophyll content under moisture deficit could be attributed to the fact that water stress damages the photosynthetic apparatus by causing changes in the chlorophyll contents and components. Lessani and Mojtahedi (2002) opined that water deficit can destroy the chlorophyll and prevent making it. A reason for decrease in chlorophyll content as affected by water deficit is that drought stress by producing reactive oxygen species (ROS) such as O^{2-} and H_2O_2, can lead to lipid peroxidation and consequently, chlorophyll destruction (Mirnoff, 1993; Foyer *et al.*, 1994). Sivakumar and Srividhya (2016) obtained 7.42% decrease in SPAD value at drought condition.

Table 2. Effect of drought stress on SPAD value at two growth stages in tomato varieties

Variety	SPAD value at					
	60 DAT			90 DAT		
	100% FC	60% FC	Reduction% at 60% FC	100% FC	60% FC	Reduction% at 60% FC
V_1	45.97c	34.13ef	25.76	43.40d	31.23e	28.04
V_2	45.00d	33.20f	26.22	48.30a	35.80c	25.88
V_3	41.65e	36.65d	12.00	48.99a	32.13e	34.42
V_4	44.93d	34.90e	22.32	47.20b	34.31d	27.31
V_5	47.93a	45.14a	5.82	46.13c	44.06a	4.49
V_6	46.83b	34.89e	25.50	46.53bc	34.40d	26.07
V_7	45.03d	43.42b	3.58	46.47bc	41.82b	10.01
V_8	47.00b	39.48c	16.00	42.03e	36.14c	14.01
Mean	45.54	37.73	17.15	46.13	36.24	21.44
CV (%)	5.64	5.64	-	6.52	6.52	-

Figures within a column having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

Table 3. Effect of drought stress on relative water content (RWC) at two growth stages in tomato varieties

Variety	Relative water content (RWC) at					
	60 DAT			90 DAT		
	100% FC	60% FC	Reduction% at 60% FC	100% FC	60% Fc	Reduction% at 60% FC
V_1	83.60c	79.61b	4.77	70.19d	65.97c	6.01
V_2	83.20c	73.79cd	11.31	74.97c	61.97d	17.34
V_3	79.50d	66.78e	16.00	64.39e	56.76e	11.85
V_4	86.48b	73.02d	15.56	77.06b	71.09b	7.75
V_5	87.60ab	85.04a	2.92	78.55a	72.86a	7.24
V_6	88.50a	74.96c	15.30	76.99b	71.06b	7.70
V_7	86.80b	85.42a	1.59	77.88ab	73.54a	5.57
V_8	76.23e	62.50f	18.01	60.98f	50.23f	17.63
Mean	83.99	75.14	10.54	72.63	65.44	10.13
CV (%)	9.65	8.52	-	7.32	6.54	-

Figures within a column having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

Relative water content

Drought (water stress) had significant effect on relative water content among different varieties observed (Table 3). Relative water content (RWC) at 60 DAT ranged from 76.23% (V_8) to 88.50% (V_6) with 100% FC and 62.50% (V_8) to 85.42% (V_7) with 60% FC. The highest reduction in RWC was in the variety V_8 (18.01%) followed by V_3 (16.00%), V_4 (15.56%) and V_6 (15.30%) and it was recorded lowest in V_7 (1.59%) and V_5 (2.92%) at 60 DAT. While at 90 DAT the highest reduction was observed in V_8 (17.63) followed by V_2 (17.34%) and V_3 (11.85%) and the lowest reduction value was found in V_7 (5.57%) followed by V_1 (6.01%) and V_5 (7.24%). According to Yamasaki and Dillenburg (1999), RWC is an appropriate physiological measure of plant water status under water stress (drought) condition. Alizade (2002) reported that leaf RWC is of one of the best growth/biochemical indices revealing the stress intensity. In this study RWC decreased at 40-50 % FC. Sibomana *et al.* (2013) noted that decreased leaf water potential leads to stomatal closure and ultimately results in low transpiration. Varieties/genotypes, which showed higher RWC ensure more favourable internal water relations of tissue and showed better drought tolerance quality. Similar results were reported earlier by Srinivas and Bhatt (1992) and Sivakumer (2017) in tomato. Since the rate of RWC is seen higher in varieties V_5, V_6 and V_7, it might be inferred that those varieties have tolerance against drought. Buhroy *et al.* (2017) reported that 11.97% reduction in RWC at 50% FC compared to 100% FC.

Number of fruits/plant and Relative no. of fruits/plant

Average number of fruits/plants ranged from 19.00 to 159.73 (100% FC) and 12.00 to 137.40 (60% FC) (Fig. 3). In both non-stress and stress condition, the maximum number of fruits/plants was recorded in V_7 (159.73 and 137.4), respectively followed by V_6 (71.60 and 55.33), respectively. The highest reduction was noticed in V_4 (36.84%) followed by V_1 (26.99%) and V_2 (27.47%) and the lowest reduction was recorded in V_7 (13.98%) and V_5 (15.86%) (Fig. 4). The lowest relative no. of fruits/plant was recorded in V_4 (63.16%) followed by V_2 (72.53%) and the highest relative fruit number was observed in V_7 (86.02%) followed by V_5 (84.14%) (Fig 4). Buhroy *et al.* (2017) reported that 39.66% in relative no. of fruits/plant at 50% FC.

Individual fruit weight and Relative fruit weight

Individual fruit weight ranged from 27.41 g to 251.67 g with 100% FC and 21.10 g to 165.41 with 40-50% FC (Fig. 5). Maximum individual fruit weight was recorded in V_4 at both 100 and 50% FC followed by V_1 and V_5 and the least individual fruit weight was obtained from V_7. The highest reduction in individual fruit weight was observed in V_8 (53.44%) followed by V_6 (36.0%) and V_4 (34.28%) and the lowest reduction was noticed in V_5 (18.86%) followed by V_1 (22.52%) and V_7 (23.02%) (Fig. 6). Maximum relative individual fruit weight was recorded in V_5 (81.14%) closely followed by V_1 (77.48%) and V_7 (76.98%); while, the lowest relative individual weight was recorded in V_8 (46.56%) (Fig. 6). Sivakumar and Srividhya (2016) obtained 32.10% decrease in tomato fruit weight at drought stress.

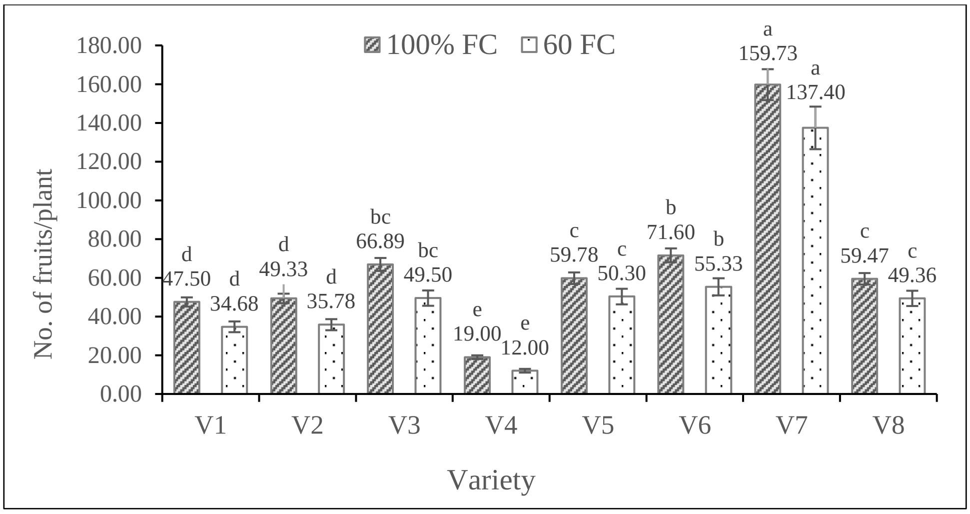


Fig. 3. Effect of drought stress on no. of fruits/plant in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

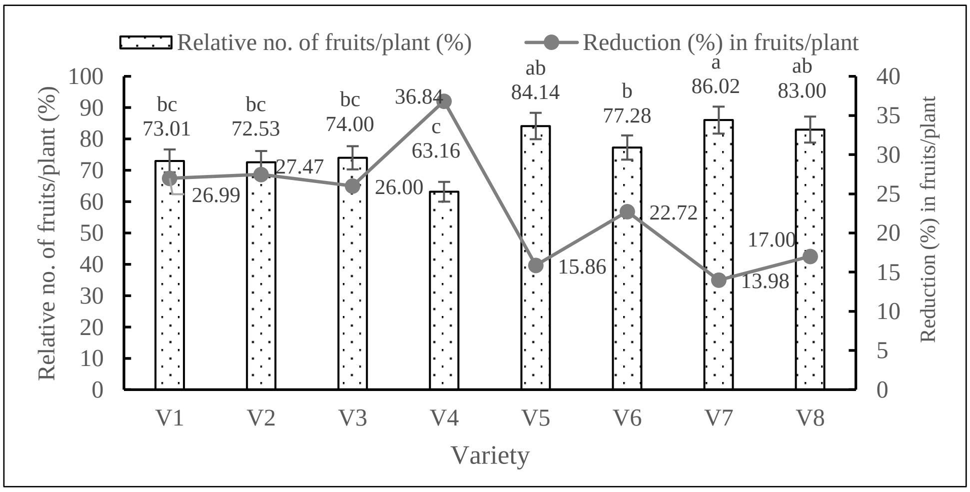


Fig. 4. Effect of drought stress on relative no. of fruits/plant and fruits/plant reduction in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

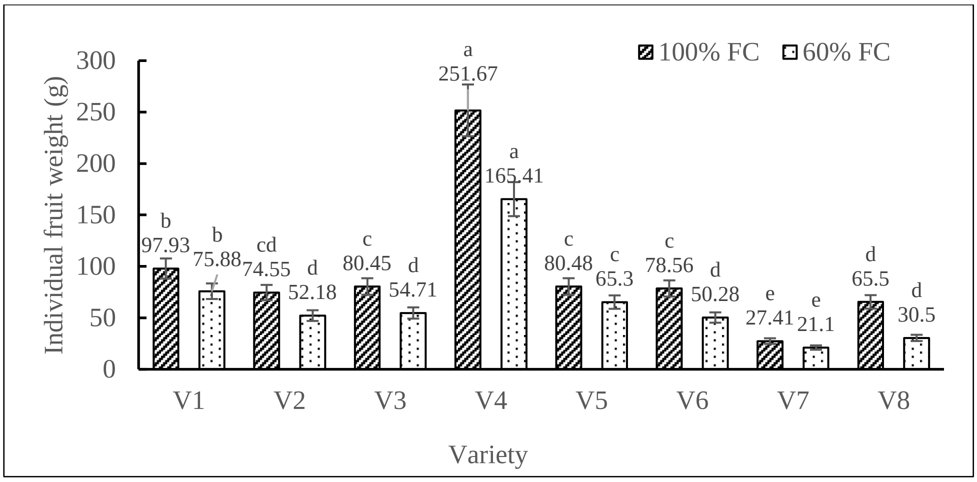


Fig. 5. Effect of drought stress on individual fruit weight in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

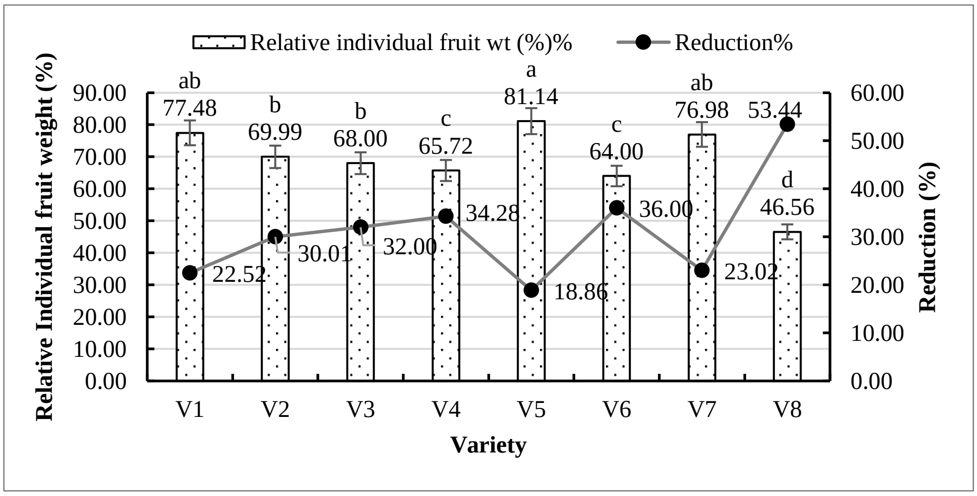


Fig. 6. Effect of drought stress on relative individual fruit weight and fruit weight reduction in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

Fruit set (%) and Relative fruit set

Fruit set percent was reduced by drought stress (Fig. 7). At 100% FC, maximum fruit set was recorded in V_6 (87.25%) closely followed by V_3 (86.80%), V_2 (86.70%), V_5 (86.70%), V_1 (85.60%) and V_7 (85.60%) and its lowest value was noted in V_8 (84.13%) (Fig. 7). But at 60% FC, the highest fruit set was observed in V_5 (84.56%) closely followed by V_7 (83.04%) and the least was found from V_3 (73.78%) closely followed by V_8 (74.03%). Maximum relative fruit set% was recorded in V_5 (97.53%) which was statistically similar to V_7 (97.01%) and V_4 (96.00%) and the lowest was recorded in V_3 (85.00%) (Fig. 8). This was in agreement with the results of Sivakumar (2017) who reported that flower abscission was higher in 50% FC than 100% FC and flower abscission range was 12.05-17.7% which indicated that fruit set percent in water stress condition was 82.3% to 87.95%. Higher fruit set% in V_5 and V_7 might be due to the maintenance of photosynthesis and efficient translocation of photosynthates to the reproductive parts under drought.

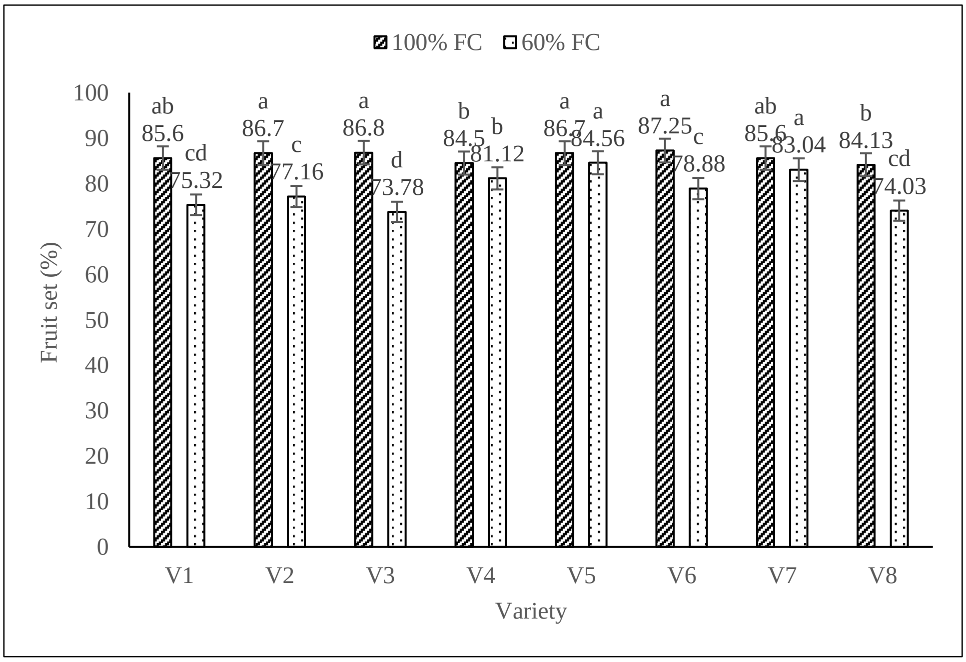


Fig 7. Effect of drought stress on fruit set percentage in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

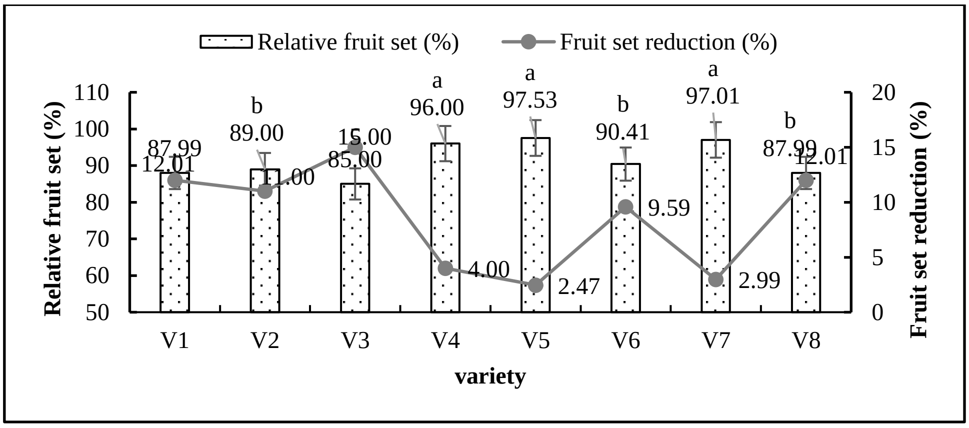


Fig 8. Effect of drought stress on relative fruit set and fruit set reduction in tomato varieties. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

Fruit yield/plant/ha and Relative fruit yield

Fruit yield/plant was decreased due to drought stress (Fig. 9). At 100% FC, fruit yield/plant ranged from 2.22 kg (V_8) to 4.60 kg (V_4), while at 60% FC, it ranged from 0.88 kg (V_8) to 2.57 kg (V_4). Maximum reduction in fruit yield/plant due to drought was observed in V_8 (60.27%) followed by V_6 (50.46%) and V_3 (49.28%) and the lowest reduction was recorded in V_5 (30.08%) closely followed by V_7 (34.42%) and V_1 (42.54%) (Fig. 10). Maximum relative fruit yield/plant was recorded from V_5 (69.92%) followed by V_7 (65.58%) and its lowest value recorded from V_8 (39.73%) (Fig. 10). Fruit yield/ha was also decreased due to drought stress (Fig. 11). At 100% FC, fruit yield/ha ranged from 53.30 t (V_8) to 105.40 t (V_4), while at 60% FC, it ranged from 21.17 (V_8) to 61.63 (V_4). Maximum reduction in fruit yield due to drought was observed in V_8 (60.27%) followed by V_6 (50.46%) and V_3 (49.28%) and the lowest reduction was recorded in V_5 (30.08%) closely followed by V_7 (34.42%) and V_1 (38.97% (Fig. 12). Maximum relative fruit yield/ha was recorded from V_5 (69.92%) closely followed by V_7 (65.58%) and V_1 (61.03%) and its lowest value was recorded from V_8 (39.73% (Fig. 12). This was in line with the report of Ramadasan *et al.* (1993) who explained that the final yield of the crop is a product of combined effects of stress on growth and various physiological processes. Reduction in fruit yield at drought stress could be attributed to decline in photosynthesis due to the decrease in chlorophyll content, fruit number, individual fruit weight and fruit set%. Buhroy *et al*. (2017) reported that 37.66% decrease occurred in fruit yield/plant at 50% FC.

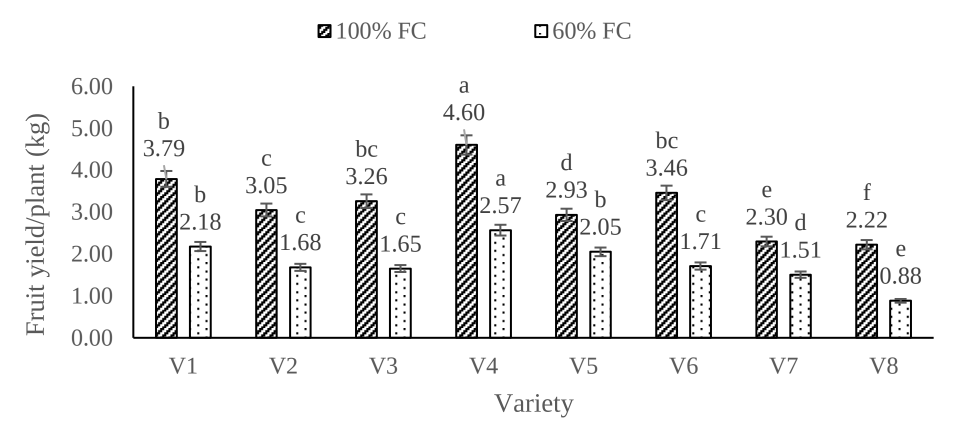


Fig. 9. Effect of drought stress on fruit yield/plant (kg) and relative fruit yield (%) in tomato. Vertical bars show ±SE of three replicates.

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21, Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

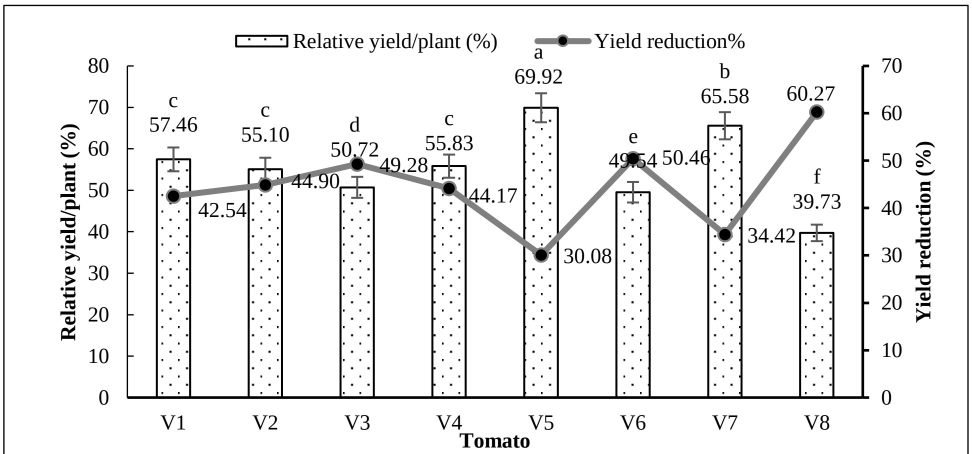


Fig 10. Effect of drought stress on fruit yield/plant (kg) and relative fruit yield (%) in tomato. Vertical bars show ±SE of three replicates

Figures on top of the bars having different letter (s) do not differ significantly at 5% level

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

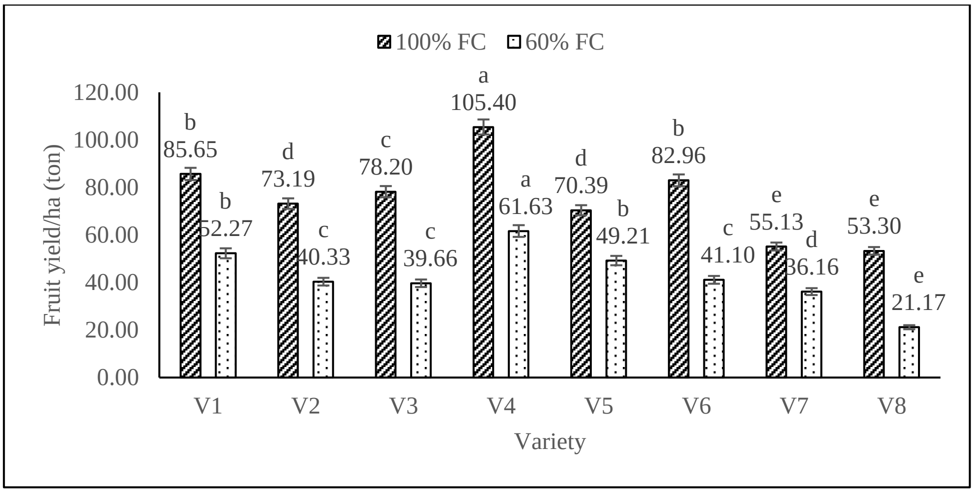


Fig 11. Effect of drought stress on fruit yield/ha (ton) and relative fruit yield (%) in tomato. Vertical bars show ±SE of three replicates

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

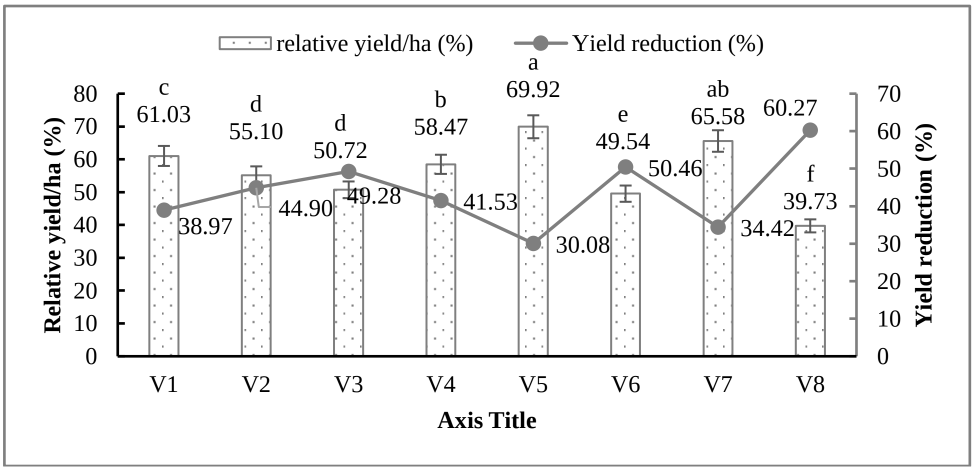


Fig 12. Effect of drought stress on relative fruit yield/ha and yield reduction in tomato. Vertical bars show ±SE of three replicates

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5= BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

Total soluble solid (TSS%)

Total soluble solid (TSS%) was increased due to drought stress (60% FC) (Fig. 13). At 100% FC, maximum TSS was observed in V_7 (7.01%) and the lowest from V_1 (5.20%) closely followed by the remaining varieties. At 60% FC, the highest TSS was recorded by V_7 (7.39%) which was statistically similar to V_5 (7.21%) and the lowest from V_3 identical with V_2, V_4 and V_6. The increase in TSS% in varieties ranged from 5.14-30.81% (Fig. 13). Maximum increase (30.51%) was noted in V_5 followed by V_1 (24.20%). Sivakumar and Srividhya. (2016) obtained 4.15% increase in TSS in tomato fruit at drought stress whereas; Kazemi *et al.* (2021) obtained 14.52% increase in TSS.

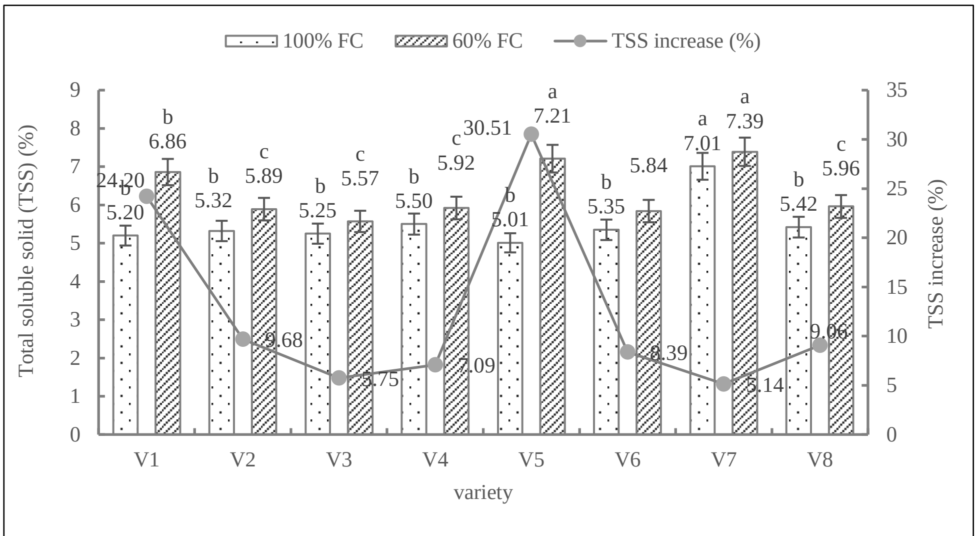


Fig 13. Effect of drought stress on total soluble solid (TSS) and TSS increase in tomato. Vertical bars show ±SE of three replicates

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

100% FC = 90-100% FC & 40% FC = 40-50% FC; V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21.

Proline content

Proline content at 90-100% FC and 60% FC was significantly influenced by drought treatments (Fig. 14) and it was increased due to drought condition. Maximum proline content was obtained from V_5 (2.68 µmolg^{-1} FW) closely followed by V_4 (2.65 µmolg^{-1} FW) and the least from V_7 (2.36 µmolg^{-1} FW) at 100% FC; whereas, at 40% FC, the highest proline content was recorded in V_5 (4.98 µmolg^{-1} FW) which was identical with V_4 (4.87 µmolg^{-1} FW), V_7 (4.87 µmolg^{-1} FW) and V_1 (4.68 µmolg^{-1} FW) and the lowest proline content was obtained from V_3 (3.46 µmolg^{-1} FW). The increase percent of proline content in varieties ranged from 28.37-51.54%. Maximum increase in proline content was seen in V_7 (51.54%) followed by V_5 (46.18%), V_4 (45.59%) and V_1 (45.73%) and the lowest increase from V_8 (29.60%) followed by V_3 (31.07%) (Fig. 14). Accumulation of proline in the plant system lowers the water potential of plant than that of soil, which helps the root to absorb water from soil. Buhroy *et al.* (2017) reported to have 15.23% proline increase in tomato at 50% FC; whereas, Khan *et al*. (2015) obtained 24.14% increased proline in the same crop under drought stress.

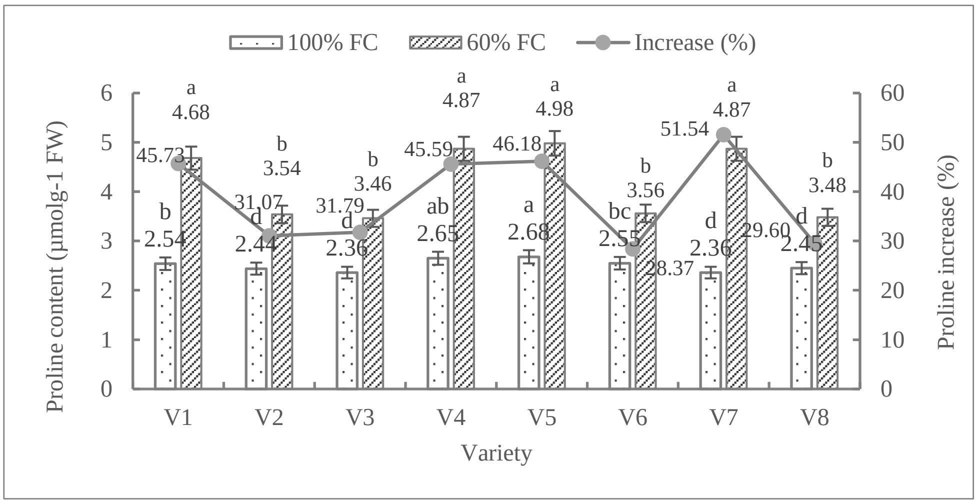


Fig 14. Effect of drought stress on total soluble solid and proline content in tomato. Vertical bars show ±SE of three replicates

Figures on top of the bars having different letter (s) do not differ significantly at 5% level.

V_1 = BARI Tomato-2, V_2 = BARI Tomato-14, V_3 = BARI Tomato-16, V_4 = BARI Tomato-17, V_5 = BARI Tomato-18, V_6 = BARI Tomato-19, V_7 = BARI Tomato-20, V_8 = BARI Tomato-21

Conclusion

Based on the above results, it can be concluded that BARI Tomato-18 and BARI Tomato-20 (cherry tomato) performed better at drought stress than other varieties and selected as moderate drought tolerant varieties.

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BULB YIELD, PRE-MATURE SPROUTING AND NITROGEN USE EFFICIENCY OF GARLIC VARIETIES AS INFLUENCED BY NITROGEN

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M. I. HAQUE[1] AND M. M. KAMAL[2]

Abstract

The field experiment was carried out at the research farm of Regional Spices Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur ($23^0 59^/$North Latitude and $90^0 24^/$East Longitude) during two successive winter seasons of 2020-21 and 2021-22, to find out the optimum dose of nitrogen and suitable garlic variety for up scaling bulb production. The experiment was laid out in a two-factor randomized complete block design with three replications having four garlic varieties (BARI Rashun-1, BARI Rashun-2, BARI Rashun-3 and BARI Rashun-4) with four different levels of nitrogen (0, 50, 100 and 150 kg ha^{-1}). A blanket dose of 60-160-20-2-1 kg ha^{-1} of P-K-S-Zn-B along with cowdung @ 5 t ha^{-1} was applied in each experimental plot. Both factors such as garlic variety and nitrogen level showed significant effects on the yield, yield components, pre-mature sprouting and nitrogen use efficiency of garlic. The highest bulb yield of (8.58 and 8.91 t ha^{-1} in 2020-21 and 2021-22, respectively) was obtained from BARI Rashun-3 regardless of N dose. On the other hand, application of 100 kg N ha^{-1} produced the highest bulb yield (8.1 and 9.55 t ha^{-1} in 2020-21 and 2021-22, respectively). The response of garlic varieties to N was appeared to be quadratic in nature (R^2 = 0.9914). From the quadratic response function, the optimum dose was estimated to be 92.75 kg ha^{-1}. The minimum number of pre-mature sprouted bulb (2.5%) was noted in BARI Rashun-4 when N was not applied. The maximum nitrogen use efficiency (138.44 and 144.72% in 2020-21 and 2021-22, respectively) was recorded from BARI Rashun-4 with 50 kg N ha^{-1}. Among the BARI released garlic varieties, BARI Rashun-3 performed better in this region. Thus, it may be concluded that BAR Rashun-3 could be cultivated by applying 92.75 kg N ha^{-1} along with blanket dose of 60-160-20-2-1 kg ha^{-1} of P-K-S-Zn-B and cowdung @5 t ha^{-1} in the Grey Terrace Soil of Madhupur Tract (AEZ-28).

Keywords: Nitrogen fertilizer, nitrogen use efficiency, pre-mature sprouting, bulb yield, garlic

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Introduction

Garlic or 'Rashun' (*Allium sativum* L.) is a major spice crop in Bangladesh belonging to the family Alliaceae. It is an aromatic herbaceous crop originated in Mediterranean region (Brewster, 2008). It is the second most important *Allium* crops after onions widely cultivated throughout the world (Ali *et al*., 2023; Usman *et al*., 2016). Its leaves, bulbils (flowers) and bulbs are used as spice and vegetables for its medicinal and seasonal properties (Kumari *et al*., 2023; Yitayih *et al*., 2017). Bangladesh is the world's third largest garlic producing country having production of 4.66 lakh metric tons bulb in 0.72 lakh hectares of land (FAO, 2023). The diversified uses of garlic with its increasing demand for domestic consumption as well as used as raw-material for pharmaceutical and cosmetic industries. The garlic productivity is lower due to genetic and environmental factors which affect its quality traits (Sahu *et al*., 2023). Spices Research Centre, Bangladesh Agricultural Research Institute, Bogura developed four high yielding garlic varieties, namely s BARI Rashun-1, BARI Rashun-2, BARI Rashun-3 and BARI Rashun-4 which are less susceptible to disease and insect pests with distinct genotypic and phenotypic variation having yield potentiality of 6-11 t ha^{-1} (Rahman *et al*., 2020). There are many factors for lower productivity of garlic such as lack of high yielding varieties, low soil fertility, imbalanced use of fertilizers, lack of irrigation facilities, inappropriate pest and agronomic management, and improper marketing facilities (Kenea and Gedamu, 2020; Haque *et al*., 2013, Nasreen *et al*., 2009). Among the yield limiting factors, nitrogen management is one of the key factors for garlic productivity as well as maintaining its quality. Nitrogen is a major element of amino acids which is the building block of proteins, nucleic acid and chlorophyll molecules (Kumari *et al*., 2023; Yitayih *et al*., 2017). The demand of N can be met up from judicious use of nitrogenous fertilizer to ensure optimum growth and development of garlic (Yousuf *et al*., 2013). The dose of N is determined generally based on soil organic matter content, crop uptake, yield levels, cropping season and also crop variety (Zaman *et al*., 2011). Nitrogen deficiency may cause stunted growth with small bulb size and reduced yields of garlic (Kevlani *et al*., 2023). Excessive N leads to pre-mature sprouting, excess vegetative growth, delayed maturity, increased susceptibility to diseases, increased premature sprouting, reduced dry matter content, storability and thus, reduced yield and quality of marketable bulbs (Anas *et al.*, 2020; Pruthi, 2001). Excessive N application has become a concern because washed out, leached out and denitrified N in ecosystem leads to significant direct and indirect negative effects on environmental quality, biodiversity, human health and sustainable agricultural production (Anas *et al.*, 2020; Kevlani *et al*., 2023). Nitrogen uptake level of garlic crops may vary from less than 50 kg to more than 200 kg depending on cultivar, climate, plant density, and fertilization and yield levels (Usman *et al*., 2016; Kenea and Gedamu, 2020).

Optimum N fertilization and N efficient germplasm with better nitrogen use efficiency (NUE) are the possible ways to overcome N application problem (Noor, 2017). Excessive application of N has now accumulated in the soil due to this high level of N application resulting in low NUE (Savci, 2012). Therefore, the experiment was conducted to study the effect of nitrogen on yield and NUE of garlic and evaluate the response of garlic varieties to nitrogen rates.

Materials and Methods

The field experiment was conducted in the research field of Regional Spices Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur, during two consecutive growing seasons (winter) of 2020-21 and 2021-22. The experimental site was situated at $23^{0}59^{/}$ North Latitude and $90^{0}24^{/}$ East Longitude, at an altitude of 8.4 m above the mean sea level. The soil of the experimental site belongs to Chhiata Soil series classified as Grey Terrace Soil of Inceptisol Order (USDA Soil Taxonomy) under AEZ-28 (Madhupur Tract) (Brammer, 1971). The initial composite soil samples (0-15 cm depth) of the experimental field were collected and analyzed in the Soil Science Laboratory, BARI, Gazipur following standard and recommended methods (Table 1). The experiment was laid out in a two-factor randomized complete block design with three replications having four garlic varieties (BARI Rashun-1, BARI Rashun-2, BARI Rashun-3 and BARI Rashun-4) with four different levels of nitrogen (0.0, 50, 100 and 150 kg ha^{-1}). The blanket dose of other fertilizers was 60-160-20-2-1kg ha^{-1} of P-K-S-Zn-B along with cowdung @ 5 t ha^{-1}. The total amount of cowdung, Triple super phosphate (TSP) for P, ½ of Muriate of potash (MoP) for K, gypsum for S, $ZnSO_4$ for Zn and boric acid for B were applied during final land preparation. Urea as a source of N was applied in 3 equal splits at 30, 45 and 60 days after planting (DAP) and the rest half of MoP was applied at 45 DAP. The unit plot size was 3 m x 3 m. The cloves of garlic bulb were used as planting materials. The similar sized cloves (2.0 to 2.5 g) were planted on 09 November 2020 and 10 November 2021, for the first and second year, respectively, with a spacing of 15 cm x 10 cm. The cloves were placed into the soil 3-4 cm deep with the growing point upward and covered lightly with soil for consolidation. Before planting, the cloves were treated with Autostin (Carbendazim) @ 2 g kg^{-1} to reduce the primary seed borne diseases. Weeding was done three times at 25, 50 and 75 DAP manually by handpicking. The experimental plots were irrigated four times at 30, 60, 80 and 110 DAP by surface flooding method and stopped three weeks before harvest to allow for uniform maturity. Spraying of Rovral (Iprodione) @ 2 g L^{-1} + Ridomil Gold (Mancozeb + Metalaxyl) @ 2 g L^{-1} was done at every 10 days interval for controlling purple blotch disease and Imitaf (Imidacloprid) @ 2 ml L^{-1} for management of *Thrips* were done throughout the cropping season.

Table 1. Physical and chemical properties of initial soil at the experimental field

Soil characteristics	Analytical value		Analytical method
	2020-21	2021-22	
Soil Textual class	clay loam	clay loam	Hydrometer method
Bulk density (g cm^{-3})	1.38	1.39	Core sampling method
Particle density (g cm^{-3})	2.59	2.61	Pycnometer method
Soil pH	6.3	6.3	Soil: water=1:2.5
Total N (%)	0.09	0.09	Modified Kjeldhal Method
Organic C (%)	0.88	0.89	Wet oxidation method
Available P (ppm)	6.82	6.81	Bray and Kurtz method
Exchangeable K (meq100g^{-1}soil)	0.06	0.06	N NH_4OAc extraction method
CEC (meq 100g^{-1} soil)	9.35	9.05	Schollenberger method
Available S (ppm)	6.8	6.9	Calcium dihydrogen phosphate extraction method
Available B (ppm)	0.11	0.12	Calcium chloride extraction method
Available Zn (ppm)	0.42	0.43	DTPA Extraction method
Available Cu (ppm)	0.17	0.18	DTPA Extraction method
Available Mn (ppm)	0.65	0.66	DTPA Extraction method

Harvesting of garlic was done on 02 April both the years, when around 75% of the leaves of the plants in each plot become straw colour, dry and/or shown senescence with neck fall then the bulbs were harvested by pulling up single plants by hand. The harvested bulbs were cured in the field and sun-dried for 7 days, folding of leaves over the bulbs was done for protecting them from sunburn. After a week of drying, necks and roots were cut. Yields obtained from the net plot were weighed and recorded after curing. After harvesting, 15 (fifteen) selected garlic plants from each plot were uprooted, air-dried in the laboratory and finally oven-dried for 72 hours at 70^0C to estimate the dry matter production. The dry matter was calculated using the following formula:

DM = [{(DY /15) x NP} X 10000)]/1000

Where,

DM = Dry matter (kg ha^{-1})

DY = Total dry matter yield of 15 plants per plot (g)

NP = Total number of plants per plot

For computing nitrogen uptake at the younger and entirely expanded leaf of garlic at 45 DAP (when leaf nutrient concentration was high) was taken after beginning of clove differentiation by sampling of 15 (fifteen) leaves at four distinct points of every plot were cut at the bottom, chopped with a sharp knife, air dried for 3 days then oven dried for 72 hours at 70^0C followed by grinding the oven-dry samples by an electric grinding machine.

Nitrogen uptake from the soil was calculated by using the formula:

Nitrogen uptake = % A x Y / 100 kg ha^{-1}

Where,

% A = Nitrogen content of plant in percent; Y = Total dry matter production of plant (kg ha^{-1})

Nitrogen use efficiency was calculated by using following formula:

NUE= (NU/NA) X 100

Where,

NUE = Nitrogen use efficiency (%)

NU = Total amount of nitrogen uptake (kg ha^{-1})

NA = Total amount of applied nitrogen (kg ha^{-1})

Nitrogen recovery efficiency was calculated by using following formula:

$NRE = \{(NU_{fertilized} - NU_{un\text{-}fertilized}) / N_{fertilizer\ dose}\} \times 100$

Where,

NRE = Nitrogen recovery efficiency (%)

$NU_{fertilized}$ = Total amount of nitrogen uptake under fertilized plot (kg ha^{-1})

$NU_{un\text{-}fertilized}$ = Total amount of nitrogen uptake under un-fertilized plot (kg ha^{-1})

$N_{fertilizer\ dose}$ = Total amount of nitrogen fertilizer applied under fertilized plot (kg ha^{-1})

The recorded data on different parameters were subjected to statistical analysis using *R* version 3.5.0 to find out the significant of variation among the treatments. The difference between treatments means were judged by the Least Significant Difference (LSD) test at 5% level of significance.

Results and Discussion

Effect of varieties on yield and yield contributing characters of garlic

The garlic varieties differed significantly for yield and most of the yield contributing characters viz. plant height, number of leaves per plant, bulb size, number of cloves, bulb size, bulb and biomass yield regardless of N dose (Table 2a and 2b). The pre-mature sprouting of garlic also differed significantly among the tested varieties (Figure 1). The tallest garlic plant (61.86 and 60.97 cm), maximum number of leaves

(9.21 and 10.0), maximum bulb size (3.44 cm x 3.15 cm and 3.82 cm x 3.49 cm), maximum number of cloves per plant (20.85 and 51.78), heaviest bulb (24.0 g and 29.8 g), bulb yield (8.58 t $ha^{-1}$and 8.91 t ha^{-1}) and biomass yield (3.35 and 3.49 t ha^{-1}) were recorded from BARI Rashun-3 in 2020-2021 and 2021-2022, respectively, which was followed by BARI Rashun-4 and these were significantly higher over other two varieties (Yousuf *et al*., 2016). However, the smallest garlic plant (54.51 and 60.97 cm), minimum number of leaves (7.88 and 8.0), minimum bulb size (3.28 cm x 3.15 cm and 3.66 cm x 3.28 cm), minimum number of cloves per plant (19.01 and 17.55), lightest bulb (21.57 g and 27.53g), minimum bulb yield (7.08 t $ha^{-1}$and 8.91 t ha^{-1}) and minimum biomass yield (3.07 and 3.27 t ha^{-1}) were noted from BARI Rashun-1. The maximum average pre-mature sprouted bulb of garlic (12.83%) was noted in BARI Rashun-1 and the minimum pre-mature sprouted bulb (4.75%) was recorded in BARI Rashun-4. It might be due to greater genetic variation among the tested garlic varieties in respect of bulb size & weight, clove numbers and pre-mature sprouting. The results are in agreement with Gashaw (2021) and Usman *et al.* (2016).

Table 2a. Effect garlic varieties on yield and yield components of garlic

Variety	Plant height (cm)		No. of leaves/plant		Bulb length (cm)		Bulb diameter (cm)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
V_1	54.51c	51.78b	7.88c	8.0b	3.28	3.66	2.91	3.28
V_2	56.09bc	52.33b	8.03bc	8.25b	3.34	3.73	2.92	3.33
V_3	61.86a	60.97a	9.21a	10.0a	3.44	3.82	3.15	3.49
V_4	58.57ab	58.83a	8.99ab	9.83a	3.35	3.74	3.06	3.25
CV (%)	7.39	7.55	2.04	7.23	NS	NS	NS	10.49

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

V_1 = BARI Rashun-1; V_2 = BARI Rashun-2; V_3 = BARI Rashun-3 and V_4 = BARI Rashun-4, Y_1 = 2020-21, Y_2 = 2021-22.

Table 2b. Effect of garlic varieties on yield and yield components of garlic

Variety	No. of cloves/ bulb		Single bulb weight (g)		Yield (t ha^{-1})		Biomass (t ha^{-1})	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
V_1	19.01b	17.55b	21.57c	27.53a	7.08c	8.05b	3.07b	3.27
V_2	19.58ab	18.41ab	23.38ab	29.63b	7.13bc	8.28b	3.21ab	3.35
V_3	20.85a	19.77a	24.08a	29.80b	8.58a	8.91a	3.35a	3.44
V_4	20.62a	18.85ab	23.07b	27.95b	7.63b	8.44b	3.29a	3.34
CV (%)	7.63	13.12	6.94	14.90	11.02	8.24	6.78	NS

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

V_1 = BARI Rashun-1; V_2 = BARI Rashun-2; V_3 = BARI Rashun-3 and V_4 = BARI Rashun-4, Y_1 = 2020-21, Y_2 = 2021-22.

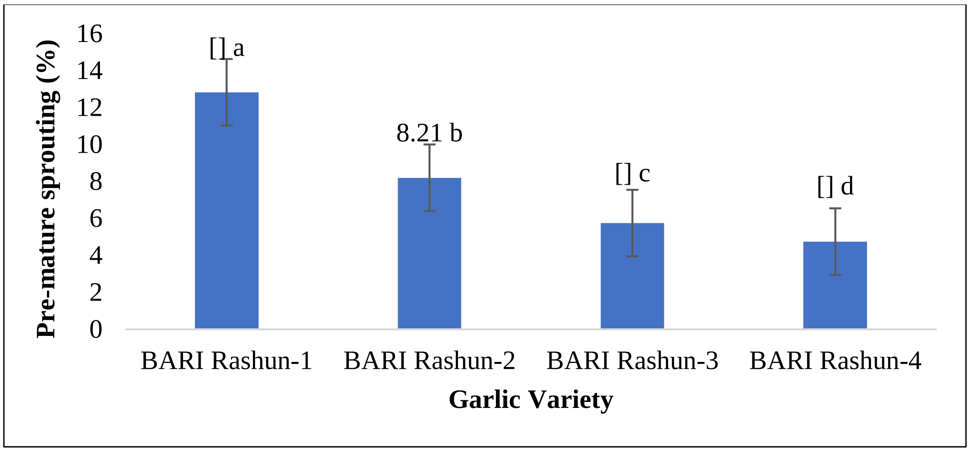

Fig. 1. Pre-mature sprouting of garlic varieties (average of two years).

Effect of nitrogen on yield and yield contributing characters of garlic

Application of N significantly influenced the yield contributing characters and yield of garlic (Table 3a and 3b) and also pre-mature sprouting of garlic (Figure 2). The tallest garlic plant (60.21 and 57.91 cm), maximum number of leaves (9.73 and 10.75), maximum bulb size (3.92 cm x 3.37 cm and 4.54 cm x 3.87 cm), maximum number of cloves per plant (21.16 and 19.97), heaviest bulb (24.11 g and 36.52 g), bulb yield (8.1 t ha^{-1} and 9.55 t ha^{-1}) and biomass yield (3.37 and 3.92 t ha^{-1}) were observed from application of nitrogen @100 kg ha^{-1} in 2020-21 and 2021-22, respectively, which was followed by nitrogen @ 150 kg ha^{-1}. However, the smallest garlic plant (51.47 and 51.16 cm), minimum number of leaves (7.21 and 7.0), minimum bulb size (2.75 cm x 2.52 cm and 2.98 cm x 3.20 cm), minimum number of cloves/plant (17.69 and 15.66), lightest bulb (21.63 g and 25 g), minimum bulb yield (6.64 t $ha^{-1}$and 6.85 t ha^{-1}) and minimum biomass yield (2.52 and 2.76 t ha^{-1}) were documented in control treatment (N_0) in 2020-21 and 2021-22, respectively. This might be due to optimum level of nitrogen which is a major constitute of chlorophyll that enhances to produce maximum photosynthates, a simulative effect on cell division and cell enlargement leading to vigour's growth and increased uptake of nutrients at higher levels to produced assimilates to fill the sink which result in increased bulb size and weight (Fathi, 2022). The bulb size and weight of garlic decreased beyond optimum levels might be due to imbalance of nutrients for excess application of nitrogen (Diriba-Shiferaw *et al*., 2015). It is well established that nitrogen is the major responsible element for photosynthesis and maintaining photosynthate from source to sink (Anas *et al*., 2020). This investigation is similar with the findings of Gashaw (2021), Kenea and Gedamu (2020) and Yousuf *et al*. (2013). The maximum average pre-mature sprouted bulb (10.75%) was recorded from the application of N @ 150 kg ha^{-1} and the minimum pre-mature sprouted bulb (5.33%) was noted in control treatment, which indicate that higher dose of N might have caused pre-mature sprouting of garlic, which is not desirable and so N dose should be optimized considering yield as well as quality of garlic (Pruthi, 2001).

Table 3a. Effect nitrogen on yield and yield attributing characters of garlic

Nitrogen (kg ha^{-1})	Plant height (cm)		Number of leaves/ plant		Bulb length (cm)		Bulb diameter (cm)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
0	51.47b	51.16b	7.21c	7.0d	2.75d	2.98d	2.52c	2.75d
50	59.39a	57.14a	8.20b	8.66c	3.16c	3.41c	2.98b	3.20c
100	60.21a	57.91a	9.73a	10.75a	3.92a	4.54a	3.37a	3.87a
150	59.97a	57.69a	8.97ab	9.66b	4.57b	4.03c	3.17ab	3.52b
CV (%)	7.39	7.55	2.04	7.23	12.13	7.29	13.06	10.49

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

Y_1 = 2020-21, Y_2 = 2021-22.

Table 3b. Effect nitrogen on yield and yield attributing characters of garlic

Nitrogen (kgha^{-1})	Number of cloves/ bulb		Single bulb weight (g)		Yield (t ha^{-1})		Biomass (tha^{-1})	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
0	17.69b	15.66b	21.63c	25.0d	6.64b	6.85d	2.78d	2.76d
50	20.68a	19.69a	23.05b	29.93c	7.75a	8.35c	3.07c	3.15c
100	21.16a	19.97a	24.21a	36.52a	8.10a	9.55a	3.66a	3.92a
150	20.54a	19.27a	23.21b	33.36b	7.91a	8.97b	3.39b	3.58b
CV (%)	7.63	13.12	6.94	14.90	11.02	8.24	6.78	12.11

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

Y_1 = 2020-21, Y_2 = 2021-22.

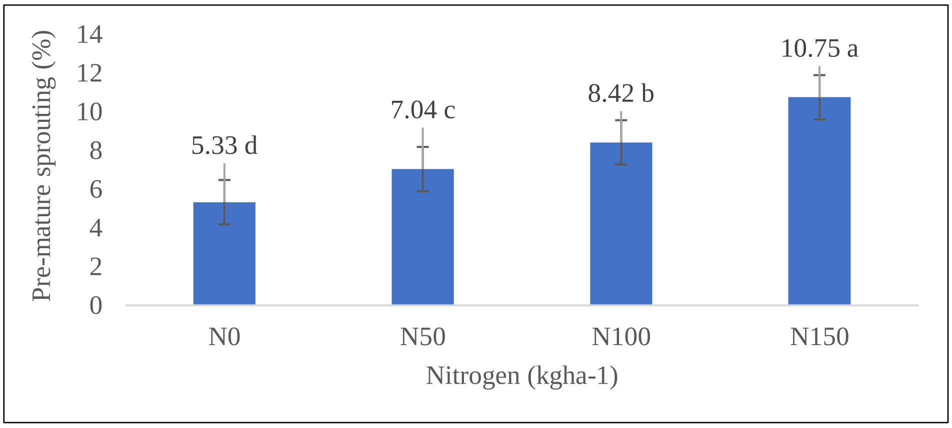

Fig. 2. Application of nitrogen on pre-mature sprouting of garlic (average of two years).

Response of garlic to nitrogen

Garlic responded to added nitrogen significantly. However, from regression analysis, a quadratic response (R^2 = 0.9914) was noted (Table 5). The bulb yield increased up to 100 kg N ha^{-1} and thereafter declined due to application of higher dose. From this quadratic response function, the optimum dose of N for garlic cultivation is estimated to be (92.75 kg ha^{-1}) and the maximum bulb yield is expected to be 11.88 t ha^{-1}. The nitrogen use efficiency showed that each 1 kg of N could produce 18.55 kg ha^{-1} garlic bulb up to optimum level after which bulb yield could reduce to 0.2 kg ha^{-1} for each 1 kg of applied N. Response of different levels of nitrogen from 0.0 to 150 kg N ha^{-1} on garlic in positive increment of yield and thereafter the yield declined. It might be due to excessive nitrogen creates imbalance of nutrients (*Zaman et al.*, 2011).

Table 5. Response function of garlic to nitrogen for bulb yield (using pooled data)

Response function	Pooled in both the years
Regression equation	$Y = -0.0002N^2 + 0.0371N + 6.7175$
R^2	0.9914
Optimum rate of N (kg ha^{-1})	92.75
Maximum bulb yield (t ha^{-1}) for optimum N level	11.88
Production of bulb (kg) for 1 kg N (use efficiency)	18.55
Beyond optimum level the reduction of bulb (kg) for each 1 kg N	0.2
Optimum economic rate of N (kg ha^{-1})	92.7

Effect of garlic varieties and nitrogen on nitrogen content, uptake and use efficiency of garlic

Nitrogen content

Nitrogen content in garlic plant was significantly influenced by variety and nitrogen levels (Tables 6-7). Considering the main effect of variety, the maximum N content per plant (2.2 and 2.33%) was recorded from BARI Rashun-3 which was significantly higher overall other varieties in both the years. The lowest N content (2.11 and 2.21%) was observed in BARIN Rashun-1 in both the years (Table 6). Application of nitrogen fertilizer significantly increased then nitrogen content in garlic plant. The maximum N content per plant (2.22 and 2.44%) was noted with the application of 150 kg N ha^{-1}. And the minimum N content (2.07 and 2.08%) was recorded in control (Table 7). Maintaining optimum level of nitrogen in soil had improved nutritional status in garlic plants. Similar results were reported by Cunha *et al*. (2015) and Yitayih *et al.* (2017).

Nitrogen uptake

Nitrogen uptake by garlic plant varied due to single as well as interaction application of variety and nitrogen (Tables 6-7). Irrespective of N dose, the maximum nitrogen uptake (79.42 and 91.73 kg ha^{-1}) was observed with BARI Rashun-3 (V_3) where the minimum N uptake (64.78 and 72.27 kg ha^{-1}) was recorded in BARI Rashun-1 (Table 6). The maximum nitrogen uptake (79.42 and 91.73 kg ha^{-1}) were observed from 100 kg N ha^{-1} (N_3) and the minimum (57.55 and 57.01 kg ha^{-1}) were observed from native fertility (Table 7), regardless of variety. A steady supply of nitrogen stimulates root & shoot growth and development which governed uptake of macro and micro nutrients. These results of present study are at par with the findings of Kumari *et al.*, (2023) and Thangasamy and Chavan (2017).

Nitrogen use efficiency

Nitrogen use efficiency (NUE) of garlic varied due to irrigation regimes and nitrogen levels (Tables 6-8). Considering the main effect of variety, the maximum of nitrogen use efficiency (99.16 and 106.05%) was recorded with BARI Rashun-3 and the minimum (86.37 and 96.36%) at BARI Rashun-1 in both the years (Table 6). On the other hand, considering the nitrogen dose, the maximum nitrogen use efficiency (130.78 and 137.98%) was observed by the application of 50 kg N ha^{-1} but gradually decreased with higher dose N applied in garlic (Table 7). The interaction effect of varieties and N levels on nitrogen use efficiency (NUE) of garlic was considerable. Similar result was documented by Sahu *et al.* (2023). NUE is an indicator for a crop to use the nitrogen fertilizer that has been supplied. NUE depends on the physiological and metabolic changes, such as N uptake by plant, assimilation from root to other parts, source sink relationship for transportation, signaling and regulatory path-ways which are responsible for N status within plan (Anas *et al.,* 2020).

Table 6. Effect of variety on nitrogen content, uptake and use efficiency of garlic

Garlic Variety	N content per plant (%)		N uptake (kgha^{-1})		N use efficiency (%)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
BARI Rashun-1	2.11c	2.21b	64.78	72.27	86.37	96.36
BARI Rashun-2	2.13bc	2.24ab	68.37	75.04	91.16	100.05
BARI Rashun-3	2.20a	2.33a	74.37	80.15	99.16	106.87
BARI Rashun-4	2.16b	2.26ab	71.06	75.48	94.75	100.64
CV (%)	3.78	9.00	-	-	-	-

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

Y_1 = 2020-21, Y_2 = 2021-22

Table 7. Effect of nitrogen levels on nitrogen content, uptake and use efficiency of garlic

Nitrogen ($kgha^{-1}$)	N content per plant (%)		N uptake ($kg\ ha^{-1}$)		N use efficiency (%)		N recovery efficiency (%)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
0	2.07d	2.08d	57.55	57.01	-	-	-	-
50	2.13c	2.19c	65.39	68.99	130.78	137.98	15.68	23.96
100	2.22a	2.44a	79.42	91.73	79.42	91.73	21.87	34.72
150	2.17b	2.34b	75.24	87.35	50.28	58.23	11.79	20.23
CV (%)	3.78	9.00	-	-	-	-		

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

Y_1 = 2020-21, Y_2 = 2021-22.

Conclusion

The garlic variety cv. BARI Rashun-3 appeared as the potential variety in respect of bulb yield followed by BARI Rashun-4. Regardless of variety, the garlic plant performed the best with 100 kg N ha^{-1}. Nitrogen response to garlic yield was quadratic in nature (R^2 = 0.9914). From the quadratic response function ($Y = 6.7175 + 0.0371N - 0.0002N^2$), the optimum dose and optimum economic dose were estimated to be 92.75 and 92.70 kg ha^{-1}, respectively. Therefore, BARI Rashun-3 may be cultivated by applying 92.75 kg N ha^{-1} along with blanket dose of 60-160-20-2-1 kg ha^{-1} of P-K-S-Zn-B plus cowdung @ 5 t ha^{-1} in Grey Terrace Soil and similar other soils under AEZ-28. Similar trials may be conducted in different AEZs of the country for finding out suitable variety (s) and the optimum dose of N for maximizing the yield of garlic.

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IMPACT OF SULFUR LEVELS ON THE GROWTH AND YIELD OF WINTER ONION IN LEVEL BARIND TRACT OF BANGLADESH

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Abstract

A field experiment on onion (cv. BARI Piaz-1) was conducted at the Spices Research Centre, Shibganj, Bogura, from October 2018 to March 2019–19 to assess the influence of sulfur (S) levels on onion growth and yield. Five sulfur levels, viz. 0, 15, 30, 45, and 60 kg ha^{-1} were employed in the RCBD trial and replicated thrice. Various S concentrations substantially influenced plant height, number of leaves per plant, bulb diameter and bulb production. Application of 30 kg S ha^{-1} resulted in maximum plant height (50.57 cm), number of leaves plant^{-1} (7.68) at 75 days after transplanting (DAT), bulb diameter (5.24 cm), bulb yield (12.9 t ha^{-1}) and marginal benefit-cost ratio (MBCR) (12.77). From the regression curve, the optimum level of S for the desired yield was determined to be 45 kg S ha^{-1}. Therefore, it may be recommended that application of sulfur @ 45 kg ha^{-1} along with a blanket dose of 100-50-75-4-1.5 kg ha^{-1} of N-P-K-Zn-B and cowdung 5 tha^{-1} for the production of onion bulbs in the agro-ecological zone (AEZ-25) (Level Barind Tract) of Bangladesh.

Keywords: *Allium cepa*, Winter onion, MBCR, Growth, Sulphur, Yield, AEZ-25.

Introduction

Onion (*Allium cepa* L.), a member of Alliaceae family, is a one of the most important vegetable crops grown worldwide due to their economic, nutritional, and medicinal benefits. It is popularly known as 'Peyaz' in Bangladesh grown as spice crop throughout the country during the *rabi* (winter) season. In Bangladesh, during 2022-23, onion is cultivated in 2.036 lakh hectares of land with an annual production of 25.47 lakh metric tons (Anon., 2024). The mean yield is 12.51 ton/ha which is lower in comparison to the world's production (19.3 t/ha). In India average bulb yield is 12.5 t/ha, whereas bulb yield is 41.12 t/ha in the USA. Low fertilizer levels, a dearth of high-yielding quality storable cultivars, inadequate cultural management, and farmers' ignorance and negligence of the significance of sulfur in crop productivity are the causes of Bangladesh's low onion production.

Onion is a highly sulfur-responsive crop as S is an important component of Allicin (allyl thiosulfinate) which is a sulfenic acid thioester. Sulfur is an essential nutrient

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for increasing the productivity and quality of onion bulbs (Lakkineni and Abrol, 1994). Sulfur shortage has been widespread in Bangladesh and most other agricultural areas of the world during the last few decades. The S deficiency issue in Bangladesh's soils has gotten worse due to several factors, including the use of fertilizers like urea, triple super phosphate, muriate of potash, and diammonium phosphate; cultivation of modern high yielding varieties (HYVs); increased cropping intensities; and sparing application of organic manure. As a result, it is now a limiting factor for increased yields and fertilizer efficiency. According to a study conducted by the Soil Resources Development Institute (SRDI) in 2000, about 11.1 million hectares of the nation's land was lack of fertility.

Sulfur deficiency has increased by 11 lakhs in 10,000 hectares of land nationwide in the last 20 years between 2001 and 2020 (Mamun, 2023). Recently, it has been observed that a little over 76 lakh forty thousand hectares, or 51.8% of the land, lack sufficient sulfur (Huda, 2023). It should be noted that in Bangladesh's northern region, soils deficient in sulfur make up approximately 7 M ha, or 52%, of agricultural lands (SRDI, 1999). Roughly 44% of the total cultivated area in Bangladesh comprises soils that are lacking in available sulfur (Hussain, 1990). However, field S fertility is frequently neglected, and crop symptoms of S deficiency can occasionally be misinterpreted for P or N deficits or aluminium toxicity. Sulphur deficiency issues are becoming more common as a result of the widespread use of concentrated fertilizers with low S contents (Hitsuda, *et al.*, 2005). Sulphur status (% of arable lands) under different fertility classes for loamy to clayey soils of upland crops is presented in Fig. 1.

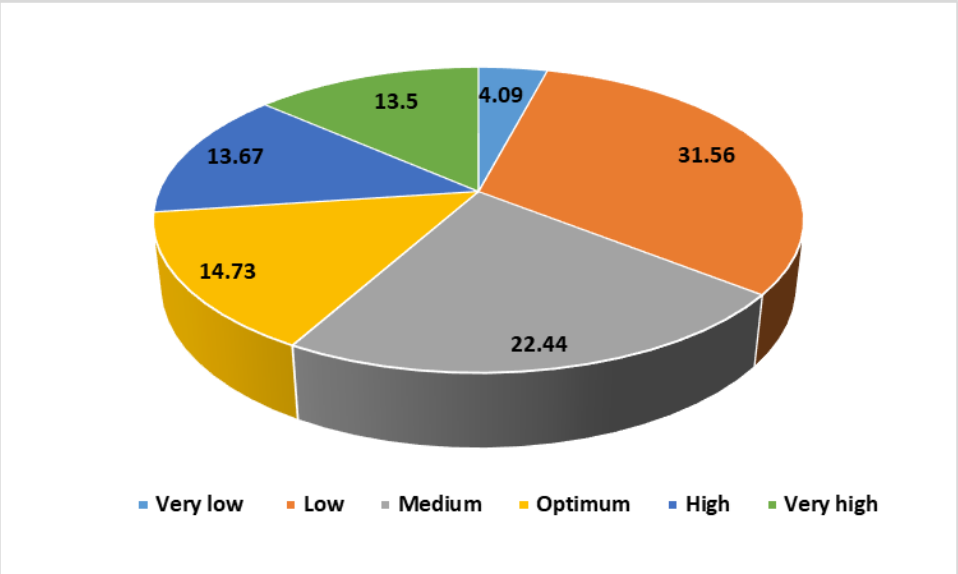

Fig. 1 Sulphur status (% of arable lands) under different fertility classes for loamy to clayey soils of upland crops. (Soil Fertility Atlas Bangladesh, 2020).

Secondary compounds containing S are crucial for disease and pest resistance in addition to their nutritional value and flavor (Bell, 1981). Onion yield and quality are negatively impacted by severe S deficiency during bulb development (Ajay and Singh, 1994). Furthermore, it has been discovered that S improves the quality of bulbs, particularly their pungency and flavors, in addition to increasing their yield (Jaggi and Dixit, 1999). According to Singh and Rathi (1987) as well as Balasubramonian *et al.* (1979), fertilizing onions with S increased their production of dry matter. At all ages, sulfur-deficient plants showed a marked decrease in catalase activity as well as poor utilization of phosphorus, nitrogen, and potash. There is little information available in Bangladesh regarding the influence of sulfur on the production of dry matter, its distribution among various plant parts, growth traits, and yield of onion. The current study, therefore, was conducted to evaluate how different sulfur levels affected onion growth and yield.

Materials and Methods

The study was conducted at the research field at Spices Research Centre (SRC) research field in Shibganj, Bogura, Bangladesh year 2018–19, to ascertain the influence of varying sulfur levels on onion growth and yield. The experimental site was part of the AEZ-25: Level Barind Tract and was located at latitude 24°51′ N and longitude 89°22 E. with 1762 mm of annual rainfall on average, it had a subtropical climate. Composite soil samples (0–15 cm depth) were taken from the experimental field and analyzed to assess the soil's initial nutrient status (Table 1) experimental plots.

Table 1. Analytical value of the experimental soil during 2017-18 and 2018-19

Texture	pH	OM	Ca	Mg	K	Total N	P	S	B	Zn	Cu
		%	(meq/100g soil)			%	(ug/g soil)				
2017-18											
Clay loam	5.8	1.02	2.4	0.93	0.33	0.06	15.2	8.3	0.13	1.25	0.12
2018-19											
Clay loam	5.8	1.00	2.2	0.95	0.37	0.058	15.28	9.3	0.15	1.26	0.11
Critical level	-	-	2.0	0.8	0.20	-	14	14	0.2	0.6	0.2

A randomized complete block design (RCBD) was followed with three replications of five different levels of sulfur, viz. 0, 15, 30, 45, and 60 kgha^{-1}. Unit plot dimension was 3 m x 2.5 m. A blanket dose of fertilizer @ 100-50-75-1.5-4 kg ha^{-1} of N-P-K-B-Zn plus cowdung 5 t ha^{-1} was used with treatment doses of S of the experiment. During the final land preparation, urea, triple super phosphate, and muriate of potash along with a treatment dose of gypsum (form of S) were applied as a part of the blanket dose of one-third of nitrogen and the entire amount of potassium, zinc, and boron, respectively. Two weeks prior to the last stage of land preparation, total amount of well-decomposed cowdung was used. In the thirdandfifth weeks following transplanting, the remaining two thirds of the urea was applied in two equal installments as top dressing 25 and 45 days after transplanting (DAP). Forty five days old BARI Piaz-1 seedlings were transplanted on 11 December 2018 maintaining 10 cm in both row and plant spacing.

Weeding and mulching were done as needed. Water cane with fine meshed nozzle was used to irrigate the young plants. Throughout the cropping season, three irrigations were applied. Pesticide Furadan 3G @ 20 kg ha^{-1} was used as a soil treatment to prevent cutworms (*Agrotis ypsilon*). Onion purple blotch disease was managed by applying fungicide Rovral 50 WP and Amister Top to the crop alternately at the right time.

When flower stalks appeared during the crop's growing season, they were clipped off to prevent bolting. The crop was harvested on March 23 2019 since eighty per cent of the plants reached maturity, meaning that most of their leaves had dried out and they collapsed from the neck. On 25, 50, and 75 DAT, growth data was recorded at the vegetative stage. The final harvesting of onion was done at 100 DAT. Ten randomly chosen onion plants were taken during harvesting from each plot and their yield attributes were recorded. Plot wise bulb weight was noted and converted to yield (tons) per hectare. The amount of sulfur in the onion extract was measured with a spectrophotometer using the turbidity method (Hunter, 1984). Barium chloride ($BaCl_2$. $2H_2O$) was used to create turbidity and the ASI method was used to measure it at a wavelength of 425 nm (Hunter, 1984).

R statistical software (http://www.R-project.org) was used to analyze the data. Analysis of variance was used to examine the yield and yield-contributing traits (the Agricolae R package and anova function; De Mendiburu, 2017). The regression analysis was done with the help of R software.

Mean separation was done by Least Significant Different (LSD) test.

Results and discussion

Effect of Sulfur levels on growth of onion

Plant height

Plants treated with varying amounts of sulfur fertilizer were noticeably taller than those treated with absolute control (Fig. 1). Indeed, throughout the growing season, the plant heights under the various treatments were statistically identical. Throughout the growing season, the plant height was at 75 DAT slightly declined at harvest, but T_3 (30 kg ha^{-1}) always gave the tallest plant at each DAT. At 75 DAT, application of 30 kg S ha^{-1} resulted in tallest plants (50.57 cm), which was statistically similar to 45 and 60 kg S ha^{-1}, (Fig. 1). The control (0.0 kg S ha^{-1}) produced the smallest plant (38.5 cm) at 75 DAT. Anwar *et al. (*2001) and Forney *et al. (*2010) both reported similar results indicating that sulfur is necessary for healthy vegetative growth and bulb development in onions.

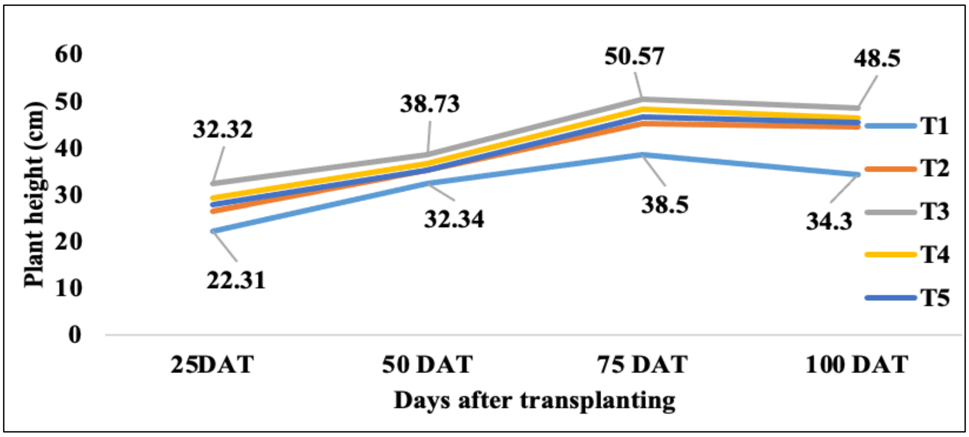

Fig. 1. Effect of different sulphur levels on plant height of onion at different DAT.

Number of leaves per plant

The number of leaves per plant^{-1} showed no discernible change at 25 DAT ranging from 3.14 to 4.32, with T_3 (30 kg S ha^{-1}) exhibiting the highest leaf number and T_1 (control) exhibiting the lowest leaf number (Fig. 2). Regardless of treatments, the number of leaves increased as the plant grew and reached its peak 75 DAT ranging from 5.52 to 7.68. It is reported that sulfur fertilizer produced the highest plant height, number of leaves per plant, bulb diameter, bulb weight, and yield (Dabhi *et al.*, 2004; Jaggi, 2005, and Nasreen *et al.*, 2007).

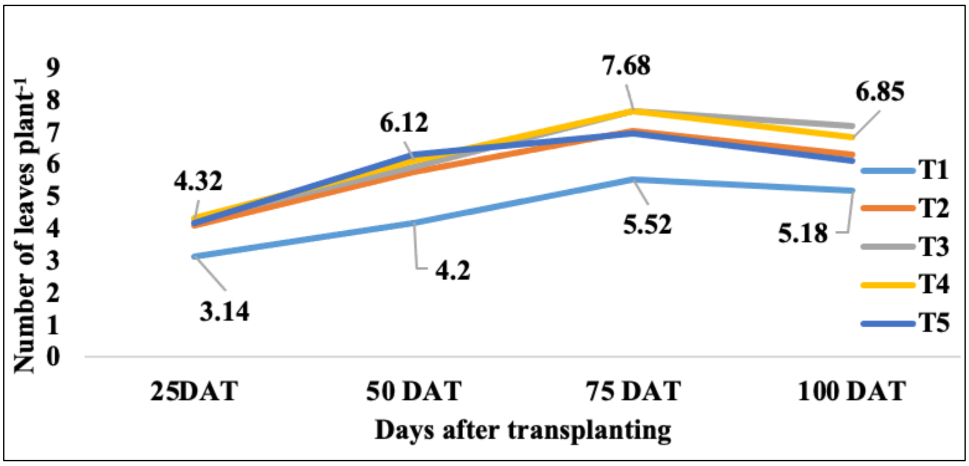

Fig. 2. Effect of sulphur on the number of levels plant^{-1} of onion at different DAT.

Effect of Sulfur levels on yield and yield components of onion

Single bulb weight, bulb size (diameter and length) and yield were significantly influenced by different levels of sulfur (Table 2).

Bulb length

The maximum length of bulb was obtained at 30 kg S ha^{-1} (4.03 cm), which was statistically similar to 45 kg S ha^{-1} (3.84 cm) and 60 kg S ha^{-1} (3.79 ha-1) (Table 2). The control treatment recorded the lowest bulb length (2.94 cm).

Bulb diameter

The fertilization with sulfur caused a significant variation in bulb diameter (Table 2). Bulb diameter varied between 3.57 and 5.24 cm due to the different levels of sulfur application. The plants with the largest bulb diameter were those treated with 30 kg S ha^{-1} (5.24 cm) identical with 45 kg S ha^{-1} (5.22 cm) and 60 kg S ha^{-1} (5.21 cm) and the control treatment gave rhe lowest bulb diameter (3.57 cm).

Weight of single bulb

The weight of a single bulb ranged from 16.98 to 34.08 g with various S levels (Table 2). The maximum single bulb weight (34.08g) was observed at 30 kg S ha^{-1} (34.08 g) closely followed by 45 kg S ha^{-1} (29.18 g) and 60 hg S ha^{-1} (31.3 g). The weight of a single bulb was significantly affected by the plant receiving 30 kg S ha^{-1}, but it tended to decrease as more sulfur fertilizer was added. The lowest bulb weight was obtained from the control (no S (16.98 g). The outcomes concur with those of Ahmed *et al*. (1988). The outcome may be explained by sulfur's beneficial effects on lowering soil pH, boosting flocculation of soil particles, enhancing soil structure, and raising the availability of specific plant nutrients in the soil (El-Galla *et al.*, 1989). Another reason could be that onions require more sulfur than other crops do (Schultz *et al.*,1966), or that sulfur is needed for the synthesis of coenzyme A and amino acids, which are necessary for the elaboration of proteins, as well as for the formation of specific disulfide linkages that have been linked to the structural properties of plant protoplasm (Marschner, 1998).

Table 2. Yield and yield components of onion bulb as influenced by different levels of Sulfur fertilizer

Treatments (kg ha^{-1})	Length of bulb (cm)	Diameter of bulb (cm)	Wt. of single bulb (g)
T_1: S= 0	2.94d	3.57c	16.98e
T_2: S= 15	3.41c	4.78bc	19.58d
T_3: S= 30	4.03a	5.24a	34.08a
T_4: S= 45	3.84ab	5.12a	29.18ab
T_5: S= 60	3.79ab	5.21a	31.3ab
Significance Level	**	**	**
CV (%)	4.98	8.91	5.67

In a column, means followed by the same letters did not differ significantly. '**' indicates significant at 1% level of significance, CV= Coefficient of variation

Bulb yield

With the application of sulfur bulb yield significantly increased up to 30 kg S ha^{-1} and then declined (Table 3). The maximum bulb yield (13.35 tha^{-1}) was obtained from the application of 30 kg S ha^{-1} followed by 45 kg ha-1 (12.90 t ha^{-1}) and 60 kg S ha^{-1} (12.85 t ha^{-1}). Production of taller plants with more leaves may result in increased vegetative structure for nutrient absorption and photosynthesis, as well as increased assimilate production to fill the sink and increase bulb size and weight. However, this could explain any increase in bulb yield of less than 45 or 60 kg S ha^{-1}. Beyond 30 kg S ha^{-1}, however, a negative response to sulfur was noted. Singh and Rathi (1987) also reported similar results. According to Nasreen *et. al.* (2007), fertilizing with nitrogen and sulfur was found to increase the availability of nutrients in the soil, and plant uptake may be the result of synergistic effects. Another explanation might be that onions require more sulfur than other crops, and their needs are higher (Marschner, 1995). According to Tisdale and Nelson (1985) and El-Shafie and El-Gamaily (2002), sulfur plays a significant role in the production of plant protein and certain hormones. It is also essential for enzymatic activity, chlorophyll formation, the synthesis of certain amino acids, and vitamin synthesis. As a result, sulfur has a positive effect on onion yield. Singh and singh (1997) demonstrated that the highest mean yield values were attained by onions that received up to 40 kg of S ha^{-1}. The influence of sulfur on onion yield may be explained by the significant role sulfur plays in the synthesis of certain hormones and plant proteins. Additionally, sulfur is essential for enzymatic activity, the formation of chlorophyll, the synthesis of certain amino acids, and the synthesis of certain vitamins. As a result, sulfur promotes healthy vegetative growth, which increases onion yield.

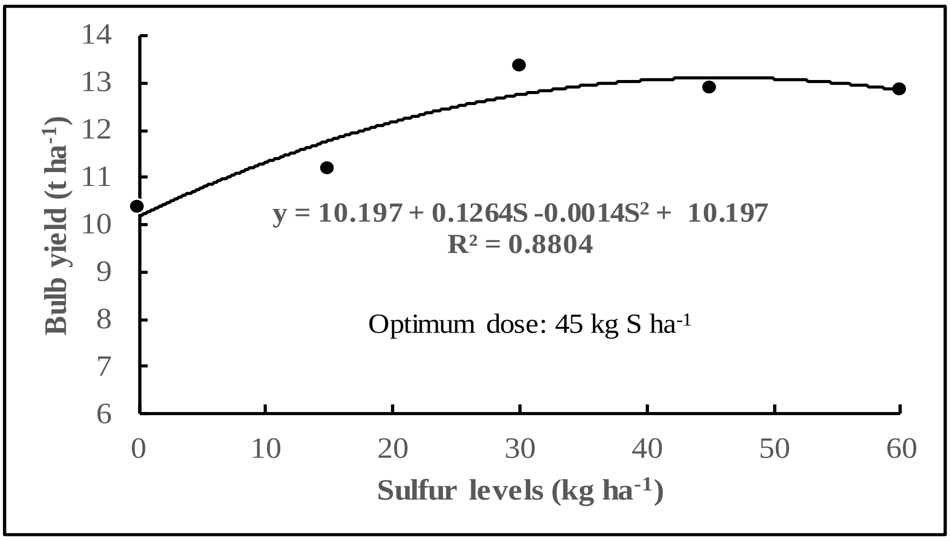

Fig. 3. Relationship between sulfur levels and bulb yield of onion.

Relationship between sulfur levels and bulb yield of onion

According to polynomial regression analysis, there was a positive correlation (R^2= 0.8821) between sulfur and bulb yield (Fig. 3). This result indicated that the bulb yield of onion was increased with the increase of sulfur application up to a certain limit (30 kg ha-1) beyond which yield declined. Based on the regression curve, the optimal level of S for yield was determined to be 45 kg S ha^{-1}. The R^2 value 0.8804 indicated that 88.04% yield was due to S application and the rest 11.94% yield was due to other factors influenced the onion crop.

Nutrient uptake

Considerable differences were noted between the sulfur levels in terms of nutrient concentration and uptake (Fig. 4 and 5). The concentration of sulfur in onion bulbs increased as the amount of sulfur was applied. Application of sulfur @ 30 kg ha^{-1} resulted in an uptake of 57.41 kg ha^{-1} (Fig. 5); this was found to be significantly higher than the values recorded with the remaining levels.

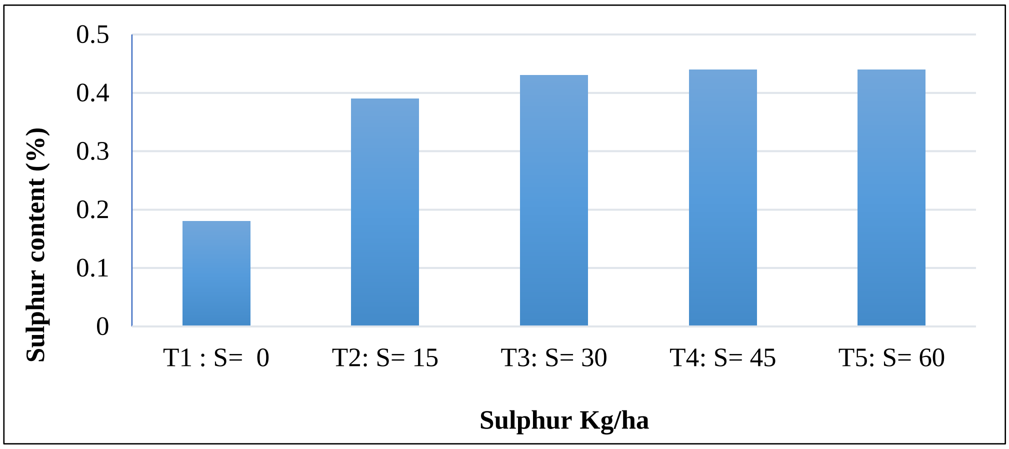

Fig. 4 Effect of various sulfur levels on sulfur concentration in onion (*Allium cepa* L.).

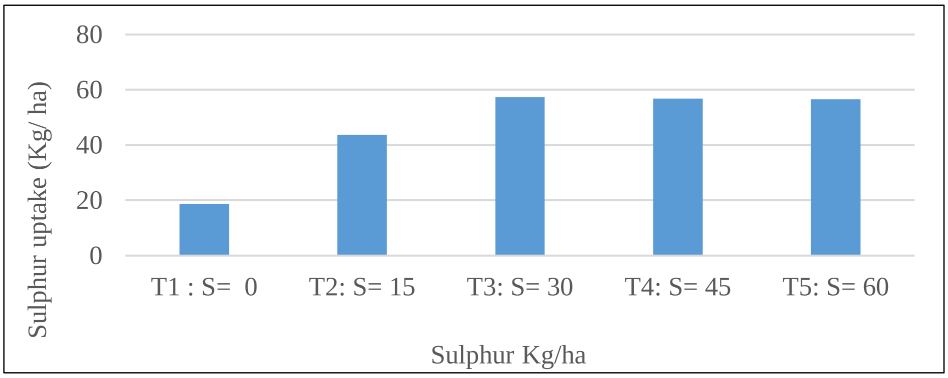

Fig. 5 Effect of sulfur various levels on sulfur uptake in onion (*Allium cepa* L.).

The main function of sulfur in balanced nutrition and in physiological processes such as the synthesis of sulfur-containing amino acids and the development of a profused root system, which leads to increased nutrient uptake and ultimately increases photosynthesis, may be the cause of the increase in growth, yield, and yield-related attributes. Better quality, increased nutrient uptake, and sustained nutrient bulb up in the soil have also reported similar findings. (Dudhat *et al.*, 2011; Jaggi, 2004; Nasrin *et al.*, 2007).

Economic performance

Table 3 presents an economic study of onion cultivation. Treatment T_3 (S= 30 kg ha^{-1}) had the highest marginal benefit-cost ratio (MBCR) (12.77). In respect of of MBCR, it might, therefore, be suggested to use 30 kg S ha-^{1} in addition to a blanket dose of 100-50-75-4-1.5 kg ha-1 of N-P-K-Zn-B plus 5 t ha^{-1} cowdung to increase onion bulb yield.

Table 3. Economic performance of different treatment combinations on bulb yield of onion

Treatment (S kg ha^{-1})	Bulb Yield (t ha^{-1})	Gross income (Tk ha^{-1})	Additional yield over control (t ha^{-1})	Additional income over control (Tk ha^{-1})	Cost of treatment (TK ha^{-1})	Net income (TK ha^{-1})	MBCR
T_1: S= 0	10.39	155850	-	-	0	-	-
T_2: S= 15	11.2	224000	0.81	16200	4150	12050	2.90
T_3: S= 30	13.35	267000	2.96	59200	4300	54900	12.77
T_4: S= 45	12.90	258000	2.51	50200	4450	45750	10.28
T_5: S= 60	12.85	257000	2.46	49200	4600	44600	9.69

MBCR= Marginal benefit-cost ratio, [Price of Onion bulb @Tk. 20.00 per kg; Gypsum: Tk. 10/kg Cost of human labour (fertilizer application): Tk.400/person/day.

Conclusion

The experimental results revealed that variation in sulfur levels had a significant influence on yield, growth, and yield contributing characteristics. Based on the information supplied so far, it might be suggested that the application of 30 kg S ha^{-1} generated the best yield (13.35 t ha^{-1}) when compared to the other sulfur doses. The optimum dose of S determined from the regression curve was 34.77 kg ha-1. Application of fertilizers in the form of urea, TSP, MoP, Zinc sulphate and boric acid @ 100-50-75-4-1.5 kg ha-1 of N-P-K-Zn-B plus 5 t ha-^{1} cowdung with 45 kg S ha^{-1} supplied from gypsum may be the best combination for onion production in Level Barind Tract (AEZ-25) of Bangladesh.

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BIOLOGY OF TWO SPOTTED SPIDER MITE, *TETRANYCHUS URTICAE* (ACARI: TETRANYCHIDAE) ON TARO

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Abstract

The biology of twospotted spider mite, *Tetranychus urticae* Koch was studied at the Integrated Pest Management Lab of Entomology division, Bangladesh Agricultural Research Institute (BARI) Gazipur following leaf disc method during March-May, 2022 at 25±2^0 C and 55±5% RH. It was revealed that biology of *T. urticae* consisted of egg, larva, protonymph, deutonymph and adult stages and brief quiescent period called nymphochrysalis, deutochrysalis and teliochrysalis. Egg incubation period 2.90±0.29, larval 1.3±0.2 and 2.7±0.54, protonymphal 2.8±0.25 and 3.0±0.35 and deutonymphal period of 2.4±0.43 and 2.9±0.51 days were recorded in its male and female, respectively. Males took less time to develop overall 6.45±0.30 days than females 8.25±0.28 days from egg to adult emergence. Males were smaller than females, according to morphometric measurements. Both parthenogenetic and bisexual reproduction were noted. The offspring of mated females were 1:2.32 males to females, while unmated females produced only males. An average of 62.0 ± 8.98 eggs were produced by mated females and 38.2 ± 6.36 by unmated females. Correspondingly mated females laid 7.0 to 10.0 (mean 8.6±0.68) and unmated females laid 2.0 to 5.0 (mean 4.0±0.55) eggs per day. The observed adult longevity was 9.30± 0.83 days for males, 12.2±0.80 days for mated females, and 10.0±1.3 days for unmated females, respectively.

Keywords: Spider mite, taro, arrhenotoky, sex ratio, lifer cycle.

Introduction

Twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) is one of the most important pests in many crop plants particularly vegetables including taro, and their feeding activity is based on sucking leaf cell contents (Parmagnani *et al*., 2023).The outbreak of this pest becomes secondary pest in agricultural systems that is assumed to be the consequences of frequent and indiscriminate use of toxic chemicals, especially pyrethroid insecticides by the vegetable growers (Dobson *et al*., 2002). Moreover, warm and dry weather is favorable for the multiplication and spread of this pest (Jeppson *et al.,* 1975). It is reported as one of the important pests of vegetable and ornamental crops and the outbreak of this pest in different vegetables in Bangladesh has become a serious problem for the growers. Twospotted red spider mite has been an alarming pest on bean, brinjal, taro, cucurbits and okra etc. which build up from February and decline during July under north Indian conditions (Singh and Singh, 1993).

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Phytophagous spider mites cause damage by piercing leaf cells and ingesting chlorophyll (Croft *et al*., 1998; Seymour, 1982). In high numbers these mites cause leaf discoloration and drying, thus reducing photosynthetic activity and lowering yield and crop quality (Flaherty *et al*., 1992; Hanna *et al*., 1996,). Outbreaks are often caused by the use of broad-spectrum insecticides which interfere with numerous natural enemies that help to manage the mite populations. Spider mites often become secondary pests in agricultural systems and the most common method of control of *T. urticae* is by using chemicals insecticide. A major problem in the control of *T. urticae* using chemical insecticides causes the ability to develop resistance rapidly after a few applications (Rauch & Nauen 2002). The frequent application of acaricides, combined with the short life cycle and high reproductive potential of spider mite, results in the rapid development of resistance (Tirello *et al*., 2012; Van Leeuwen 2010). In addition, intense and continuous use of chemicals causes environmental pollution and disruption of ecological balance. For developing effective and sustainable management approach of this pest, thorough knowledge about their biology is a prime requisite. Taro being the important host crop of twospotted spider mite, only very limited information is available on the biology of this pest on taro leaf and hence, the present study was conducted.

Material and Methods

The study on the development and life history of *T. urticae* was conducted in the IPM Laboratory of Entomology Division, Bangladesh Agricultural Research Institute during March-May, 2022 at 25 ± 2^0 C and 55±5% RH.

Maintenance of the host plant (Taro) in net house

The taro plant was transplanted in 12-inch diameter plastic pot in the net house. Recommended dosages of Farm Yard Manure (FYM) and fertilizers were applied to these plants and the plants were watered as and when required to maintain optimum moisture in the pots. The taro plants were allowed to grow and artificially infested with *T. urticae* and the leaves from these plants were used for biology and life table study. Taro plants were transplanted every 15 days in order to ensure continuous availability of taro leaves for biology and life table studies in the laboratory.

The duration of developmental stages of *T. urticae* was studied on excised leaf disc of taro leaves. Leaf discs were made with fresh taro leaf without mite infestation. Each leaf disc was circular in appearance with 2cm diameter. Twelve leaf discs were prepared. The leaf discs were placed on cotton bed in petri dish (5 cm × 1 cm) facing under surface upward. The cotton bed was kept wet by adding with water with the help of dropper so that the discs remained fresh. The adult female mites were collected from the mass cultural of *T. urticae* on taro plants in the pots at the IPM net house and were transferred to each leaf disc for laying eggs. The discs containing adult females were checked after 24 hours of mite transfer. The mites were removed at least one egg was found. In this way 15 eggs were collected on leaf discs. Keeping only one egg on each disc the others were destroyed. The discs were checked after every 24 hours and the stages of mite development were noted and the duration of hatching, larval, protonymph and deutonymph period was recorded till the appearance of their adulthood. The leaf discs were changed after 3 to 4 days to ensure their freshness. The immature nymphs were transferred to new disc very carefully with the help of camel hair brush. Deutonymphs of *T. urticae* were collected from the potted taro plants of laboratory culture. Five deutonymphs were transferred on each leaf disc. The disc containing deutonymphs were observed twice daily at 9:00 AM and 5:00 PM. The time of adulthood of the deutonymphs was recorded after moulting. All the mites were removed keeping one male and one female on each disc after moulting. The males were also removed after laying the first egg by the female. In this way more than 5 discs with ovipositing females were maintained for this experiment. The discs were checked after every 24 hours interval with the aid of a stereo binocular microscope. The leaf discs were also changed after every three days in the same way as described earlier. All the discs were checked and the number of eggs laid was counted till the death of the adult. The eggs were hatched into larvae and the larva undergoes moulting to become protonymph and deutonymph. The developmental duration of each stage such as egg, larva, nymph and quiescent stages were recorded. The morphometric measurement of different stages was recorded with the help of a standardized occular micrometer fitted to a camera equipped stereo binocular microscope (Olypus SZ61).

Results and discussion

The life cycle of *T. urticae* consisted of egg, larva, nymph (protonymph, deutonymph) and the adult. Developmental period of various stages and reproductive attributes are presented in Table 1 to Table 3.

Incubation period (Egg): *T. urticae* preferred to colonize and generally lay eggs on the underside of the leaves. Gravid female laid eggs singly or in groups ventral side of the leaves, often near the veins and the midrib of host leaf. Eggs were spherical and transparent when freshly laid, but turned creamy white prior to hatching. During this stage, two dark colored eye spots, corresponding to the simple eyes of the larvae, were clearly visible. Eggs of *T. urticae* measured 136.44±11.68 µm in diameter (Table1). The incubation period ranged from 2.0 to 3.50 days with an average of 2.90±0.29 days (Table 2).

Larval period: Newly hatched larva was creamy coloured, hexapod and small in size. On feeding the color changed from creamy to pale green. The simple eyes on the dorso-lateral idiosoma were clearly distinguishable at this stage. The larvae possessed only three pairs of legs. The larval period ranged from 1.00 to 2.00 days with average of 1.3±0.2 days for male and in case of female 2.7±0.54 days with a range of 1.0 to 4.0 days was observed (Table 2). The larva measured 154.58±3.95 µm in length and 118.87±4.11 µm in breadth (Table 1). Initially the larva crawled around for some time and anchored at a place to feed on the cell sap.

Nymphochrysalis period: The dark green matured larva stopped feeding and moved to a suitable place on the leaf and entered into the quiescent stage (called nymphochrysalis) by anchoring itself to the leaf surface. During this stage, the anterior 2 pairs of legs were extending straight forward and kept close to each other and posterior legs were extended backwards and held close to the sides of opisthosoma. This stage lasted for 0.25 to 1.30with average of 0.66±0.21 days for male and 0.25 to 1.50 with average of 0.70±0.24 days for female (Table 2). Nymphochrysalis measured 178.58 ± 4.96 µm in length and 129.76 ± 4.11 µm in breadth (Table 1).

Protonymph: At the end of this nymphochrysalis stage, moulting took place. Protonymph is the first nymphal stage emerged by splitting open the larval skin along the dorsal midline and was characterized by the presence of four pairs of legs. The newly emerged protonymph was oval shaped and dark green in color at the beginning, which later turned into amber color. It was larger and darker as compared to the larva. This stage lasted for 2.0 to 3.5 with average of 2.8±0.25 days for male and 2.0 to 4.0 with average of 3.0±0.35 days for female (table 2). Protonymph measured 195.48±8.21 µm in length and 131.72±1.80 µm in width (Table 1).

Deutochrysalis: At the end of protonymphal period, the protonymph entered its second quiescent stage called the deutochrysalis. It remained anchored to the leaf +in a manner similar to that of nymphochrysalis. Its body measured 229.19±7.98µm in length and 141.02±1.11µm in width (Table 1). This period lasted for 0.89±0.24 days for male and 0.95±0.20 days for female.

Table 1. Morphometric measurement of various stages of the twospotted spider mite, *T. urticae*

Stages	Length (µm)		Width(µm)	
	Range	Mean±SE	Range	Mean±SE
Egg (Diameter)	113.6-167.8	136.44 ±11.68	113.6-167.8	136.44±11.68
Larvae	144.7-168.4	154.58±3.95	111.5-129.1	118.87±4.11
Nymphocrysalis	168.3-195.9	178.58±4.96	123.92-134.4	129.76±4.11
Protonymph	225.13-179.52	195.48±8.21	127.77-134.11	131.72±1.80
Deutocrysalis	199.78-245.13	229.19±7.98	129.93-149.31	141.02±1.11
Deutonymph	275.0-353.5	315.34±14.96	147.7-167.1	160.76±3.47
Teliocrysalis	320.7-393.61	371.37±13.23	183.11-197.03	190.04±5.10
Adult male	358.2-451.01	398.65±15.56	160.13-227.05	197.61±2.30
Adult female	428.9-478.1	452.72±13.41	214.3-233.9	224.02±9.31

Deutonymph: Deutonymph is the second nymphal stage. Sexual characters could be distinguished from this stage onwards, and it was pale reddish, female being larger and broader and male elongated. They were actively moving and feeding. Deutonymphal stage lasted for 1.0 to 3.5 with average of 2.4±0.43 days for male and 1.0 to 4.0 with average of 2.9±0.51 days for female (Table 2). Deutonymph measured 315.34±14.96 µm in length and 160.76±3.47 µm in width (Table 1).

The developmental stages of *T. urticae* on taro consists of egg, larva, protonymph, deutonymph and adult and quiescent period such as protochrysalis, deutochrysalis and tiliochrysalis recorded in the present study have also been reported by Krishna and Bhaskar (2014) in *T. urticae* infesting on okra plant.

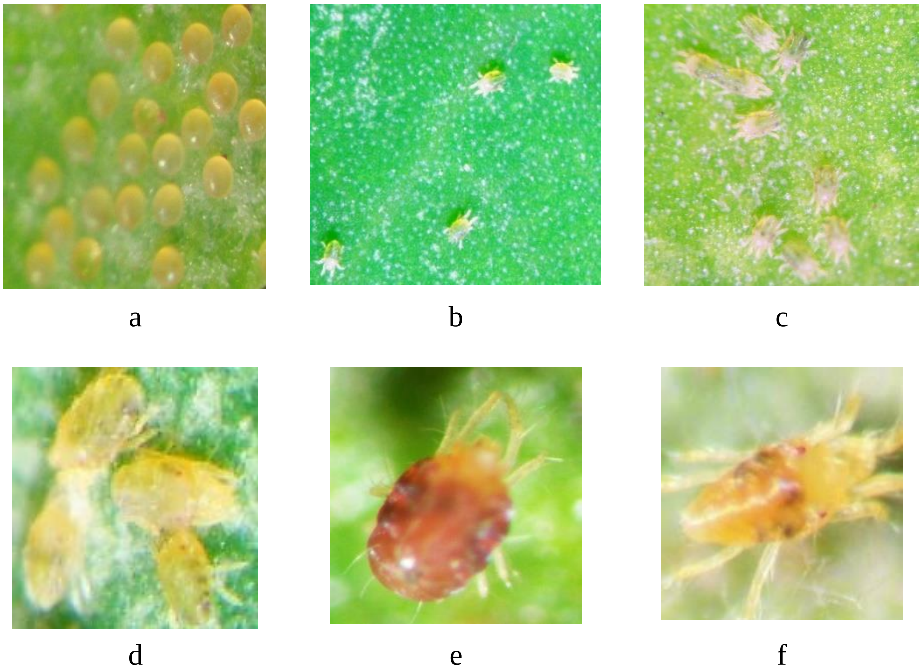

Fig. 1. Stereo micrograph of different developmental stages of *T. urticae*: a) egg, b) larva, c) protonymph, d) deutonymph, e) adult female & f) adult male.

Teliochrysalis: The deutonymph stage was preceded by the quiescent stage before it moulted into an adult stage. It remained inactive by anchoring itself to leaf. The moulting of quiescent deutonymph resulted in the emergence of adult. This stage was only found in female *T. urticae* whereas in case of male it was absent. It is measured 371.37±13.23 µm in length and 190.04±5.10µm in width (Table 1), and lasted for 1.0 to 1.50 with average of 1.0±0.16 days (Table 2).

Total Development period: The total development period from egg to adult emergence was 7.45±0.34 days for males and 8.25±0.25 days for females. The total developmental period for male was less compared to female. Males had been observed to complete their life cycle in 6.73 days and females in 7.52 days on okra (Aswathi and Bhaskar, 2014); Veerendra *et al.* (2014) observed duration of 12.55± 0.82 days on grapevine. The early emergence of male ensures sexual reproduction against parthenogenesis which is common in *T. urticae*. Several workers had already reported a similar trend in the development biology of different species of *Tetranychus* infesting various crops. Rajkumar *et al.* (2005) recorded a shorter development time for male (10.7 days) compared to female (12.36 days) in *T. urticae* on jasmine.

Table 2. Developmental periods of life stages of *T. urticae* on taro under laboratory condition

Stages	Sex	No. of observation	Range	Duration in days (Mean±SE)
Incubation (egg)		30	2.0-3.5	2.9±0.29
Larval	Male	15	1.0-2.0	1.3±0.20
Larval	Female	20	1.0-4.0	2.7±0.54
Nymphocrysalis	Male	15	0.25-1.3	0.66±0.21
Nymphocry	Female	20	0.25-1.5	0.7±0.24
Protonymph	Male	15	2.0-3.5	2.8±0.25
Protonymph	Female	20	2.0-4.0	3.0±0.35
Deutocrysalis	Male	15	0.2-1.5	0.89±0.24
Deutocrysalis	Female	20	0.5-1.5	0.95±0.20
Deutonymph	Male	15	1.0-3.5	2.4±0.43
Deutonymph	Female	20	1.0-4	2.9±0.51
Teliocrysalis	Female	20	1.0-1.5	1.0±0.16
Adult	Male	15	7.00-8.5	7.45±0.34
	Female	15	7.5-9.00	8.25±0.25
Adult longevity	Male	15	7.0-12.0	9.3±0.83
	Unmated Female	20	6.0-14.0	10.0±1.3
	Mated female	20	11.0-15.0	12.2±0.80
Total life cycle	Male	15	12.0-19.0	14.3±1.30
	Female	20	20.0-26.0	23.1±0.98

Adult: The adult female measured 452.72±13.41 µm in length and 224.02±9.31 µm in width whereas male measured 398.65±15.56 µm in length and 197.61±2.30 µm in width (Table 1).

The mites exhibited sexual dimorphism. Males were reddish green or pale red and smaller with body tapering posteriorly to a blunt point; the body of the adult male was narrow elongated, oval with a distinct abdomen (Picture 1f). They also have numerous long hairs on their legs, and long but sparse hairs on their body. The females were bigger than males with rounded or oval abdomen. Females were bright red and later turned to deep red or brick red in colour, larger than male with longer setae over the body and legs (Picture 1e). Both males and females had bright red eye spots on the dorsolateral idiosoma.The deutonymph and adult females of *T. urticae* developed on taro were larger in size compared to males as already reported by Krishna and Bhaskar (2014) in *T. urticae* on Okra plant.

Longevity: Adult males recorded a mean longevity of 9.30±0.83 days, while the mated and unmatedfemales showed 12.2±0.80 and 10.0±1.3 days, respectively (Table 2).

Reproductive biology of *T. urticae*: Reproductive biology of *T. urticae* consists of mating behavior, preoviposition, oviposition and postoviposition periods and fecundity etc.

Mating behavior: It was found that, males always emerged earlier than the females and were found actively moving in search for females to mate. After finding the quiescent female deutonymph (teliochrysalis) they rested near or over the quiescent female deutonymphs. It placed the anterior pair of legs on female deutonymphs and waited for its emergence in order to mate immediately after the emergence. Mating took place immediately after the emergence of the female. Sometimes there was competition between two or more males. In some cases, males helped the females for emerging out of deutonymphal skin by pulling the ecdysial skin. Mating

lasted for 2-3 min, and was observed to mate with several females. This peculiar behaviour prior to mating was common among *T. urticae* and other spider mites (Aswathi and Bhaskar, 2014; Veerendra *et al.*, 2014).

Pre oviposition period

The females laid eggs after a gap of certain period. The mean pre oviposition period in unmated and mated females lasted for 2.9±0.75 and 2.2±0.51 days, respectively (Table 3).

Oviposition and post oviposition periods: Oviposition and post oviposition periods lasted for 8.8± 0.80 and 3.0± 0.65 days in case of mated females and 4.2±0.58 and 2.10±0.33 days in case of unmated females as presented in Table 3.

Fecundity, sex ratio and egg viability of *T. urticae*: Fecundity data revealed that mated females laid more eggs than unmated females. The total fecundity of mated female was 49-97 eggs (mean- 62.0±8.98), and that of unmated being 16-50 eggs (mean-38.2±6.36). Correspondingly mated females laid 7.0 to 10.0 (mean 8.6±0.68) eggs per day and unmated females laid 2.0 to 5.0 (mean-4.0±0.55) eggs per day. Mated females laid a greater number of eggs (62.0±8.98) compared to unmated females (38.2±6.36); and this observation is in accordance with Prasad and Singh (2011) in *T. urticae*. High fecundity of mated females of *T. urticae* was reported by Rajkumar (2003). Mated female produced both male and female’s progeny in the ratio of 1:2.32, while unmated female produces only male (1:0.0).

Female biased sex ratio was also reported by Krishna and Bhaskar (2014) in *T. urticae* on Okra. Arrhemotoky is also reported by Banato and Gutierrez (1999) in other species of *Tetranychus*. The viability of eggs of mated female was 96.88% and 82.02% of unmated female (Table 3). The higher egg viability (96.88%) observed in this study is evidence of the high biotic potential. A higher egg viability of 96.5% in *T. urticae* was reported on rose (Kaur *et al.*, 2012). The egg viability of 92.1% and 96.5% in *T. urticae* was recorded on Okra and gerbera plants by Krishna and Bhaskar (2014) and Silva *et al*. (2009), respectively.

Table 3. Ovipositional period, fecundity and egg viability of *T. urticae* on taro under laboratory condition

Particulars	Sex	No. of observation	Range	Duration in days (Mean±SE)
Pre oviposition period	Unmated female	12	1.0-5.0	2.9±0.75
	Mated female	15	1.0-4.0	2.2±0.51
Oviposition period	Unmated female	10	3.0-6.0	4.2±0.58
	Mated female	12	7.0-11.0	8.8±0.80
Post oviposition period	Unmated female	10	1.0-3.0	2.1±0.33
	Mated Female	12	2.0-5.5	3.0±0.65
Rate of egg laying	Unmated female	10	2.0-5.0	4.0±0.55
	Mated female	12	7.0-10.0	8.6±0.68
Fecundity	Unmated female	10	16.0-50.0	38.2±6.36
	Mated female	12	49.0-97.0	62.0±8.98
Sex ratio (Male: Female)	Unmated female	157	1:0.00-1:0.00	1:0.00
	Mated female	310	1:1.94 -1:2.88	1:2.32
Egg viability (%)	Unmated female	191	56.25-96.88	82.02
	Mated female	320	94.0-98.98	96.88

Total life cycle

Males completed their life cycle in 14.3±1.30 days whereas; females took 23.1±0.98 days to complete their life cycle. It was clear from the results that males took less time than females to complete their life cycle (Table 2).

The observations on the development of egg, larva and nymphs of *T. urticae* on taro in the present study are more or less similar to the earlier findings of Prasad and Singh (2011), Kaur *et al.* (2012) and Aswathi and Bhaskar (2014). Difference in duration of development could also be influenced by sex; host plants, temperature etc.

The shorter developmental period and high fecundity was observed in the present study. The shortening of life cycle along with significant increase in the rate of reproduction with the increase in temperature enables these mites to fast multiply and attain pest status especially during the drier and hotter months of the year (Siddhapara and Virani, 2018).

Conclusion

Due to climate change and over use of synthetic chemical insecticides to control insect pests, spider mite infestation in different crops is on the rise at present. For developing sustainable mite management technology, proper documentation of its biology could play a vital role. In Bangladesh, along with different crops, spider mite is a serious pest of taro. Since the biology of spider mites was studied on taro crops. The findings of the study would be of particular help for developing sustainable mite management options, thereby increasing the productivity of this crop in Bangladesh.

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