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ARTICLE

Effects of transplanting date and salinity stress on yield and yield-attributing traits of perilla (*Perilla frutescens* (L.) Britton)

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ABSTRACT Perilla (*Perilla frutescens* (L.) Britton) is a potential oilseed crop with high nutritional and medicinal value. Its productivity is strongly influenced by transplanting time and soil salinity. The objectives of the study are to determine the optimal transplanting time and to assess the impact of salinity on yield-attributing traits. Two separate experiments were conducted to fulfill the objectives. In the first experiment, seedlings were transplanted on three dates (August 1, August 26, and September 11) following a randomized complete block design with three replications. Importantly, transplanting of perilla seedlings on August 1 resulted in a significant delay in flowering and maturity, whereas plant height (PH), number of branches per plant (NBP), number of inflorescences per plant (NIP), and seed yield per plant (SYP) increased significantly compared to other transplanting dates. The second experiment was conducted under pot culture conditions where three salinity treatments, namely control, 10 dS m^{-1}, and 20 dS m^{-1} were applied through irrigation water at the reproductive stage of plant growth and continued for three weeks. Imposition of salinity stress resulted in a significant decrease in days to maturity, PH, NBP, NIP, inflorescence length, 1000-seed weight, SYP, and SPAD values, while the highest negative effects were recorded at 20 dS m^{-1} salinity. Overall, early August is the optimum transplanting time for maximizing yield in perilla, and both 10 and 20 dS m^{-1} salinity stress had negative effects on yield-attributing traits, with stronger reductions at 20 dS m^{-1}. Further studies under field conditions will give more insight into the salinity tolerance of perilla for formulating sustainable management strategies.
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INTRODUCTION

Perilla (*Perilla frutescens*) is an annual, short-day, aromatic herbaceous oilseed crop belonging to the Lamiaceae family, traditionally valued for its medicinal and culinary properties (Wu et al. 2023). It has a long history of cultivation throughout East Asia for a variety of traditional uses, with China being the primary center of genetic diversity (Pusadee et al. 2017; Ahmed and Al-Zubaidy 2020). Since then, its agricultural presence has spread to the US, Africa, and Europe, where it is becoming well-known due to its growing economic significance (Rouphael et al. 2019). Perilla is often divided into two main kinds based on morphological characteristics and usage: *P. frutescens* var. *frutescens* (green-leaved, widely known as Perilla Green) and *P. frutescens* var. *crispa* (purple-leaved, commonly known as Perilla Red) (Lee and Ohnishi 2001). In Korea, the green-leaved cultivar is commonly grown as a leafy crop and for oil extraction (Nitta et al. 2003). According to Zhang et al. (2012) and Lin et al. (2020), perilla exhibits significant ecological adaptability, thriving in open, sunny, humid conditions and exhibiting complex responses to abiotic challenges such as soil salinity, temperature, and drought stress.

Perilla has recently gained attention for its rich phytochemical composition and associated health benefits. It contains important compounds such as phenolic acids, flavonoids, and polyunsaturated fatty acids, particularly α-linolenic acid (54–64%) and linoleic acid (14%) (Dhyani et al. 2019). Due to its high omega-3 content, perilla is considered a nutritionally valuable crop and has long been used in traditional Asian medicine for various therapeutic purposes (Von Schacky 2000). Perilla may also serve as a natural vitamin E substitute (Pusadee et al. 2017). It is used in traditional Asian medicine to treat respiratory problems, digestive issues, seafood poisoning, and to maintain energy balance (Bahuguna and Prasad 2014).

In addition to its nutritional and therapeutic benefits, perilla serves as a functional oilseed crop in Bangladesh, where edible oil production is insufficient to meet national needs. Bangladesh only covers 10-15% of its annual edible oil needs through domestic production, relying mainly on imports of crude soybean and palm oil. Strengthening local oilseed production is necessary to reduce import dependency and improve health security. Perilla has emerged as a promising functional crop due to its tolerance to abiotic stresses and potential for high-quality edible oil. However, perilla yield is a complex quantitative trait that is highly influenced by agronomic practices (e.g., transplanting date and defoliation) and environmental factors such as soil salinity and temperature stress (Shen et al. 2018; Salachna et al. 2019).

Research on perilla and related crops highlights several agronomic factors that play a significant role in their growth. Among those, transplanting date plays a critical role in determining crop growth and yield. As a short-day plant, perilla's flowering is strongly affected by photoperiod and plant age (Yun et al. 2023). In Bangladesh, the crop is most suited for cultivation during the Kharif-II season (mid-July to mid-November), with flowering normally occurring from the last week of September to the first week of October, coinciding with the natural shortening of day length. Furthermore, plants are subjected to a variety of environmental challenges, such as drought, heat, heavy metals, salt, flooding, cold, and UV radiation, which limit agricultural yields and development worldwide (Mareri et al. 2022; Abbas et al. 2024). Soil salinity affects around 20% of irrigated land worldwide and is expected to rise with climate change (Munns and Tester 2008; Machado and Serralheiro 2017). In Bangladesh, 30% of cultivable land lies in coastal areas, where 53% is impacted by salinity due to tidal flooding, storm surges, and saline water intrusion (Rasel et al. 2013). Cropping intensity in the coastal areas of Bangladesh is very low as compared to the national average. Incorporating short-duration, high-yielding, and salt-tolerant perilla into the cropping patterns of coastal regions holds significant potential to mitigate food and nutritional insecurity through diversification of the cropping system. Under salinity stress, the accumulation of Na^+ and Cl^- hinders the intake of water and nutrients, leading to stunted development, early maturity, and decreased yield (Negrão et al. 2017). To combat salinity stress, plants either eliminate excess salt or adjust to osmotic imbalance and ion toxicity (Deinlein et al. 2014; Liang et al. 2018). It has been reported that mild to moderate salinity can increase secondary metabolites such as rosmarinic acid and polyphenols, whereas increasing salinity stress decreases perilla germination and growth (Zhang et al. 2012; Rouphael et al. 2019). Despite the potential of perilla, limited research has been conducted on how transplanting date/time and salt stress affect yield and yield-attributes in Bangladesh's agroecological conditions.

This study aimed to determine the optimum transplanting date for maximizing seed yield of perilla under Bangladesh conditions and to evaluate the effects of different levels of salinity on its growth, yield, and yield-attributing traits. We hypothesized that variation in transplanting dates and salinity levels would significantly influence the phenological development and yield-attributing traits of perilla.

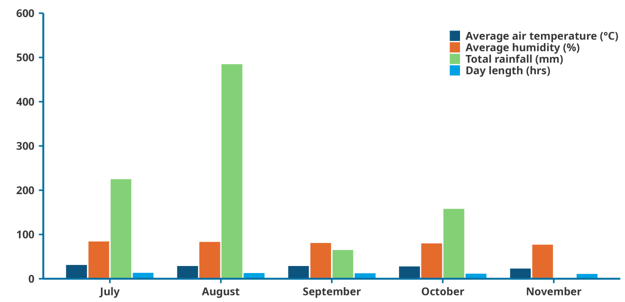

Figure 1. Selective weather characteristics during the perilla growing season of 2021 in Mymensingh, Bangladesh. Source: Department of Irrigation and Water Management, BAU (2021)

MATERIALS AND METHODS

Experiment 1: Effects of transplanting dates on yield-attributing traits of perilla

Plant materials, site, and season

The experiment was conducted using the SAU Perilla-1 variety at the Farm Research Laboratory of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh, during the Kharif-II season (July 2021 to November 2021). The experimental area's land was medium high, belonging to the Agro-Ecological Zone-9 (Old Brahmaputra Flood Plain). The soil's pH was between 6.5 and 6.7, and the texture was sandy loam. The weather report for the first experimental period is presented in Figure 1.

Land preparation and fertilization

With a power tiller, the experimental field was prepared by plowing and cross-plowing. During land preparation, weeds and rubbish were cleared. To make the soil to an appropriate tilth and level, proper laddering was done. Fertilizers such as cow dung, urea, triple superphosphate (TSP), and muriate of potash (MP) were applied at rates of 4000, 125, 150, and 50 kg ha^{-1}, respectively.

Design and layout of the experiment

The experiment was conducted following a randomized complete block design (RCBD) with three replications. The individual plot size was 3.5 m x 2 m. In each plot, five rows were prepared at a distance of 40 cm, and eight seedlings were planted, keeping plant to plant distance of 40 cm apart. Block to block distance was 60 cm.

Seedlings raising and transplanting in the field

Seeds were sown in a large plastic tub filled with field soil, and the seedlings were grown with proper care. After that, 25-day-old seedlings were transplanted in the field on August 1, August 26, and September 11, and were considered as first transplanting (T1), second transplanting (T2), and third transplanting (T3), respectively. The selected transplanting dates (August 1, August 26, and September 11) were chosen to represent early, mid, and late planting windows within the Kharif-II season in Bangladesh. This period coincides with progressive changes in photoperiod, temperature, and rainfall, which are known to influence the growth and flowering behavior of short-day crops like perilla.

Intercultural operation

To maintain suitable growing conditions, agronomic practices such as gap filling, weeding, and irrigation were done whenever necessary. To control insect infestation, the commercial insecticide Tido Plus was sprayed twice during the growing period according to the manufacturer's recommendation. Other intercultural operations were carried out when needed.

Data collection and analysis

Data on eight quantitative traits were recorded: days to first flowering (DFF), days to maturity (DM), plant height (PH), number of branches per plant (NBP), number of inflorescences per plant (NIP), inflorescence length (IL), 100-seed weight (100-SW), and seed yield per plant (SYP). Data were collected from ten randomly selected plants from each replicate.

Minitab 19 Statistical Software was used to do statistical analysis on the collected data. To evaluate the differences between three different transplanting dates, an analysis of variance (ANOVA) was used for each attribute. The Tukey test was used to separate the means at a 5% probability level. The data were analyzed using a RCBD with three replications. Each treatment mean was based on observations from 30 plants (10 randomly selected plants per replication).

Experiment 2: Effects of salt stress on yield-attributing traits of perilla

Plant materials, site, season, and experimental design

During the period of Kharif-II season (July-November 2024), the experiment was conducted at the net house of the Farm Research Laboratory of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh, using SAU Perilla-1 variety. The experiment was conducted under pot culture conditions following a RCBD with three replications and three treatments: control and two different levels of salinity stress, S1 (EC = 10 dS m^{-1}) and S2 (EC = 20 dS m^{-1}). Total of 15 pots were used for each treatment, with one plant maintained per pot. Each replication consisted of five pots representing five individual plants.

Seedling raising, pot preparation, and seedling transplanting

Perilla seeds were sown in a large plastic tub on July 6, 2024, for raising seedlings and continued to grow for 35 days. After 35 days, the seedlings were transplanted into a small-sized earthen pot filled with field soil. The pot size was 24 cm in diameter and 18 cm in depth. Each pot was loaded with 7 kg of field soil. Initially, soil was collected from the field, and weeds and trash were taken out, and the soil was gently ground. The soil was prepared by mixing the recommended doses of cow dung, urea, TSP, MP, gypsum, zinc sulphate, and boric acid at equivalent rates of 4000, 125, 150, 50, 100, 10, and 10 kg ha^{-1}, respectively. Finally, each pot was filled with 7 kg of soil mixture, and 35-day-old seedlings were transplanted into the earthen pot. Each pot was maintained with a single seedling and received a light irrigation after transplanting.

Imposition of salt stress

Salt stress was applied during the reproductive stage (just before the first flower opening) using saline irrigation water (EC = 10 dS m^{-1} and 20 dS m^{-1}), while preserving 80% field capacity. The saline solution was prepared by dissolving analytical-grade NaCl in tap water. Pre-weighed NaCl was gradually added to a known volume of water and thoroughly mixed until complete dissolution. Electrical conductivity (EC) was measured using a calibrated EC meter and adjusted to the desired levels. The plants were irrigated with saline irrigation water directly at two-day intervals and continued for three weeks. The plants were then grown according to standard cultural procedures and harvested at maturity. The amount of water applied was adjusted based on pot weight to keep the soil moisture close to 80% of field capacity across all treatments. Field capacity of the soil was determined using a gravimetric method by saturating the soil with water, allowing it to drain for 48 hours, and then measuring its moisture content.

The selected salinity levels (10 and 20 dS m^{-1}) were chosen to represent moderate and high salinity conditions commonly found in coastal regions of Bangladesh (Abdullah et al. 2026). Salinity stress was imposed at the reproductive stage because this phase is particularly sensitive to environmental stress and directly determines

Table 1. Analysis of variance (mean square) of different transplanting dates on yield-attributing traits of perilla

Sources of variation	DFF	DM	PH	NBP	NIP	IL	100-SW	SYP
Treatment	432.11***	577.44***	3927.52***	104.31***	25197.3***	52.22*	0.00749*	604.95***
Replication	0.78	0.78	2.93	0.19	1.6	5.69	0.00008	0.67
Error	1.78	1.44	3.99	0.44	80.8	4.77	0.00099	8.14

Note: * and *** indicate significant at 5% and 0.1% level of significance, respectively. DFF=Days to first flowering; DM=Days to maturity; PH=Plant height; NBP=Number of branches per plant; NIP=Number of inflorescences per plant; IL=Inflorescence length; 100-SW=100-seed weight; SYP=Seed yield per plant.

final yield through its effects on flowering, seed set, and grain filling. Imposing stress at this stage allows for a clearer assessment of its impact on yield-attributing traits, minimizing confounding effects associated with earlier growth stages. This approach is commonly used in stress physiology studies to evaluate the yield response of crops under controlled stress conditions (Vispo et al. 2015).

Intercultural operations

Agronomic practices, including weeding and staking, were done to maintain ideal growing conditions. To control insect infestation, the commercial insecticide Tido Plus was sprayed twice during the growing period according to the manufacturer's recommendation. Additional intercultural operations were done whenever necessary.

Data collection and analysis

Data were recorded for seven yield-related traits: days to maturity (DM), plant height (PH), number of branches per plant (NBP), number of inflorescences per plant (NIP), inflorescence length (IL), 1000-seed weight (1000-SW), and seed yield per plant (SYP). SPAD values were recorded 18 days after the onset of salt stress treatment. For each treatment, data were collected from five plants per replication, giving 15 observations per treatment. Minitab 14 (Minitab Inc., State College, Pennsylvania) statistical software was used for analyzing data. To differentiate the treatment means, the Tukey test was used at 5% probability level. For Experiment 2, each treatment consisted of three replications with five selected plants per replication.

RESULTS

Experiment 1: Effect of transplanting date on yield and yield-attributing traits of perilla

Table 1 presents the results of the analysis of variance of different transplanting dates on yield-attributing traits of perilla. The results revealed highly significant differences ($p < 0.001$) among treatments for all traits studied, except for inflorescence length and 100-seed weight, which exhibited significant variation at the 5% probability level. The mean performance of the perilla for yield-attributing traits on three different transplanting dates is displayed in Figure 2. The same genotype (SAU Perilla-1) was used in both Experiment 1 and Experiment 2, and

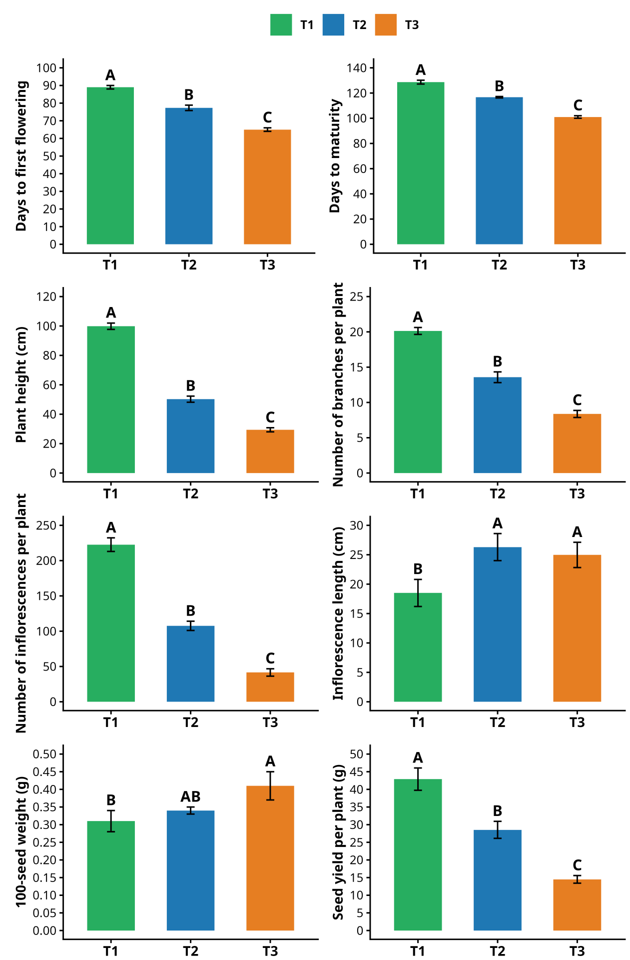

Figure 2. Effects of transplanting dates on yield and yield-attributing traits of perilla. Each bar represented as the mean values ± standard deviation of three replicates. Different letters indicate significant differences following Tukey's test at $p < 0.05$. Here, T1= Transplanting date August 1; T2= Transplanting date August 26 and T3= Transplanting date September 11.

Figure 3. Phenological appearance of the plants perilla at the flowering stage established from different dates of transplanting. Here, T1= transplanting date August 1; T2= transplanting date August 26 and T3= transplanting date September 11.

seeds were obtained from a single uniform seed lot to ensure experimental consistency.

Days to first flowering

Days to first flowering showed a significant variation due to the differences in transplanting dates (Fig. 2). Maximum days (89.00) for first flowering were recorded in the plants established from the first transplanting date (T1 = August 1), followed by the second (T2 = August 26) and third date (T3 = September 11) of transplanting (77.33 and 65.00 days, respectively). Plants grown from the second and third transplanting dates showed a decreasing trend of the requirement of days to first flowering (13.11 and 26.97% decrease as compared to the plants grown from the first transplanting) (Fig. 2).

Days to maturity

Significant variation in days to maturity was also observed due to differences in transplanting dates. Maximum days required to maturity (128.67) were recorded in the plants grown from early transplanting (August 1), followed by late transplanting (August 26 and September 11) (116.67, and 101.00 days, respectively) (Fig. 2). Like days to first flowering, days to maturity also showed a decreasing trend with the delay of transplanting (9.33 and 21.50% decrease as compared to the first transplanting) (Fig. 2).

Plant height

Plant height showed a significant variation with respect to the differences in the transplanting dates (Fig. 2). The highest plant height (99.83 cm) was recorded in the plants established from the first transplanting (August 1), followed by the second and third transplanting (August 26 and September 11) (50.23 and 29.40 cm, respectively). Plant height showed a sharp decrease from early to late transplanting (49.68 and 70.55% decrease as compared to first transplanting) (Fig. 2). The phenological appearance of the seedlings is also consistent with the experimental results (Fig. 3).

Number of branches per plant

The maximum number of branches per plant was recorded in plants transplanted on August 1, followed by August 26 and September 11 (20.13, 13.57, and 8.37, respectively) (Fig. 2). Like other traits, the number of branches per plant also showed a sharp decrease with respect to early to late transplanting. Plants grown from second and third transplanting dates showed a 32.62 and 58.44% decrease in the number of branches per plant as compared to the plants established from the first transplanting (Fig. 2).

Number of inflorescences per plant

A sharp variation in the number of inflorescences per plant was recorded due to differences in transplanting dates (Fig. 2). The maximum number of inflorescences per plant (222.63) was recorded in the plants grown from the 1st transplanting, followed by the plants grown from the 2nd and 3rd dates of transplanting (107.6 and 41.53, respectively). A sharp decrease in the number of inflorescences per plant was recorded in the plants grown from the 2nd and 3rd dates of transplanting. Plants grown from the second and third transplanting dates showed a 51.67 and 81.34% decrease in the number of inflorescences per plant, respectively, as compared to the plants grown from the first transplanting (Fig. 2).

Table 2. Analysis of variance (mean square) of different salinity stress on yield-attributing traits of perilla

Sources of variation	DM	PH	NBP	NIP	IL	1000-SW	SYP	SPAD
Treatment	68.49**	198.21**	15.82**	1855.26**	1.23*	0.904***	228.34***	281.95***
Replication	6.53	9.00	5.65	124.06	0.15	0.005	11.35	3.55
Error	3.11	7.04	0.59	42.43	0.14	0.009	2.35	2.14

Note: *, **, and *** indicate significant at 5%, 1%, and 0.1 % level of significance, respectively. DM=Days to maturity; PH=Plant height; NBP=Number of branches per plant; NIP=Number of inflorescences per plant; IL=Inflorescence length; 1000-SW=1000-seed weight; SYP=Seed yield per plant; SPAD=Soil and plant analysis development.

Inflorescence length

Inflorescence length showed a significant variation with respect to planting dates (Fig. 2). The highest inflorescence length was recorded in the plants that were transplanted on August 26, followed by September 11, and August 1 (26.30, 24.97, and 18.5 cm, respectively). Inflorescence length showed a non-significant difference in the plants grown from the 2nd and 3rd dates of transplanting. Importantly, inflorescence length showed a significant increase in the plants grown from the 2nd and 3rd transplanting (29.66 and 25.91%, respectively) as compared to the plants grown from the first transplanting (Fig. 2).

100-seed weight

According to the mean value, the highest 100-seed weight was recorded in the plants grown from the 3rd transplanting (September 11), followed by the second and first transplanting (0.41, 0.34, and 0.31 g, respectively) (Fig. 2). Like inflorescence length, 100-seed weight showed an increasing trend from the plants established from the 1st to 3rd transplanting. The second and third transplanted plants showed an 8.60 and 31.18% increase in 100-seed weight, respectively, as compared to the plants grown from the 1st transplanting (Fig. 2).

Seed yield per plant

Significant variability in seed yield per plant was found with respect to transplanting dates (Fig. 2). The highest seed yield per plant was recorded in the plants transplanted on August 1, followed by the plants grown from August 26 and September 11 transplanting (42.90, 28.53, and 14.50 g, respectively). Seed yield per plant showed a sharp decrease from the first planting date to the third date of transplantation. Plants grown from the second and third transplanting showed a 33.49 and 66.20% decrease in seed yield per plant compared to the plants grown from the first transplanting (Fig. 2).

Experiment 2: Effect of salt stress on yield and yield-attributing traits of perilla at the reproductive stage

The results of the analysis of variance showed significant variations among treatments for the traits 1000-SW, SYP, and SPAD ($p<0.001$); DM, PH, NBP and NIP ($p<0.01$); IL ($p<0.05$) (Table 2). The mean performance of the perilla for yield-attributing traits was displayed in Figure 4, and the phenological differences are shown in Figure 5.

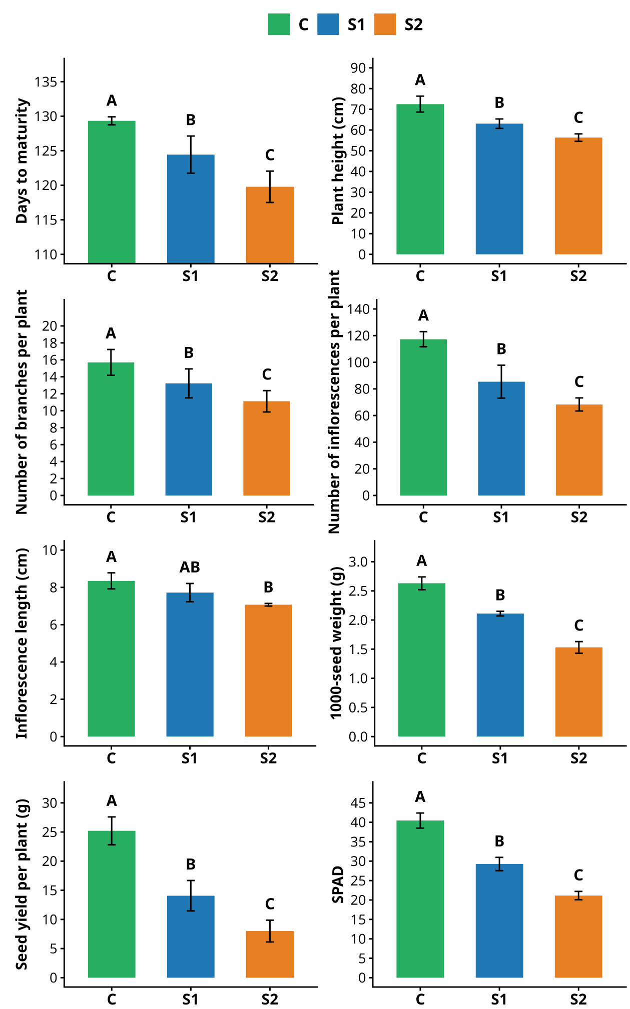

Figure 4. Effects of salt stress on yield and yield-attributing traits of perilla grown under different levels of salinity stress. Each bar represented as the mean values ± standard deviation of three replicates. Different letters indicate significant differences following Tukey's test at $p < 0.05$. Here, C= control condition, S1 = 10 dSm^{-1} salinity and S2= 20 dSm^{-1} salinity.

Figure 5. Phenological appearance of the representative perilla plants grown under control and 10 dSm^{-1} and 20 dSm^{-1} salt stress.

Days to maturity

Under control conditions, perilla plants required maximum days (129.33) to mature, whereas the minimum days (119.78) were recorded under 20 dS m^{-1} salinity stress (Fig. 4). Salt stress resulted in a significant decrease in days to maturity (3.78 and 7.39% by 10 and 20 dS m^{-1} salinity stress) as compared to control (Fig. 4).

Plant height

The highest plant height (73.52 cm) was recorded under control conditions, whereas 63.07 cm and 56.34 cm plant height were recorded under 10 and 20 dS m^{-1} salinity stress (Fig. 4). A significant decrease in plant height (13.03 and 22.31% by 10 and 20 dS m^{-1} salinity stress, respectively) was recorded as compared with the control under salt stress (Fig. 4).

Number of branches per plant

The maximum number (15.70) of branches per plant was recorded under control conditions, whereas the minimum number (11.11) was recorded under 20 dS m^{-1} salinity stress (Fig. 4). A sharp reduction in the number of branches per plant was recorded with the increasing level of salinity stress. The number of branches per plant showed a decreasing trend with the increasing level of salinity stress (15.80 and 29.24% decrease by 10 and 20 dS m^{-1} salinity stress, respectively) as compared with the control (Fig. 4).

Number of inflorescences per plant

The highest number of inflorescences per plant (117.33) was recorded under control conditions whereas minimum number (68.33) was recorded under 20 dS m^{-1} salinity stress (Fig. 4). A sharp decrease in inflorescence number was noted with the increasing level of salinity stress (27.17 and 41.76% by 10 and 20 dS m^{-1} salinity stress, respectively) as compared with the control (Fig. 4).

Inflorescence length

Like the inflorescence number, the highest inflorescence length (8.35 cm) was recorded under control conditions, whereas the lowest (7.07 cm) was recorded under 20 dS m^{-1} salinity stress (Fig. 4). Inflorescence length decreased with the increasing level of salinity stress (7.54 and 15.33% reduction by 10 and 20 dS m^{-1} salinity stress, respectively) as compared with the control (Fig. 4).

1000-seed weight

According to the mean value, 1000-seed weight was recorded for 2.63, 2.11, and 1.53 g under control, 10, and 20 dS m^{-1} salinity stress, respectively (Fig. 4). Like other traits, a significant decrease in 1000-seed weight was also recorded upon the imposition of salinity stress (19.77 and 41.83% reduction by 10 and 20 dS m^{-1} salinity stress, respectively) as compared with the control (Fig. 4).

Seed yield per plant

Significant variability in seed yield per plant was found under control and salinity stress (Fig. 4). The highest seed yield per plant (25.20 g) was recorded under control conditions, while the lowest seed yield (8.0 g) was recorded in the plants treated with 20 dS m^{-1} salinity stress. Seed yield per plant showed a sharp reduction (44.17 and 68.25% by 10 and 20 dS m^{-1} salinity stress) as compared with the control in the plants grown under salinity stress (Fig. 4).

SPAD value

The highest SPAD value (40.45) was recorded in the leaves of control-grown plants, whereas the lowest value (21.14) was noted in the plants treated with 20 dS m^{-1} salinity stress (Fig. 4). Importantly, SPAD values decreased by 29.26% and 42.50% in plants treated with 10 and 20 dS m^{-1} salinity, respectively, compared with the control (Fig. 4).

DISCUSSION

Effect of transplanting date on yield and yield-attributing traits of perilla

In Bangladesh, oil crops are typically cultivated and harvested during the *Robi* season (winter), leading to intense competition for land with other crops such as boro rice, wheat, pulses, and vegetables. In Bangladesh, perilla cultivation has been found suitable for cultivation in Kharif-II season (Kabir et al. 2025). Therefore, as a supplementary oilseed crop, perilla can help in reducing the deficit of the national production of high-quality edible oil seeds. To achieve maximum seed yields and sustainable agricultural production, the transplanting or sowing time should be optimized through replicated trials in Bangladesh's various agro-ecological zones. The present study clearly shows that the date of transplanting had a strong influence on the growth behavior, phenology, and yield performance of perilla. Noticeable differences among transplanting dates indicate that this crop is highly sensitive to planting time. Among the tested dates, transplanting in the first week of August proved to be the most suitable, as plants grown during this period consistently showed better growth and seed yield compared to later planting (Figs. 2 and 3). In contrast, delayed transplanting resulted in a progressive reduction in these traits, although it increased 100-seed weight and inflorescence length.

The observed reduction in days to first flowering and days to maturity with later transplanting aligns with Perilla's nature as a short-day plant. When transplanting was delayed, plants were exposed to shorter day lengths at an earlier stage, which likely triggered earlier floral initiation and reduced the overall growth duration. As a result, late-sown plants completed their life cycle more quickly but failed to accumulate sufficient vegetative biomass. Similar responses have been reported earlier, where delayed planting in perilla accelerated phenological development but reduced yield potential (Jong-Sun 2005; Kim et al. 2021). Similarly, reduced plant height, number of branches per plant, and number of inflorescences per plant with delayed transplanting further support this explanation. Early sown plants benefited from a longer vegetative period, which allowed better stem elongation, branching, and canopy development. In contrast, late-sown plants had limited time for vegetative growth, resulting in smaller plant size and fewer branches (Figs. 2 and 3). Since branching directly determines the number of reproductive sites, this reduction ultimately affects inflorescence formation and yield (Lee and Ohnishi 2001). Jong-sun (Jong-Sun 2005) demonstrated that delayed transplanting from April to July resulted in decreased plant height, with plants showing highly negative correlations between transplanting dates and height characteristics. This occurs because perilla is a short-day plant that flowers consistently in early-to-mid September regardless of transplanting time, compressing the vegetative growth phase in late-sown plants. Similar effects are observed in soybeans, where late transplanting reduces plant cycle duration primarily during the reproductive phase, with decreased node numbers on main stems (Martins et al. 1999).

The increase in 100-seed weight observed under later transplanting is mainly linked to a natural trade-off between seed number and seed size. When perilla is sown late, plants have a shorter vegetative period due to shorter day length, which limits branching and reduces the number of inflorescences and seeds. Since fewer seeds are growing on the plant, more resources can be gathered in each seed because the available photosynthates are distributed over a smaller sink. As a result, even though total yield decreases, individual seeds are heavier (Bahuguna and Prasad 2014; Kim et al. 2021). Similar reactions have been noted in perilla and other oilseed crops when restricted growth circumstances or delayed seeding prioritize seed filling over seed quantity. Ju et al. (2012) also found that delayed transplanting reduced stem height, node numbers, branches, clusters per plant, and capsules per cluster and grain yield due to reduced cluster numbers and ripened grain percentage.

Therefore, from an agronomic perspective, the results indicate that the first week of August is the optimal transplanting time for perilla because climatic conditions in this period favor extended vegetative growth, higher branching, and abundant inflorescence development that confers maximum seed yield. Overall, these findings indicate the critical time of transplanting for optimizing growth and productivity of perilla, and this knowledge is essential for designing effective cropping schedules, particularly in the Mymensingh region of Bangladesh.

Effects of salt stress on yield-attributing traits of perilla

Soil salinity is a major abiotic stress that adversely affects plant growth and productivity. It is more severe, particularly in coastal regions where saline intrusion is increasing due to sea level rise because of climate change (Munns and Tester 2008). Osmotic stress impairs roots' capacity to absorb water, resulting in physiological drought conditions, while an excessive accumulation of Na^+ and Cl^- ions interferes with enzyme activity, membrane stability, and cellular metabolism (Deinlein et al. 2014; Negrão et al. 2017). Furthermore, the excess Na^+ competes with the essential elements like K^+, Ca^{2+}, and Mg^{2+}, leading to nutrient imbalance (Liang et al. 2018). Together, these physiological disturbances constrain photosynthesis, carbon assimilation, and assimilate translocation, thereby reducing plant growth and reproductive development (Sudhir and Murthy 2004; Verma et al. 2024).

Perilla is a moderately salt-tolerant plant, and its salinity tolerance mechanism has been depicted through assessments of the antioxidant defense system, lipid membrane peroxidation, and the accumulation of proline and soluble sugars (Zhang et al. 2012). In the present study, perilla plants exhibited significant reductions in both vegetative and reproductive traits associated with yield under salinity stress as compared to control (Figs. 4 and 5). Days to maturity decreased significantly with the increasing level of salinity stress. This can be attributed to a stress-escape mechanism, where plants accelerate maturity under unfavorable conditions to ensure reproduction. Similar results have been reported in wheat, rice, and canola, where salinity stress-induced early maturity has been observed (Zhang et al. 2022; Wang et al. 2022). Plant height declined as the salinity level increased, which occurred through multiple interconnected negative consequences of salinity stress. Salinity reduces plants' ability to take up water, causing immediate growth rate reductions through hormonal signals generated by roots (Munns 2002). This osmotic stress creates physiological drought conditions, forcing plants to undergo anatomical changes in xylem structure to prevent cavitation and cell collapse (Zhang and Dai 2019). The stress manifests as decreases in stem length, leaf number, lateral branches, and organ diameter (Ahmed 2022). Similar reductions in plant height have been reported in sesame and sunflower under saline conditions (Khatun et al. 2023).

The number of branches and inflorescences per plant and the length of the inflorescence decreased sharply with the increasing level of salinity stress (Fig. 4), indicating that salinity limits branching and floral initiation by reducing assimilate availability and hormonal regulation (Negrão et al. 2017). Salinity also delays the appearance of inflorescences and increases flower abortion, with altered source-sink relationships and reduced carbohydrate availability in inflorescences contributing to impaired reproductive development (Ghanem et al. 2009). Similar results were also reported by Zhang et al. (Zhang et al. 2012) in perilla. In rice, salinity reduces the number of primary and secondary panicle branches, likely due to increased Na^+ accumulation, reduced K^+, impaired photosynthate translocation, and decreased starch synthetase activity, all of which contribute to reduced fertility and seed set (Abdullah et al. 2002). 1000-seed weight decreased both at 10 dS m^{-1} and 20 dS m^{-1} salinity level which reflects insufficient carbohydrate partitioning to the developing seeds. Similar reductions in yield components under salinity have been reported in canola and soybean, where reduced photosynthetic supply and ion toxicity disrupted seed filling (Phang et al. 2008; Wang et al. 2022). Seed yield per plant was reduced by 44% at 10 dS m^{-1} and by 68% at 20 dS m^{-1}, primarily due to fewer inflorescences, smaller inflorescence length, and decreased seed weight (Fig. 4). Salinity impairs pollen viability, fertilization, and embryo development, leading to poor seed set. Salinity disrupts nutrient uptake and metabolism, leading to nutritional disorders that significantly reduce growth rates and ultimately cause drastic yield reductions (Ali et al. 2022; Gursoy 2024). The SPAD value (chlorophyll index) decreased with the increase of soil salinity, which indicates chlorophyll degradation and impaired photosynthetic capacity. Reduced chlorophyll content under salinity is often associated with oxidative stress and disorganization of thylakoid membranes (Sudhir and Murthy 2004; Wydrzynski 2008). A decline in photosynthetic efficiency under salt stress has been widely reported in oilseed crops and is considered a primary factor for yield loss (Wang et al. 2022). Overall, perilla yield and other yield-attributing traits are significantly reduced in response to salinity stress that emphasizes the need for salt-tolerant varieties for maximizing yield and for improved soil and water management in the coastal zone of Bangladesh.

CONCLUSIONS

This study revealed that transplanting date and soil salinity significantly affect the growth and yield of perilla. The first week of August showed the best performance under the conditions of the present study, ensuring maximum seed yield and favorable agronomic traits, while delayed transplanting reduced plant performance. On the other hand, increasing salinity levels (10-20 dS m^{-1} NaCl) caused a substantial decline in yield and related traits. These findings underscore that early August transplanting may be considered for improving yield under the conditions of the present study in Bangladesh and particularly at Mymensingh region. Additionally, the development and cultivation of salinity-tolerant perilla varieties are recommended for sustainable production, particularly in the coastal regions affected by soil salinity. Implementing these strategies can enhance the availability of perilla as a nutrient-rich oilseed crop, which may contribute to improving perilla productivity and its potential role in local oilseed production systems.

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