J Bangladesh Agril Univ 22(4): **412–421**, 2024 https://doi.org/10.3329/jbau.v22i4.78839

ISSN 1810-3030 (Print) 2408-8684 (Online)

Journal of Bangladesh Agricultural University

Journal home page: http://baures.bau.edu.bd/jbau

Research Article

Effects of Varieties and Pot Colours on Boosting Capsicum Growth and Yield

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ARTICLE INFO

Article history
Received: 4 July 2024
Accepted: 24 December 2024
Published: 31 December 2024

Keywords
Intruder,
Bomby,
Purple Beauty,
Pot colour,
Capsicum

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OPEN ACCESS

Abstract

Heat stress can significantly hinder root growth in containerized plant production, a concern that growers often overlook. One potential solution is using different container colors to minimize the effects of sunlight on the heat balance of growing media. The current varieties of capsicum (*Capsicum annuum* L.) often exhibit inadequate stress tolerance, limiting capacity for boosting yield in containerized systems. This research investigated the influence of pot colour and variety selection on the growth and productivity of capsicum in a containerized system within subtropical environments. Twelve treatments were tested, including three capsicum varieties ('Intruder', 'Bomby', 'Purple Beauty') and four pot colours (red, black, white, green). Results showed that 'Purple Beauty' capsicum grown in white pots demonstrated superior vegetative growth and phenological attributes compared to those grown in black pots. Soil temperatures at a depth of 5 cm were found to be 3-4°C lower in white pots and highest in black pots. Specifically, 'Purple Beauty' grown in white pots exhibited a 27.3% increase in plant height and a 22.6% larger leaf area compared to 'Intruder' grown in black pots. Twelve weeks post-transplant, the chlorophyll index (SPAD) was 12.1% higher, and shoot and root dry weights were increased by 49.6% and 55.2%, respectively, for 'Purple Beauty' in white pots compared to 'Intruder' in black pots. Additionally, 'Purple Beauty' in white pots showed a 16.1% higher leaf relative water content (LRWC) and 29.7% less electrolyte leakage. Flowering in 'Purple Beauty' grown in white pots began six days earlier, with 25.6% higher fruit sets and 34.8% fewer flower drops compared to 'Intruder' in black pots. Marketable fruit yields for 'Purple Beauty' in white pots were 35.4% higher than those for 'Intruder' in black pots. These findings suggest that 'Purple Beauty' significantly benefits from cultivation in white pots, leading to improved plant growth, reduced heat stress, and enhanced fruit yield in a containerized production system.

Introduction

Capsicum (*Capsicum annuum* L.) is a relatively new crop in Bangladesh's agriculture, but it is quickly becoming popular due to its high returns, nutritional value, and suitability for urban farming, such as rooftop gardening. As of the 2020-21 fiscal year, capsicum is considered a minor crop in Bangladesh, with only 54.02 acres cultivated, producing 176.51 metric tons (BBS, 2021). Capsicum is sensitive to cold and is primarily grown during the early Rabi season in Bangladesh, making it highly vulnerable to heat stress (Rahman et al., 2022). Research has shown that the physiological and phenological attributes of plants are rigorously affected due to abiotic stresses (Rajametov et al., 2021). It is speculated that approximately 1.5°C temperatures increase in Asia in 2050 due to global warming, posing a significant threat to crop production (IPCC, 2022).

It is a significant challenge to grow plants in a containerized system where roots are badly affected by extreme temperatures. Substrate temperatures above 30°C can significantly slow root growth, which in turn impacts the entire plant growth and development. For instance, in containerized systems, extremely high temperatures especially in root-zone areas can lead to a series of physiological and phenological events such as drops of leaf, and flowers, delays in flowering, checked photosynthesis, less translocation of nutrients and water as well as chlorosis (Markham III et al., 2011). In urban agriculture, vegetables are often grown in containers of various colors without considering the impact of color on root-zone temperature. As global warming causes air temperatures to rise, one of the primary challenges in container cultivation is exposing both roots and shoots to higher temperatures, and heat-tolerant vegetable cultivars are not widely available. Using lighter-colored containers, which reflect

Cite This Article
Hossain, I., Dash, P.K. and Ray, J. 2024. Effects of Varieties and Pot Colours on Boosting Capsicum Growth and Yield. *Journal of Bangladesh Agricultural University,* 22(4): 412-421. https://doi.org/10.3329/jbau.v22i4.78839

more solar radiation and absorb less solar energy, may improve root growth by reducing heat stress (Xu et al., 2023).

Vegetable availability is crucial for food security, with capsicum being a highly valuable commodity for urban markets. Research has shown that crop yields are significantly influenced by the interaction of crop varieties, environmental conditions, and management strategies (Potgieter et al., 2021). Thus, it is crucial to identify appropriate varieties and modulate agronomic practices to boost crop yield and address food security issues meeting the food demand of burgeoning populations (Aldubai et al., 2022). Identifying high-temperature-tolerant varieties could allow for successful cultivation and management of capsicum in pots while maintaining high yields and fruit quality. Rooftop vegetable production is gaining popularity due to its benefits. The choice of cultivars for growing vegetables in any production system is a vital decision to increase business productivity. There is limited information on the performance of capsicum varieties grown in pots of different colors under subtropical climatic conditions. Additionally, few studies have examined the sensitivity of root architecture to temperature changes due to the difficulty of directly observing underground parts (Aidoo et al., 2016). This study hypothesizes that investigating heat-mitigating practices, such as using pots of different colors, can benefit capsicum growth and development. Thus, this study aimed to assess capsicum varieties under various pot color conditions for better growth and yield.

Material and Methods

In this study, three capsicum varieties were used: 'Intruder' (Syngenta India Private Limited, Maharashtra, India), known for its good foliar disease tolerance and high yield; 'Bomby' (Syngenta India Private Limited), recognized for its red color, suitability for long-distance transportation, and excellent shelf life; and 'Purple Beauty' (Sandia Seed Company, Castle Rock, Colorado, USA), valued for its high yield and attractive colors. Capsicum seeds were initially sown in 50-cell polystyrene trays (Kunal Trading Company, Delhi, India) with dimensions of 15 cm height/depth and 12 cm at the top. A mixture of cocopeat (90%) and perlite (10%) enriched with dehydrating bacteria was used to fill the trays (Chandra Prakash and Co., Jaipur, Rajasthan, India). The seedlings were grown for 32 days in a greenhouse before being transplanted into main pots. Seedlings were fertilized every four days using a balanced NPK (20-20-20) fertilizer (Aashi Chem, Surat, Gujarat, India), starting at 21 days after germination.

The experiment was carried out using a complete block design with capsicum varieties ('Intruder', 'Bomby', 'Purple Beauty') as Factor A and pot colors (Red, Black, White, and Green) as Factor B, each treatment replicated three times. The pots (height: 17 cm, top: 15 cm, bottom: 12 cm) were filled with dry sandy clay texture soil (7 kg) consisting of 16% sand, 36% silt, 51% clay, 2.4% organic matter with 38% field capacity (FC) soil moisture and inherent soil salinity of 0.55 dS·m^{-1}. For potting soil preparation, the recommended fertilizer rates for capsicum mentioned in Krishi Projukti Hatboi (2019) were followed. Pots were spaced 60 cm apart with a row spacing of 80 cm. Air temperature and RH during the experimental period were recorded from the nearest weather station (Agromet Station, Khulna District, Khulna, Bangladesh). Plants were manually irrigated when needed to maintain optimum soil moisture content at the desired FC for proper capsicum growth and development.

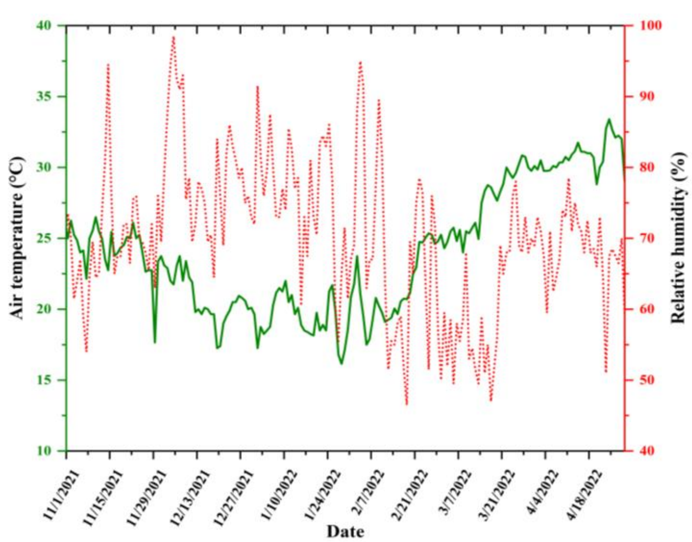

Figure 1. Weather (RH and air temperature) was monitored continuously throughout the experiment.

Plant height was recorded at 12 WAT using a meter scale. For root and shoot biomass determination, the samples were collected treatment-wise, washed, prepared, and dried (72°C) until a constant weight was achieved.

The chlorophyll index (SPAD value) was measured using a SPAD meter (SPAD-502 Plus; Konica Minolta, Japan). Leaf area (cm^2) was measured at 12 WAT by taking top-down images of capsicum plants using a DLSR camera (Nikon AF-S DX; D5500, Thailand). ImageJ software (1.54j) was used to analyze the images as described by Dash et al. (2023b). The temperature of pot soil was recorded daily between 12:00 and 2:00 p.m. at a depth of 5 cm using a digital soil moisture meter (Zoeyec; PMS710 Soil Moisture Meter, USA). Leaf relative water content (LRWC) was measured following the procedure mentioned by Mukherjee et al. (2023). To measure LRWC, fully extended leaves were collected and weighed for their fresh weight (FW) immediately. The leaves were then cut into 2 cm segments, soaked overnight in distilled water, and their turgid weight (TW) was recorded. Finally, the turgid leaves were oven-dried at 70 °C until a constant weight was achieved, and the dry weight (DW) was noted. LRWC was computed finally by this formula:

$$\text{LRWC (\%)} = \frac{FW - DW}{TW - DW} \times 100 \qquad (1)$$

Electrolyte leakage (EL) was estimated according to the procedure stated by Dash et al. (2023b) by this formula:

$$\text{EL (\%)} = \frac{EC1}{EC2} \times 100 \qquad (2)$$

Here, electrical conductivity was computed using the CON 150 conductivity meter (Thermo Scientific; Collyer Quay, Singapore). The membrane stability index (MSI) was evaluated using the CON 150 conductivity meter described by Hayat et al. (2008), with the formula:

$$\text{MSI (\%)} = (1 - \frac{EC1}{EC2}) \times 100 \qquad (3)$$

To monitor flowering characteristics, days to first flowering and 50% flowering were recorded. Similarly, flower set and fruit drop attributes of tagged flowers due to the treatment variation were evaluated. Marketable fruits were harvested twice weekly from January 20 to April 30, 2022. The cumulative yield (FY) per plant was calculated based on these harvests.

The data were analyzed to assess the treatment differences and compared mean by Tukey's HSD test at $p \leq 0.05$ (OriginLab Corporation; Origin 2023, 9.6.5, USA). Similarly, correlation, principal component analysis, heat map, and cluster analysis were also carried out to depict the impact of varieties and pot colour combinations to improve the productivity of capsicum.

Results

Black colour pots resulted in 3-4°C higher soil temperatures than white colour pots (Figure 2). After the black colour (16.7%), green and red colour pots exhibited 6.4% and 9.2% more soil temperatures compared to the white colour pots. Soil temperatures did not appear to be influenced by capsicum varieties. However, capsicum plants survived properly in pot conditions. There was no significant effect of different capsicum varieties and pot colours differences on plant survival (Table 1). Capsicum varieties and pot colours had a significant influence on plant height. 'Purple Beauty' capsicum grown in white colour pots showed 27.3% better plant height, which was significantly higher than 'Intruder' capsicum grown in black colours pots (Figure 3A). At 12 WAT, the 'Purple Beauty' capsicum grown in white colour pots showed 22.6% better leaf area, which was significantly higher than the 'Intruder' capsicum grown in black colours pots (Figure 3B). Similarly, root and shoot biomass were higher when the 'Purple Beauty' capsicum was grown in white colour pots in contrast to the 'Intruder' capsicum was grown in black colours pots (Figure 4). The pot colors significantly affected the chlorophyll index (SPAD value), LRWC, EL, and MSI (Table 1). Capsicum grown in white colour pots showed the better performance to improve physiological traits than those grown in black colours pots. For example, higher SPAD value (%), LRWC (%), and lower EL (%) when capsicum was grown in white colour pots than grown in black colours pots irrespective of capsicum varieties whereas that interaction effect was non-significant for MSI (%) (Figure 5).

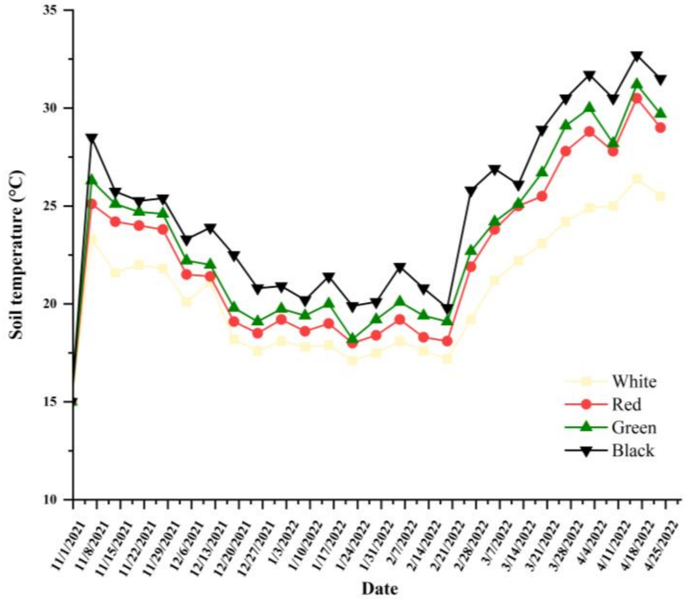

Figure 2. Soil temperature was recorded from each colour of pot at a depth of 5 cm.

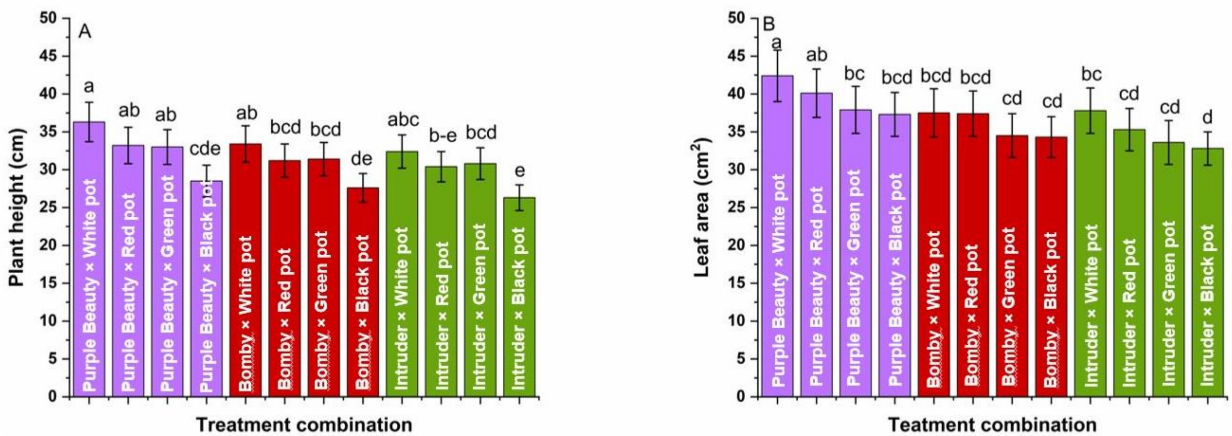

Figure 3. Effect of capsicum varieties and pot colours on plant height (A) and leaf area (B).

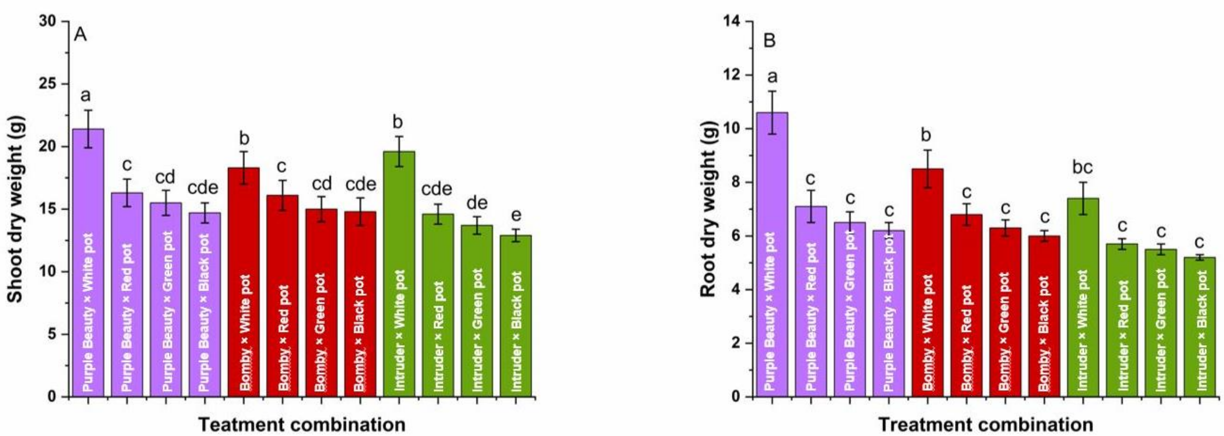

Figure 4. Effect of capsicum varieties and pot colours on shoot dry weight (A) and root dry weight (B).

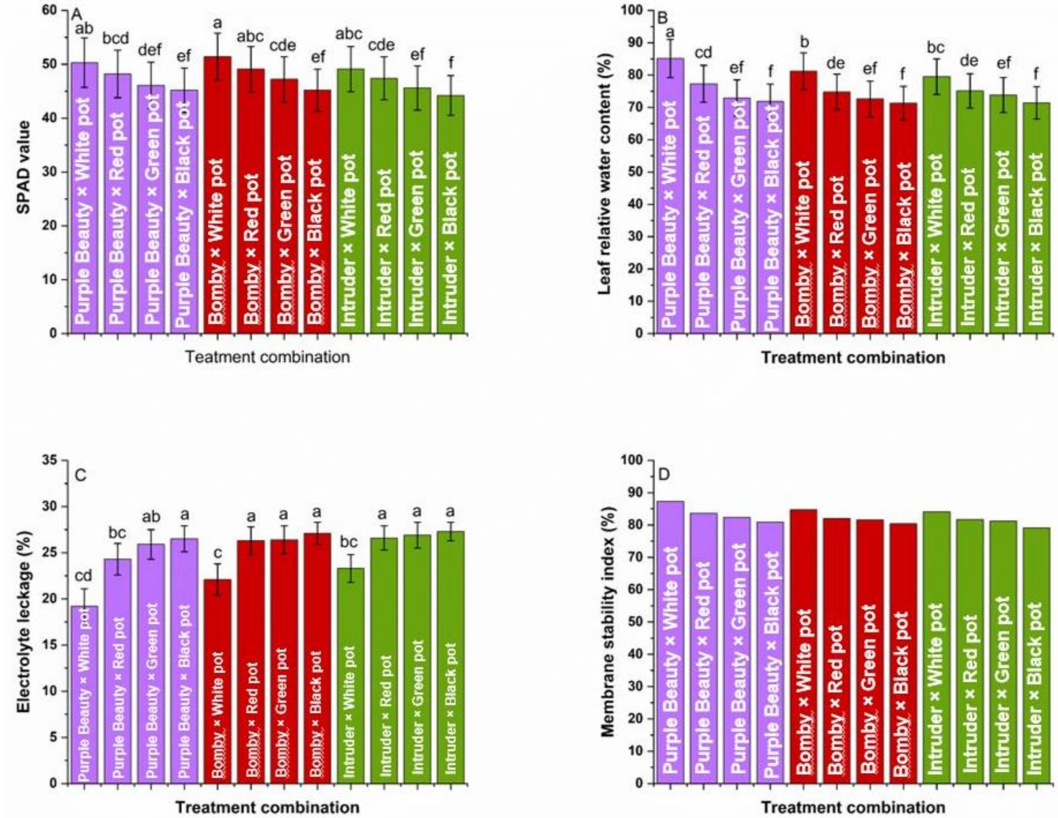

Figure 5. Effect of capsicum varieties and pot colours on chlorophyll index value (SPAD) (A), LRWC (B), EL (C), and MSI (D).

Table 1. ANOVA (two-way) represents the significance level of the main factor (varieties and pot colours) and interaction effect (varieties × pot colours) on the growth, physiological, phenological, and capsicum fruit yield

Traits	Capsicum variety (A)	Pot colours (B)	A × B
Growth parameters			
Plant survival (%)	NS	NS	NS
Plant height (cm)	**	**	**
Leaf area (cm^2)	**	**	*
Shoot dry matter (g $plant^{-1}$)	*	**	*
Root dry matter (g $plant^{-1}$)	*	**	*
Physiological traits			
Chlorophyll index (SPAD value)	*	*	*
Leaf relative water content (%)	*	*	*
Electrolyte leakage (%)	*	*	*
Cell membrane stability index (%)	*	*	NS
Phenological attributes			
Days required to first flower	NS	**	*
Days required to 50% flower	*	**	**
Flower drop (%)	NS	**	*
Fruit set (%)	NS	**	**
Fruit yield and other trait			
Fruit yield (g $plant^{-1}$)	*	**	**
Soil temperature (°C)	NS	**	**

NS, *, ** denote NS non-significant, $p < 0.01$, and $p < 0.05$, respectively.

There were significant capsicum varieties and pot colours effects on 50% flowering, which differed among the capsicum varieties and pot colours as shown in Table 1. Flowering occurred earlier by 6 days in ‘Purple Beauty’ capsicum grown in white pots than in 'Intruder' capsicum grown in black pots (Figures 6A and 6B). Fewer flower drops a reduction of 34.9% were observed in the ‘Purple Beauty’ capsicum grown in white pots than in the 'Intruder' capsicum grown in black pots (Figure 6C). Also, ‘Purple Beauty’ capsicum grown in white colour pots exhibited higher fruit sets compared to other treatment combinations (Figure 6D).

Marketable fruit yield was significantly influenced by capsicum varieties and pot colours (Table 1). 'Purple Beauty' capsicum grown in white colour pots had 35.4% higher marketable fruit yield than the 'Intruder' capsicum grown in black colours pots (Figure 7).

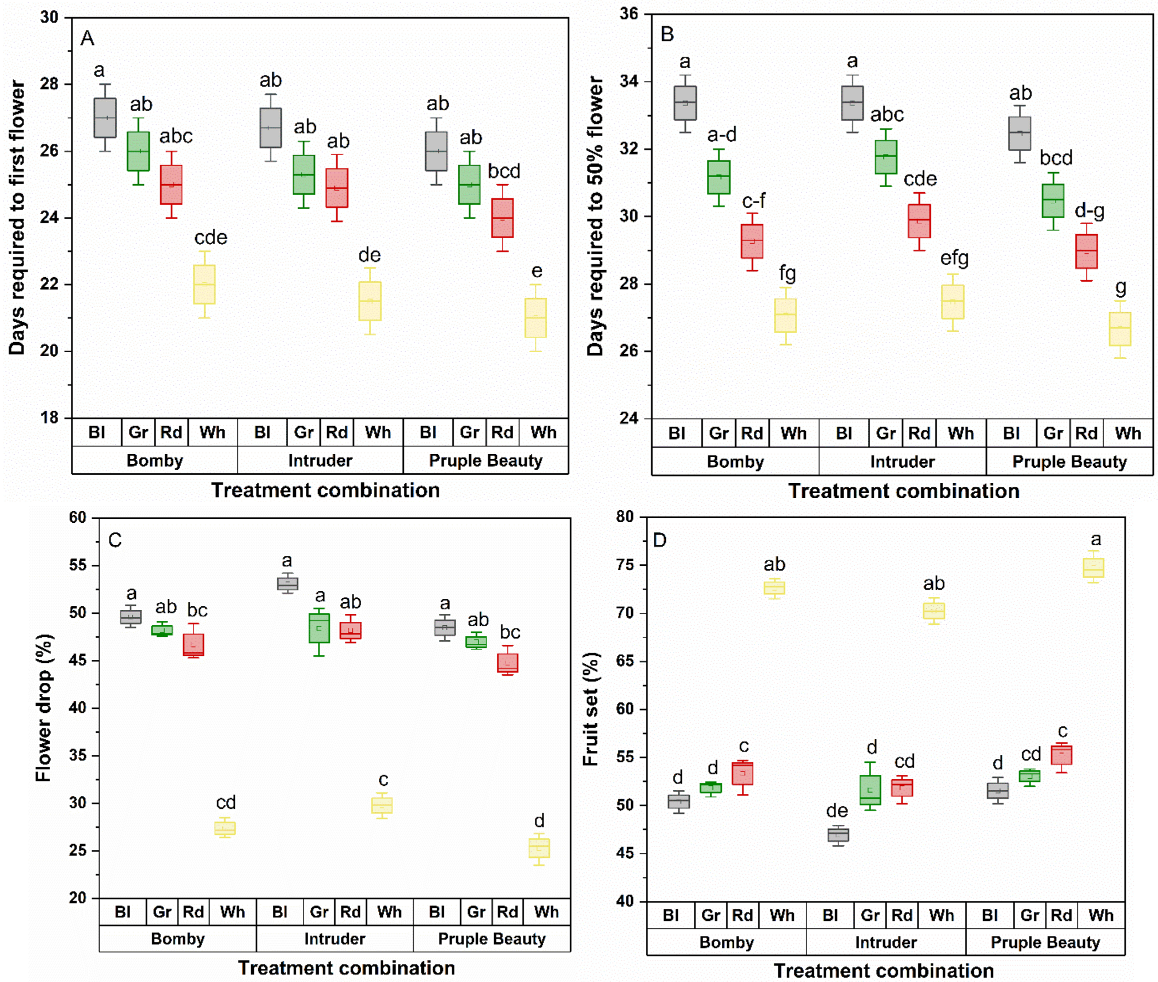

Figure 6. Effect of capsicum varieties and pot colours on phenological traits [First flower (A), 50% flower (B), drop of flower (%) (C), and set of fruit (%) (D)].

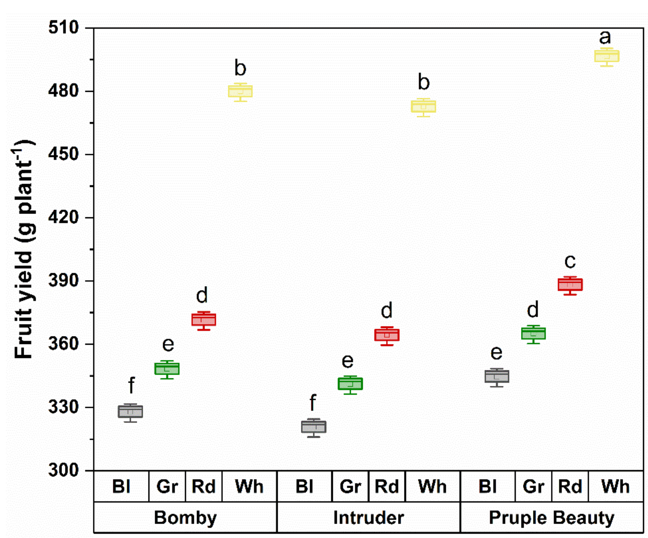

Figure 7. Effect of capsicum varieties and pot colours on fruit yield.

The growth, physiological, phenological, and yield parameters were positively or negatively correlated with each other illustrate in Figure 8. Plant survival (PSurv) showed significant positive correlations with leaf relative water content (LRWC). On the other hand, it exhibited a significant negative correlation with days required to first flower (D1F) and soil temperature (STem). Plant height (PHeight) was positively correlated with leaf area (LArea), SAPD (chlorophyll index), LRWC, SDW, RDW, and FYield. In contrast, it exhibited a significant negative association with EL, D1F, D50F, and STem. The chlorophyll index (SPAD) was positively linked with LRWC, SDR, RDW, and FYield. Additionally, LRWC showed positive correlations with MSI, FSet, SDR, RDW, and FYield. EL was positively linked with flower drop (FDrop) and Stem. The membrane stability index had a positive association with FSet, SDR, RDW, and FYield. D1F and D50F were positively linked with STem. Similarly, FDrop was positively connected with STem. FSet had a positive association with SDR, RDW, and FYield. SDW was positively linked with RDW, and FYield. Also, RDW had a positive association with FYield and a negative correlation with Stem.

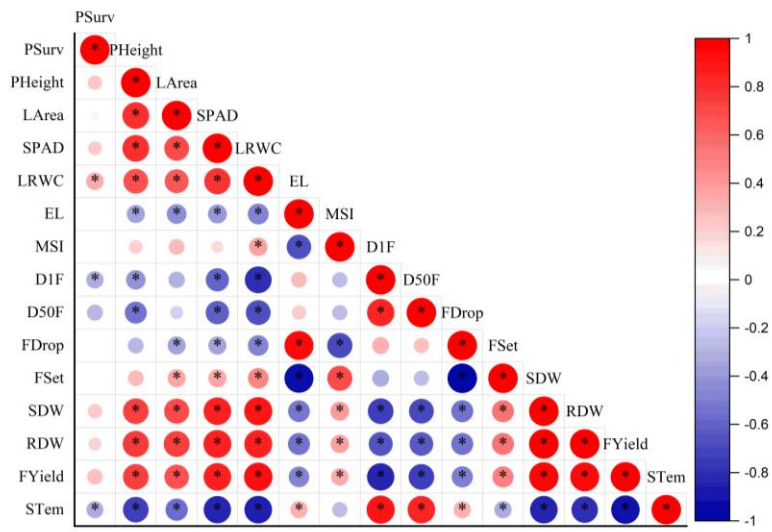

Fig. 8. A correlogram was constructed to display the relationships among average values of variables under pot conditions. The concentration and circle size denote mode the of correlation, with dark red showing strong positive correlations and intense blue indicating strong negative correlations. Cells marked with an asterisk indicate correlations significant at the $p < 0.05$ level.

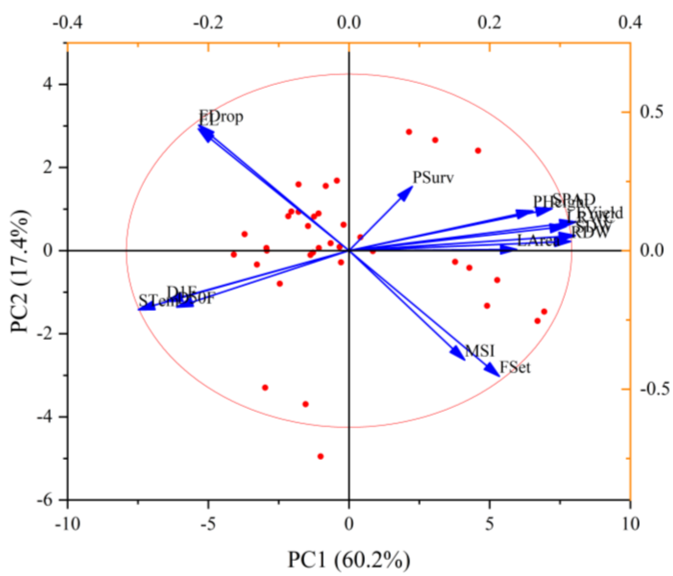

Figure 9. PCA biplot demonstrates connections among the parameters affected by capsicum varieties and pot colors under pot conditions. The biplot visualizes relationships between PC1 and PC2, highlighting how different parameters and treatments are interrelated in the dataset.

PCA was carried out to assess the variability and recognize the main traits to explain deviation. Among the principal components (PCs), PC1 explained 60.2% and PC2 justified 17.4% variability, as shown in Figure 9. The biplot perfectly illustrated the loading vectors and the analyzed variables. This graph demonstrated that parameters like plant survival, plant height, leaf area, fruit yield, fruit set, LRWC, MSI, SPAD value, SDW, and RDW were positively associated. On the contrary, parameters like flower drop, first and 50% flowering, EL, and soil temperature were negatively correlated. The results stated that capsicum varieties and pot colours had a significant effect on modulating plant growth, physiology, phenology, and yield attributes under the containerized system.

Similarly, a heatmap that demonstrates the links between variables impacted by capsicum varieties and pot colours combinations differences are shown in Figure 10. The variables were clustered based on their relations. The clusters were easily differentiated based on the grouping of the variables. The heat tolerant varieties and pot colours group included ‘Purple Beauty’ and 'White colour pot.' This combination exhibited tolerance to heat stress conditions in containerized production systems, mainly categorized by their improved growth, physiological and phenological traits, and yield. The heat-tolerant group exhibited less EL, and less drop of flower denotes blue color, and higher fruit yield per plant represents red color. On the contrary, the heat-sensitive group comprised 'Intruder and ‘black colour pot' which showed more EL, prolonged flowering, more flower drop, and lower yield.

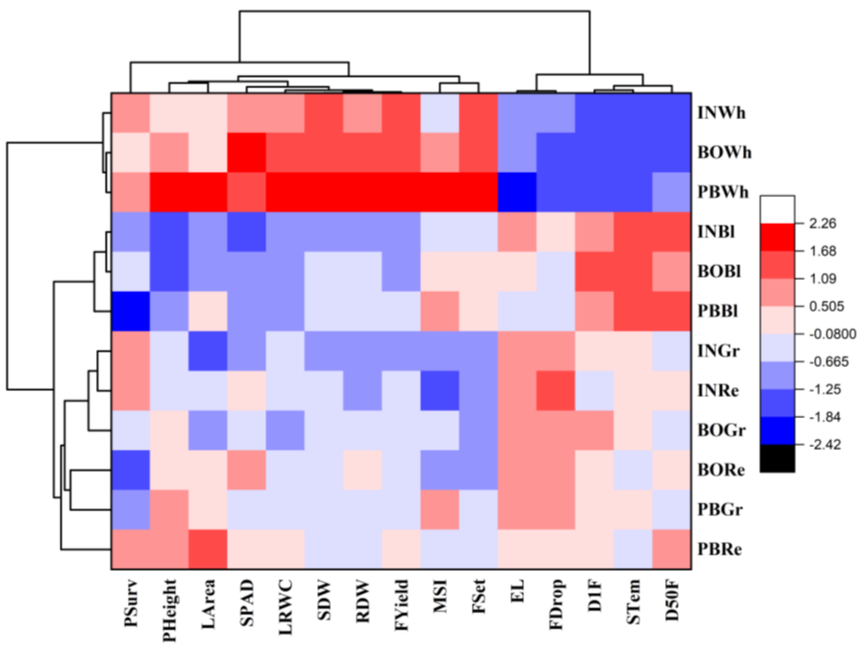

Figure 10. A heatmap and clustering analysis were conducted to visualize capsicum varieties and pot color combination effects on evaluated variables. The treatment combination belongs to each row and the variables represent each column. Blue and red colours in the cells indicate low and high relative values, respectively.

Discussion

The findings from this study demonstrated the heat-tolerant capsicum variety properly matched to specific pot colors in subtropical environments. While previous studies have extensively examined capsicum in open-field conditions (Suhel et al., 2020), relatively few efforts have focused on assessing capsicum varieties and pot color combinations for containerized cultivation in subtropical climates. This study observed significant variations among capsicum varieties in growth and development attributes. These variations offer to identify suitable capsicum varieties and pot colors better suited for containerized production systems. Daily soil temperatures varied significantly among pots of different colors. These temperatures can be high enough to hinder root growth in several species (Markham III et al., 2011). Soil temperatures in white pots were 3-4°C lower than in black pots, likely due to the higher albedo of white pots. Higher soil temperatures in red and green pots were observed compared with white pots, indicating a greater potential for root damage. Dash et al. (2022a) reported higher soil temperatures under black mulch compared to white mulch, suggesting that white mulch provides a cooler atmosphere pertinent to root growth in strawberries, whereas black mulch provides the warmest environment consistently. Soil temperature increased root biomass decreased, and white pots dominated over other colour pots for root biomass. The results revealed the negative effect of higher root zone temperature on the proliferation of root growth.

High temperatures negatively impact on the growth of the plants resulting in less shoot dry weight observed in black colour pots than in white pots. The present study demonstrates that lower root temperatures in white pots lead to improved root physiological endevour, resulting in proper water and nutrient absorption from the rhizosphere. This leads to higher physiological activity and more dry matter production, as previously observed by Markham III et al. (2011).

This study shows that SPAD, LRWC, EL, and MSI are highly influenced by pot colors and root temperature variations. For instance, 'Purple Beauty' capsicum grown in white pots exhibited a higher chlorophyll index and LRWC compared to capsicum grown in black pots. It is speculated that white pots, with their lower soil temperatures, promote better water and nutrient uptake by encouraging root spread into the soil. Lower soil temperatures, especially in heat stress conditions, enhance aeration in the rhizosphere and ensure higher LRWC, as suggested by Rabbi et al. (2021). Our findings indicate that capsicum plants grown in white pots exhibit downregulated EL, resulting in an increase in MSI compared to plants grown in black pots. A higher MSI in plants grown in white pots implies that lower root zone temperatures effectively preserve cell membrane integrity by reducing solute leakage from the cytoplasm. This aligns with the findings of Cabo et al. (2019), who stated that EL is significantly influenced by K+ efflux from plant cells and lipid peroxidation caused by reactive oxygen species (ROS). These negative effects may be reduced in plants grown in white pots, particularly under abiotic stress conditions, as suggested by Demidchik (2015).

It is assumed that capsicum varieties resilient to heat stress can survive in unfavourable conditions by adjusting to surrounding environments. Thus, selecting suitable varieties and the right pot color is a crucial initial step in capsicum production, especially in containerized systems within urban agriculture settings. Under stressful conditions, plants undergo several physiological changes resulting in poor plant growth and development. Pereira et al. (2013) reported that a reduction in stomatal conductance has led to a significant decrease in net photosynthesis in rice. 'Purple Beauty' capsicum varieties grown in white pots exhibited an accelerated flowering time in this study. This variety possibly settled more quickly in white colour pots and adopted the environments rapidly alleviated heat stress aid to strong root facilitated more physiological activities than other treatment combinations.

As described by Borghi and Fernie (2020), heat stress can negatively impact the sensitive parts of a flower (anthers and pollen), resulting in lower fruit set in tomatoes. Heat stress modulates the physiological events in plants resulting in lower fruit yield (Osei-Bonsu et al., 2022). The best performance seen in the 'Purple Beauty' capsicum variety grown in white pots in our study suggests that this particular variety and pot color efficiently mitigate heat stress and allow plants for better growth and productivity. The 'Purple Beauty' capsicum variety grown in white pots exhibited maximum fruit yield because the cooler soil temperatures in white pots promoted increased leaf greenness, resulting in higher net photosynthesis and, consequently, a higher fruit yield. Our findings align with the positive correlation between chlorophyll content, leaf greenness, net photosynthesis, and fruit yield described by Das et al. (2021). The impact of capsicum varieties and pot colours for boosting growth and yield efficiently demonstrated in this study through correlation analysis, principal component analysis, heatmap, and cluster analysis.

Conclusion

Containerized vegetable cultivation using white pots, particularly in urban agriculture, emerges as a highly viable solution to effectively address food security issues. Employing white pots and compatible capsicum varieties, such as ‘Purple Beauty’, in containerized systems holds the potential to significantly enhance agricultural productivity. These findings could be crucial for city dwellers, nursery owners, and sustainable urban agriculture initiatives. Given that the use of white pots instead of black pots may be more effective in abiotic stress conditions. Cultivating ‘Purple Beauty’ capsicum in white pots could be a prime approach for containerized vegetable production systems, helping to mitigate profit loss and quality reduction caused by heat stress.

Acknowledgment

The Agrotechnology Discipline of Khulna University provided in-kind support for this study. This research was supported monetarily by the Ministry of Science and Technology (MOST) of Bangladesh (BS 271).

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