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RESEARCH ARTICLE

Screening of Onion (*Allium cepa* L.) Genotypes for Acid Tolerance Based on Morpho-physiological and Yield-Associated Traits

Sajib Sarker[A], A.F.M. Saiful Islam[A], Md. Abdul Maleque[B], Rehenuma Tabassum[A] and Fakhrul Islam Monshi*[C]

[A] Department of Crop Botany and Tea Production Technology, Faculty of Agriculture, Sylhet Agricultural University, Bangladesh
[B] Department of Entomology, Faculty of Agriculture, Sylhet Agricultural University, Bangladesh
[C] Department of Genetics and Plant Breeding, Faculty of Agriculture, Sylhet Agricultural University, Bangladesh

*Corresponding author; e-mail: monshifi.gpb@sau.ac.bd

Abstract

Onion is one of the most valuable vegetable crops grown all over the world, but its production is severely affected by abiotic stresses like drought, waterlogging, and the acidic nature of the soil. An experiment was conducted to study the morphological and yield contributing characters of four onion genotypes (Indian Onion-1, Indian Onion-2, Indian Onion-3, and Local onion) in the acidic soil condition at Sylhet region, Bangladesh. The experiment was laid out in a completely randomized block design with three replications. Results showed that four genotypes of onion differed significantly for all the morphological and yield characters. The total yield was positively correlated with plant height, bulb fresh weight, bulb diameter, bulb length, leaf sheath fresh weight, leaf sheath dry weight, root fresh and dry weight. Considering yield and yield attributing traits, Indian Onion-2 performed better in acidic soil which had the highest in bulb fresh weight (72.60 g), total yield (1.78 t.ha^{-1}), and moisture content, followed by Indian Onion-3. Therefore, Indian Onion-2 can be selected as the best genotype for acidic soil in the Sylhet region, Bangladesh.

Keywords: evaluation, acidic soil, onion cultivar, growth parameters, yield characters

Introduction

Onion (*Allium cepa* L.) is one of the most popular commonly used vegetables after carrots, cabbages, tomatoes, and cucumbers. People have grown onion primarily for its bulb which is used for flavoring curry. It is one of the most important vegetable crops whose leafy portions are used daily as vegetables and bulbs as salad and spice (Izadkhah et al., 2011). It has great medicinal value and is also used as a preservative (Assefa et al., 2015). Because onion consists of an immense source of flavonoids in the human diet which can reduce the risk of cancer, heart disease, and diabetes (Begum et al., 2015; Bekele, 2018). In Bangladesh, although the demand for onion is increasing day by day; the area under onion cultivation is decreasing. As a result, Bangladesh has to import onion from other countries to meet its demand (Islam et al. 2007; Roy et al., 2016). Lack of modern genotypes and proper agronomic practices may be the major problems for higher yield production (Haque et al., 2011). So, improved onion genotypes would contribute to fulfilling the food demand.

Plants have the ability to adapt to grow in a certain range of environmental conditions (Gedam et al., 2021). One of the most important environmental factors influencing plant growth is growing well in the acidic soil (Karim and Ibrahim, 2013). Onion is a shallow-rooted crop, therefore, a fairly high concentration of nutrients should normally be maintained at the sub-surface of the soil for its optimum growth and yield (Fikre et al., 2021). Low and high pH negatively affects onion root growth, probably because intrinsic pH regulation systems are disturbed (Yan et al., 1992). Onion root growth is inhibited and the root morphology can change when exposed to extremely low pH soil. There is very limited research on onion cultivation and production in acidic soil, particularly in the Sylhet region, Bangladesh, where high and medium lands have acidic soils with pH ranging from 4.8-5.7 and high Iron content (Paul et al., 2021; Rahman et al., 2015). Cultivation of onion is relatively unknown to the farmers in this region due to the lack of local variety. In addition, limited research have been conducted to study the performance of the different crops in the acidic soil condition of this region (Monshi et al., 2015; Roy et al., 2016; Tabassum et al., 2015).

Crop yield could be regarded as a complex character, which is dependent on a number of agronomic characters and is influenced by many factors, which could be genetic or environmental (Sekara et al., 2017). Components of bulb quality include size, appearance, percentage of single-centered bulbs, and susceptibility to sprouting and decay in storage (Chitdeshwari et al., 2021; Tekeste et al., 2018), and the onion genotype varies in its nature of bulbing and in yield parameters and yield (Gedam et al., 2022). Nutrient management is designed to assist onion growers and crop advisors in producing a high-quality crop while protecting the environment from excess nutrients (Chattoo et al., 2019). Hence, immediate attention needs to be given to improve the productivity of onion. The knowledge about the interrelationship among bulb yield and its components and their relative contribution towards the bulb yield is important for a fruitful selection. The present investigations were, therefore, undertaken to estimate suitable genotypes having better growth and morphological characteristics and to determine suitable genotypes based on higher-yielding abilities in acidic soil of the Sylhet region.

Materials and Methods

Experimental Site and Materials

The experiment was conducted from November 2015 to April 2016 at the research farm of the Department of Crop Botany and Tea Production Technology, Sylhet Agricultural University, Bangladesh. The soil of the experimental field is clay loam type and acidic. The soil pH of the research field was 4.81. The size of the experimental plot was 2 m × 0.9 m. Among four genotypes of onion three were collected from India (Indian Onion-1, Indian Onion-2, and Indian Onion-3) and local onion cultivar was collected from the seed bank of SAU, Sylhet, Bangladesh.

Experimental Design and Layout

The experiment was laid out in a randomized complete block design with three replications. The experimental field was divided into three blocks representing three replications and each block had four individual plots. The onion seeds were transplanted in lines with a spacing of 15 cm and 12 cm for the row to row and plant to plant, respectively. There were three rows in a plot having 16 plants each.

Crop Husbandry

The total amount of cow dung (8 ton.ha^{-1}) was applied during field preparation. Except for urea, fertilizer TSP (200 kg.ha^{-1}), MoP (180 kg.ha^{-1}), gypsum (85 kg.ha^{-1}), boric acid (5.0 kg.ha^{-1}), and magnesium sulfate (90.0 kg) were applied at the time of final land preparation. Two days after fertilizer application, zinc sulfate (8.0 kg.ha^{-1}) was applied in the field. Urea (200 kg.ha^{-1}) was side-dressed in two equal installments after 30 and 70 days after planting. The land was prepared by plowing and cross-plowing using a rotavator to produce a good environment for seed germination and plant growth.

Thinning and Gap Filling

Six days after transplanting the weaker seedlings were removed and kept the healthier one in each pit. Gap filling was done three times at the seedling stage. The onion plants were harvested 83 days after planting (DAP) when they have attained the edible stage.

Methods of Data Collection

The onion plants from each plot were selected randomly for collecting data. For morphological parameters, leaf blade, leaf sheath, and bulb were separated from the plant after uprooting the plant. The length and diameter were measured at 75, 90, 105 DAP and at final harvesting (125 DAP). Similarly, for growth parameters, fresh and dry weight of the Leaf-sheath, bulb, and root were measured at 15 days intervals from 75 DAP to final harvest and oven-dried at 55^{o}C temperature for 3 x 24 h. Yield at the research farm was calculated in t.ha^{-1}.

Statistical Analysis

Data were analyzed using MSTAT software. The analysis of variance (ANOVA) was calculated for proper interpretation among the treatments. Mean separation was done by using DMRT (Duncan's Multiple Range Test) (Gomez and Gomez, 1984).

Results and Discussion

Morphological Characters

Leaf-sheath length

Leaf-sheath length varied significantly among the onion genotypes (Table 1). The leaf sheath length increased with time. Overall, Indian onion-1 has the longest leaf sheath during the plant growth (75-105 DAP), followed by Indian onion 3 and Indian onion 2. Surprisingly, the local variety had a shorter leaf sheath. The results indicated that the leaf sheath length is a little bit shorter than the usual onion leaf sheath may be the cause of acid soil which can retard its normal growth. Usually, the exotic onion germplasms especially the Indian onion varieties are popular in Bangladesh due to their fleshy flavor and the cheapest price; this crop has been cultivated in different regions of Bangladesh for proper adaption (Anik and Salam, 2015). The acidic nature of soil can hamper the growth of onion leaf sheath length, which was also reported by Roy et al. (2016).

Leaf-sheath diameter

Cumulative leaf sheath diameter was followed during the growing season (Figure 1). The genotype Indian Onion-1 is formed a large sheath diameter at the early stages of growth then slows down after 105 DAP while the genotype Indian Onion-2 begins with a small sheath diameter at the early stages, getting larger after 90 DAP. On the other hand, sheath diameter is steadily increased throughout the growth stages in both Indian Onion-3 and local varieties. Overall, all the Indian onion genotypes performed better growth than the local variety (control). The results demonstrated that the morphological growth of onion plants are not well in acid soil because acidic soil has deficient in P, Ca, and Mg, low in CEC with higher levels of exchangeable iron and aluminum that hamper the nutrient availability, resulting in the slower or minimum plant growth (Rahman et al., 2013). A leaf ratio below unity is coincident with marked swelling of the outer leaf sheaths which means minimum sheath diameter resulting in maximum bulb diameter (Roy et al., 2016).

Plant height

Plant height varied significantly among the genotypes (Table 2). In general, Indian Onion-1 was the highest, followed by Indian Onion-3 while Indian Onion-2 is not significantly different from control. At the final harvest, the highest plant height was found in Indian Onion-1 (47.8 cm) and the shortest in control (35.60 cm). The largest height (45.38 cm) was noted in the Indian Onion-1 genotype followed by Indian Onion-3 at 105 DAP. Similarly, the largest length was found in Indian Onion-1 which was 41.93 cm and 37.9 cm at 90 DAP and 75 DAP, respectively. On the other hand, at the first three stages (75 DAP, 90 DAP, and 105 DAP) the shortest plant (27.97 cm, 30.43 cm, and 32.90 cm) was found in Indian Onion-2, Indian Onion-3, and control. Similar results of variability were found in onion genotypes in which the average plant height was relatively greater than those of 50% root damage (Wen et al., 2021). The present findings of plant height on onion genotypes also corroborated with the findings of Behairy et al. (2015) and Nigatu et al. (2018) who reported that the plant height can vary due to the availability of the fertilizer and the nature of the soil.

Bulb length

Onion bulb length is a measure of healthy growth of the crop. The largest bulb length (7.20 cm) was recorded at harvest in Indian Onion-2 (Table 3) as well as the bulb length at 75, 90, and 105 DAP (5.0, 5.8, and 6.5 cm, respectively). On the other hand, the smallest bulb length was noted in control (2.63 cm) at 75 DAP among all genotypes. At 90 DAP, 105 DAP, and at harvest control had the smallest

Table 1. Leaf-sheath length (cm) of onion genotypes at different days after planting (DAP)

Variety	Leaf sheath length (cm)			
	75 DAP	90 DAP	105 DAP	At harvest
Indian Onion-1	4.60a	4.65a	5.55ab	6.41a
Indian Onion-2	3.40c	3.40c	5.10c	6.12ab
Indian Onion-3	4.07b	4.07b	5.77a	6.12ab
Local variety(Control)	3.40c	3.40c	5.23bc	5.64b
$LSD_{0.05}$	0.38	0.37	0.41	0.47
CV (%)	4.90	4.82	3.77	3.85

Note: Values having same letter (s) in a column do not differ significantly at 1% level of significance

Table 2. Plant height (cm) of onion genotypes at different days after planting (DAP)

Variety	Plant height (cm)			
	75 DAP	90 DAP	105 DAP	At harvest
Indian Onion-1	37.90a	41.93a	45.38a	47.80a
Indian Onion-2	27.97b	30.80b	34.18b	36.55b
Indian Onion-3	34.67ab	36.42ab	38.94ab	37.97b
Local variety(Control)	28.97b	30.43b	32.90b	35.60b
$LSD_{0.05}$	7.05	6.90	6.80	7.15
CV (%)	10.89	9.91	9.00	9.06
Level of significance	*	*	**	*

Note: ** = Significant at 1% level of probability, * = Significant at 5% level of probability. Values having same letter (s) in a column do not differ significantly at 1% level of significance

bulb length than other genotypes. The result noted that 7.20 cm was the highest bulb length found in Indian Onion-2 at harvest while control was smallest among all genotypes at different stages. The results of this study are in agreement with those of Nigatu et al. (2018) and Przygocka-Cyna et al. (2020) who reported an increased onion bulb length in response to fertilizers application. The length of bulb and bulb yield was significantly influenced by genotypes (Sethupathi, 2019).

Onion Growth and Yield

Bulb diameter

Significant variations in bulb diameter were found among the different genotypes (Figure 2). Bulb diameter increased in all the genotypes with the advancement of growth. Indian Onion-2 had the highest bulb diameter among the genotypes followed by Indian Onion-3, Indian Onion-1, and control. Results revealed that Indian Onion-2 had the highest bulb diameter than other genotypes because of the genetic variation present among the used onion genotypes which may influence the total yield of onion. There are many researchers who stated that bulb diameter is the most influential trait rather than the other yield contributing characters for the improvement of onion crop (Agumas et al. 2014; Ahmed et al. 2020; Gedam et al. 2022). According to Gateri et al. (2018) the abundant proteins can increase the size of the plant, including the number and size of the leaves, and accordingly an increase in photosynthates which are channeled to the bulbs.

Leaf-sheath fresh and dry weight per plant

Significant variations on leaf sheath fresh weight were found among different genotypes (Table 4). Leaf-sheath fresh weight increased in all the genotypes with the advancement of growth. Leaf-sheath fresh weight was found the highest (14.63 g) in genotype Indian Onion-1 which was the highest leaf sheath fresh weight among the genotypes. On the other hand, at the harvest stage, Indian Onion-3 produced the lowest leaf sheath fresh weight (9.43 g) among the genotypes. The present results are consistent with findings of leaf sheath length and diameter which was the highest in Indian Onion-1 may be the studied genotypes are controlled by genetic characters. Roy et al. (2016) found similar results in which significant variations on leaf sheath fresh weight were found among different studied onion genotypes.

Onion genotypes had significant differences in leaf sheath dry weight (Table 4). Leaf-sheath dry weight increased in all the genotypes with the advancement of growth. Leaf-sheath dry weight was found the highest (3.35 g) in genotype Indian Onion-1 which was also produced the highest leaf sheath dry weight among the genotypes. Similarly, leaf sheath dry weight was increased due to the growth characters of the studied onion genotypes in acidic soil (Roy et al., 2016).

Bulb fresh and dry weight per plant

The fresh weight of the bulb varied significantly among the genotypes (Table 4). Bulb fresh weight increased in all the genotypes with the advancement of growth. The highest bulb fresh weight was found in the Indian onion-2 genotype (72.60 g) followed by the Indian onion-3 genotype (71.46 g). The results illustrated that the onion bulb's fresh weight depends on the size and genotype of the onion. The onion bulb is used as a sink for photosynthates accumulation and nutrients availability from the soil which leads to increased bulb fresh weight hence increasing higher onion production (Gateri et al., 2018).

Bulb dry weight is important to maximize crop yield. It varied with different DAP among the genotypes (Table 4). Bulb dry weight increased in all the genotypes with the advancement of growth. The highest bulb dry weight was obtained in Indian onion-3 (10.11 g) and the second-highest weight was found in Indian Onion-2 (9.26 g). Although the highest bulb fresh weight was observed in the Indian Onion-2 genotype the highest dry weight was recorded in Indian Onion-3 because of bulb flesh of the Indian Onion-2 genotype has more water than the Indian Onion-3 genotype. Bulb yield had a positive, linear, and highly significant relationship with plant height, bulb length, and bulb diameter (Islam et al. 2007) which is corroborated with the present findings on onion genotypes.

Root fresh and dry weight per plant

The root fresh weight also varied significantly among the genotypes (Table 4). Root fresh weight increased in all the genotypes with the advancement of growth. The highest (3.53 g) root fresh weight was found in Indian Onion-1 in genotype and the second-highest weight was found in the local variety (2.85 g). Our results on root fresh weight demonstrated that root fresh is not directly associated with the yield of bulb length or bulb diameter. Wide variation of root fresh weight of different onion varieties have been reported (Ashok et al., 2013).

Root dry weight increased in all the genotypes with the advancement of growth. The highest (0.70 g) root dry weight was obtained in the Indian Onion-1 genotype followed by local variety (0.64 g). The present study illustrated that root fresh weight and dry is not correlated with the bulb fresh weight, bulb dry weight, and bulb diameter as well as total yield of onion. And root growth of onion depends on genetic variability and the nature of the soil which is agreed with the results of previous researchers studied in onion genotypes (Gateri et al. 2018; Noor et al. 2011; Roy et al. 2016).

Total yield

Yield is the most important characteristic of a crop and is controlled by genetic and environment. The yield of different onion genotypes was varied at the

Table 3. Bulb length (cm) of onion genotypes at different days after planting (DAP)

Variety	Bulb length (cm)			
	75 DAP	90 DAP	105 DAP	At harvest
Indian Onion-1	3.07c	3.67c	5.37b	6.08b
Indian Onion-2	5.00a	5.83a	6.53a	7.20a
Indian Onion-3	3.90b	4.77b	5.37b	5.91b
Local variety (control)	2.63c	3.33c	3.70c	4.05c
$LSD_{0.05}$	0.76	0.82	0.83	0.80
CV (%)	10.45	9.35	7.91	6.87
Level of significance	**	**	**	**

Note: ** = Significant at 1% level of probability. Values having same letter(s) in a column do not differ significantly at 1% level of significance.

Table 4. Growth parameters of different genotypes of onion

Variety	Leaf sheath fresh weight per plant (g)	Leaf sheath dry weight per plant (g)	Bulb fresh weight (g)	Bulb dry weight per plant (g)	Root fresh weight per plant (g)	Root dry weight per plant (g)
Indian onion-1	14.63a	3.36a	61.47b	6.40c	3.54a	0.70a
Indian onion-2	11.75b	2.07b	72.60a	9.27ab	1.13c	0.41b
Indian onion-3	9.43c	2.07b	71.46a	10.11a	1.09c	0.31c
Control	9.47c	0.39c	28.50c	5.38d	2.86b	0.65a
$LSD_{0.05}$	0.89	0.26	8.58	0.64	0.35	0.06
Level of significance	**	**	**	**	**	**
CV (%)	3.94	6.57	7.34	4.12	7.98	7.16

Note: ** = Significant at 1% level of probability. Values having same letter(s) in a column do not differ significantly at 1% level of significance.

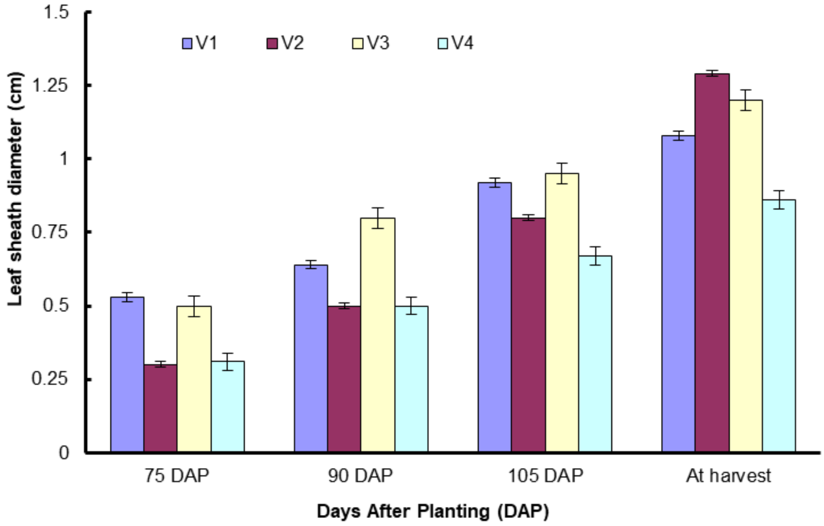

Figure 1. Leaf sheath diameter of onion genotypes at different days after planting; V_1= Indian Onion-1, V_2= Indian Onion-2, V_3= Indian Onion-3, V_4= Control.

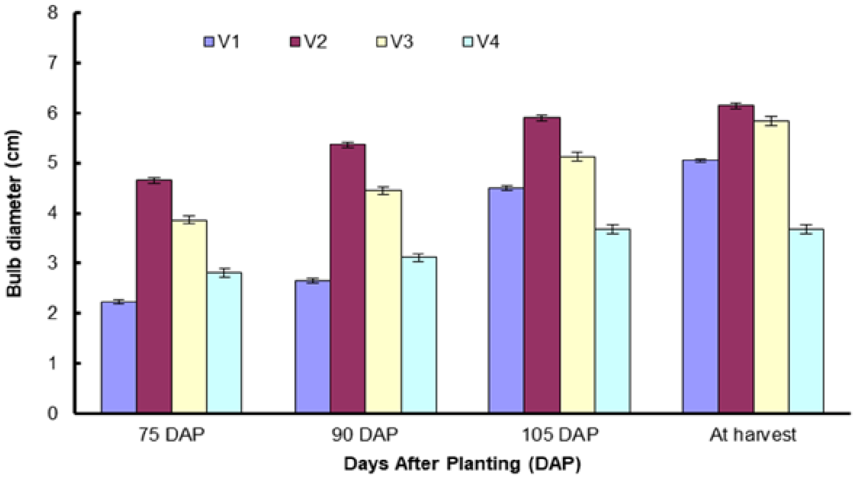

Figure 2. Bulb diameter of onion genotypes at different days after planting (DAP); vertical bar represents SD (0.05). V1= Indian Onion-1, V2= Indian Onion-2, V3= Indian Onion-3, V4= Control.

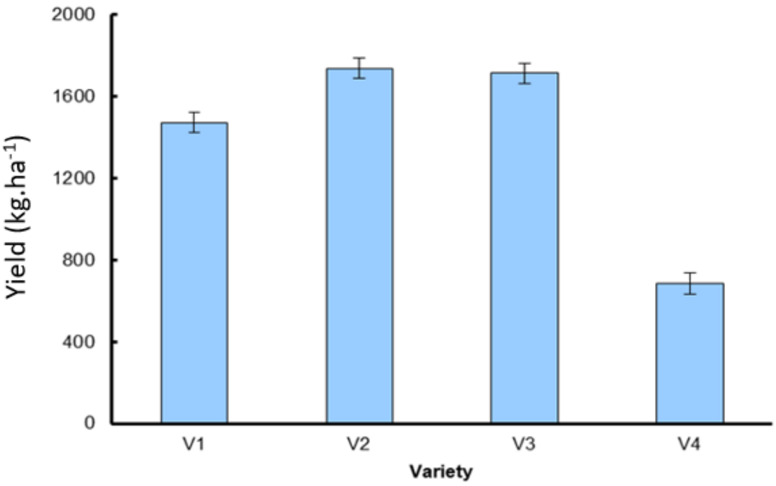

Figure 3. Yield (kg.ha-1) of onion genotypes at harvest; Vertical bar represents SD (0.05). V1= Indian Onion-1, V2= Indian Onion-2, V3= Indian Onion-3, V4= Control.

final harvest (Figure 3). Indian Onion-2 showed the highest yield (1737 $kg.ha^{-1}$) followed by Indian Onion-3 (1712 $kg.ha^{-1}$) and Indian Onion-1(1472 $kg.ha^{-1}$) which was almost three times higher than the yield of local variety(control) (685 $kg.ha^{-1}$). Moreover, the genotype Indian Onion-2 had a high amount of moisture content, so it could be used as salads and vegetables. The present findings indicated that onion bulb weight and bulb diameter are directly related to the total yield of onion which is the most dependable character for onion yield improvement. Generally, the onion production is higher in the appropriate growth condition of soil and environment but drastically reduced with the abiotic stresses like drought, waterlogged and acidic soil conditions. These could be the reason why the present findings yielded a little bit lower compared to the other standard yield producing onion genotypes as we assessed the acidic nature of the soil. Pejic et al. (2011) observed that the yield of the onion bulb was significantly higher in irrigated than in rainfed conditions. Another researcher Noor et al. (2011) stated that the application of boron and lime increases the yield up to 50% in the acidic soil condition. The present results have also corroborated the findings of Anjuma et al. (2019) in the calcareous soil and found the significantly greater economic yield, biological yield, and harvest index from the plants grown on ridges. The onion yield increased progressively with the increase in the rate of sulfur application, but independent of the level of nitrogen application (Przygocka-Cyna et al., 2020).

Conclusion

The present research findings have determined the relationships between growing conditions in the acidic nature of soil and yield traits of onion based on their morphological, growth, and yield. The four onion genotypes differed significantly for all the studied traits. Based on the morphological traits at harvest, the Indian Onion-2 genotype produced the longest bulb (7.20 cm), leaf sheath diameter (1.29 cm), and bulb diameter (6.15 cm) whereas the Indian Onion-1 genotype had the longest leaf sheath (6.41 cm) and wasthe tallest (47.80 cm). In terms of growth parameters, the Indian Onion-2 genotype produced the highest bulb fresh weight (72.6 g) along with total bulb yield (1737 $kg.ha^{-1}$) whereas Indian onion-1 yielded the highest leaf sheath fresh weight (14.63 g), leaf sheath dry weight (3.36 g), root fresh weight (3.54 g) and root dry weight (0.70 g). Therefore, Indian Onion-2 could be selected as the best genotype for the Sylhet region considering its yield and yield contributing characters followed by Indian Onion-3.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

Agumas, B., Abewa, A., and Abebe, D. (2014). Response of irrigated onion (*Allium cepa* L.) to nitrogen and phosphorus fertilizers at Ribb and Koga irrigation schemes in Amhara region, northwestern Ethiopia. *International Research Journal of Agricultural and Social Sciences* **4**, 95-100.

Ahmed, S., Rahim, M.A., Moniruzzaman, M., Khatun, M.A., Jahan, F.N., and Akter, R. (2020). Effect of bulb sizes on the seed yield of two onion (*Allium cepa* L.) varieties. *SAARC Journal of Agriculture* **18**, 51-65

Anik, A. R. and Salam, M. A. (2015). Determinants of adoption of improved onion variety in Bangladesh. *Journal of Agriculture and Environment for International Development* **109**, 71-88.

Anjuma, M. A., Muniba, H., Muhammada, D., Balalb, R. M., and Ahmad, R. (2019). Performance of two onion (*Allium cepa* L.) cultivars under two different planting systems in calcareous soil. *Journal of Horticultural Science and Technology* **2**, 54-59.

Ashok, P., Sasikala K., and Netrapal. (2013). Association among growth characters, yield and bulb quality in onion, *Allium cepa* L. *International Journal of Farm Sciences* **3**, 22-29.

Assefa, A. G, Mesgina, S. H., and Abrha, Y. W. (2015). Effect of inorganic and organic fertilizers on the growth and yield of garlic crop (*Allium sativum L.*) in Northern Ethiopia. *Journal of Agricultural Sciences* **7**, 80.

Begum, R. A., Jahiruddin, M., and Kader, M. A. (2015). Effects of zinc and boron application on onion and their residual effects on mungbean. *Journal of Progressive Agriculture* **26**, 90-96.

Behairy, A. G., Asmaa, R., Mahmoud, M. R., Shafeek, A., Ali, H., and Hafez, M. M. (2015). Growth, yield and bulb quality of onion plants (*Allium cepa* L.) as affected by foliar and soil application of potassium. *Middle East Journal of Agriculture Research* **4**, 60-66.

Bekele, M. (2018). Effects of different levels of potassium fertilization on yield, quality and storage life of onion (*Allium cepa L.*) at Jimma, Southwestern Ethiopia. *Journal of Food Science and Nutrition* **1**, 32-9.

Chattoo, M. A., Magray, M. M., Malik, A. A., Shah, M. D., and Chisti, J. A. (2019). Effect of sources and levels of sulphur on growth, yield and quality of onion (*Allium cepa L.). International Journal of Current Microbiology and Applied Science* **8**, 1462-1470.

Chitdeshwari, T., Jagadeeswari, D., Gnanasundari, R., and Shukla, A. K. (2021). Foliar fertilization of copper on the growth, yield and quality of aggregatum onion (*Allium cepa* L.). *Indian Journal of Pure and Applied Biosciences* **9**, 89-97.

Fikre. K., Yohannes, D. B., and Woldekirstos, A. N. (2021). Effects of blended (NPSB) fertilizer rate on growth, yield, and yield component of onion (*Allium cepa* L.) varieties at Jimma condition by Wolkite, Ethiopia. *Agricultural and Biological Research* **37**, 152-157.

Gateri, M. W., Nyankanga, R., Ambuko, J., and Muriuki, A. W. (2018). Growth, yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and time of topdressing. *International Journal of Plant and Soil Science* **23**, 1-13.

Gedam, P. A., Shirsat, D. V., Arunachalam, T., Ghosh, S., Gawande, S. J., Mahajan, V., Gupta, A. J., and Singh, M. (2022). Screening of onion (*Allium cepa* L.) genotypes for waterlogging tolerance. *Frontier in Plant Sciences* **12**, 727262.

Gedam, P. A., Thangasamy, A., Shirsat, D. V., Ghosh, S., and Singh, M. (2021) Screening of onion (*Allium cepa* L.) genotypes for drought tolerance using physiological and yield based indices through multivariate analysis. *Frontier in Plant Sciences* **12**, 600371.

Gomez, K. A., and Gomez, A. A. (1984). “Statistical Procedure for Agricultural Research”. International Rice Research Institute. John Wiley and Sons, New York, pp. 139-240.

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

Islam, M. K., Alam, M. F., and Islam, A. K. M. R. (2007). Growth and yield response of onion (*Allium cepa* L.) genotypes to different levels of fertilizers. *Bangladesh Journal of Botany* **36**, 33-38.

Izadkhah, M., Tajbakhsh, M., Zardoshty, M. R., and Goratteph, A. H. (2011). Evaluation effects of different planting systems on water use efficiency relative water content and some plant growth parameters in onion (*Allium cepa* L.). *Notulae Scientia Biologicae* **2**, 88-93.

Karim, S. M. R. and Ibrahim, N.R. (2013). Effect of planting time, day length, soil pH and soil moisture on onion. *International Journal of Biology, Pharmacy and Allied Sciences* **2**, 807-814.

Monshi, F.I., Bhuiyan, M.S.U., and Tabassum, R. (2015). Adaptability of litchi germplasm in hilly areas of Sylhet Agricultural University and screening their genetic variation by using RAPD markers. *International Journal of Plant Breeding and Genetics* **9**, 218-227.

Nigatu, M., Alemayheu, M., and Sillassie, A. H. (2018). Optimum rate of NPS fertilizer for economical production of irrigated onion (*Allium cepa* L.) in Dembyia District of Amhara Region, Ethiopia. *Ethiopian Journal of Science and Technology* **11**, 113 – 127.

Noor, S., Ullahr, M. H., and Kawocher, M. A. (2011). Effect of boron and lime on the yield of onion seed in acidic soil. *Bangladesh Journal of Agriculture and Environment* **7**, 24-30.

Paul, S. R., Islam, A. F. M. S., Maleque, M. A., Tabassum, R., and Monshi, F. I. (2021). Growth parameters and yield evaluation of tropical and temperate sweetpotato genotypes under acid soil conditions. *Journal of Food and Agriculture* **14**, 32-49.

Przygocka-Cyna, K., Barłóg, P., Grzebisz, W., and Spizewski, T. (2020). Onion (*Allium cepa* L.) yield and growth dynamics response to in-season patterns of nitrogen and sulfur uptake. *Agronomy* **10**, 1146.

Rahman, H., Islam, A. F. M. S., Maleque, M. A., and Tabassum, R. (2015). Morpho-physiological evaluation of sweet potato (*Ipomoea batatas* L.) genotypes in acidic soil. *Asian Journal of Crop Science*, **7**, 267-276.

Rahman, M.A., Barma, N.C.D., Sarker, M.H., Sarker, M.M.R., and Nazrul, M.M.I. (2013). Adaptability of wheat varieties in strongly acidic soils of Sylhet. *Bangladesh Journal of Agricultural Research* **38**, 97-104.

Roy, A., Islam A. F. M. S., and Tabassum, R. (2016). Morphological features and yield evaluation of onion (*Allium cepa* L.) genotypes in acid soil. *International Journal of Plant Breeding and Genetics* **10**, 116-124.

Sekara, A., Pokluda, R., Vacchio, L. D., Somma, S., and Caruso, G. (2017). Interactions among genotype, environment and agronomic practices on production and quality of storage onion (*Allium cepa* L.), a review. *Horticultural Sciences* **44***, 21-42.*

Sethupathi, S. (2019). Effect of zinc and boron on yield and quality of onion (*Allium cepa* L.) in alfisols of Tamirabarni Tract. *Madras Agricultural Journal* **106**, 293-296.

Tabassum, R., Islam, A. F. M. S., Rahman, M. M., and Monshi, F. I. (2015). Morpho-physiological features and yield attributes of soybean genotypes in acid soil. *Research Journal of Agricultural and Biological Science* **11**, 11-20.

Tekeste, N., N. Dechassa, K,. Woldetsadik, L., Dessalegne, and Takele, A. (2018). Influence of nitrogen and phosphorus application on bulb yield and yield components of onion (*Allium cepa* L.). *The Open Agriculture Journal* **12**, 195.

Wen, L., Ijenyo, M., and Abbey, L. (2021). Onion (*Allium cepa* L.) plant growth response to varying levels of leaf and root damages, a preliminary study. *Horticulture International Journal* **5**, 07-110.

Yan, F., Schubert, S., and Mengel, K. (1992). Effect of low root medium pH on net proton release, root respiration, and root growth of corn (*Zea mays* L.) and broad-bean (*Vicia faba* L.). *Plant Physiology* **99**, 415-21.

Yoldas, F., Ceylan, S., and Mordogan, N. (2019). Effect of chicken manure on yield and yield criteria of onion (*Allium cepa* L.) as second crop. *Applied Ecology and Environmental Research* **17**, 12639-12647.