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GROWTH AND REPRODUCTIVE RESILIENCE OF EGGPLANT GENOTYPES UNDER WATERLOGGING STRESS AT FLOWERING STAGE

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ABSTRACT

Excess soil moisture and short-term waterlogging constrain vegetable production, particularly during reproductive stages requiring continuous assimilate supply for fruit development. Twelve contrasting eggplant (*Solanum melongena* L.) genotypes were evaluated for growth dynamics, reproductive performance, and yield under six days of waterlogging imposed at the flowering stage. Growth traits (leaf area, root and total dry weight, CGR, RGR, NAR), reproductive traits (flower drop, fruit set), and yield attributes (fruit number, average fruit weight, yield plant^{-1}) were assessed. Significant genotype × treatment interactions were observed for most of the parameters (p < 0.001) studied. Waterlogging significantly reduced vegetative growth and growth rate indices across the genotypes, though the magnitude varied considerably. Flower drop ranged from 13.38% to 61.41%, and fruit set from 20.59% to 75.57%. Genotype '*S. undatum'* showed highest fruit set and lowest flower drop, followed by 'Kamini Brinjal' and 'BRS-20', while genotypes 'Black Small' and 'BRS-2' showed severe reproductive and yield losses. Correlation analysis revealed strong associations between growth maintenance and reproductive stability (r = 0.76-0.94), confirming that sustained biomass accumulation and growth rate under stress directly support flower retention and fruit set. The study identified genotypes '*S. undatum'*, 'Kamini Brinjal', and 'BRS-20' as the promising, warranting further evaluation for waterlogging tolerance in eggplant breeding programs.

Keywords: Crop growth rate, eggplant genotypes, flower abscission, growth analysis, reproductive stability, waterlogging stress

INTRODUCTION

Transient soil saturation and short-term waterlogging increasingly impact vegetable production systems, particularly in the regions receiving intense rainfall and having poorly drained soils. Although waterlogging effects on vegetative growth have been documented in eggplant, but limited information exists on the growth rate dynamics *viz*., crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR), during reproductive-stage stress and their quantitative relationships with fruit set. Importantly, no previous studies have systematically evaluated Indian eggplant varieties and local germplasm for waterlogging tolerance, despite their economic importance and cultivation under monsoon-prone regions**.** The twelve genotypes evaluated in this study represent contrasting tolerance levels identified through systematic screening of forty diverse accessions including locally adapted Indian cultivars and the wild relative '*S. undatum'* (Bal *et al.*, 2025). This study addressed the knowledge gap by integrating growth analysis with reproductive assessment under controlled waterlogging conditions and establishing quantitative relationships between biomass maintenance and reproductive stability through correlation analysis. Such conditions frequently occur during monsoon season in tropical and subtropical agro-ecosystems and can severely disrupt normal plant growth and productivity. When soil pores become filled with water, oxygen diffusion to the root zone declines rapidly, creating hypoxic or anoxic conditions that impair root respiration, nutrient uptake, and overall plant metabolic activity (Setter and Waters, 2003; Bailey-Serres *et al.*, 2012). The consequences of waterlogging are particularly severe during reproductive phase of crop development. At this stage, plants require continuous assimilate supply to sustain flowering and fruit development. Any disruption in carbon assimilation or assimilate translocation can therefore lead to flower abortion, reduced fruit set, and ultimately yield loss (Colmer and Voesenek, 2009; Li *et al.*, 2011; Sasidharan *et al.*, 2018). Short episodes of waterlogging, even if temporary, may significantly alter plant growth patterns by affecting biomass accumulation, leaf development, and root function.

Eggplant (*Solanum melongena* L.), commonly known as brinjal, is one of the most important vegetable crops cultivated across tropical and subtropical regions. It is valued for its high nutritional content, including dietary fiber, vitamins, minerals, and antioxidant compounds, and contributes significantly to vegetable production and farmer livelihoods in many parts of Asia (Hanson *et al.*, 2006; Daunay, 2008). Eggplant is particularly sensitive to excess soil moisture because its root system requires well-aerated soil conditions for normal metabolic activity. In India, eggplant is cultivated extensively under diverse agro-climatic conditions; however, its productivity is often affected by various abiotic stresses, including excess soil moisture.

Growth analysis provides a useful approach for evaluating plant responses to environmental stress. Parameters such as crop growth rate, relative growth rate, and net assimilation rate integrate several physiological processes including leaf expansion, photosynthetic efficiency, and dry matter production. Changes in these indices under stress conditions can, therefore, provide insights into how effectively plants maintain growth under unfavourable environments (Radford, 1967; Hunt, 1990). In addition to vegetative growth responses, reproductive stability is an important indicator of stress tolerance in vegetable crops. Traits such as flower retention and fruit set directly reflect the plant's ability to sustain reproductive development under adverse soil conditions. However, information linking growth dynamics with reproductive responses under short-term waterlogging conditions is limited in many vegetable crops, including eggplant. In a previous screening study involving forty eggplant genotypes, considerable variation in tolerance to excess moisture stress was identified, which provided the basis for selecting contrasting genotypes for detailed physiological evaluation (Bal *et al.*, 2025). Therefore, the present study was aimed to evaluate selected eggplant genotypes for their growth dynamics and reproductive responses under short-term waterlogging imposed at reproductive stage. The study intended to identify the genotypes capable of maintaining biomass accumulation and reproductive performance under excess moisture conditions

MATERIALS AND METHODS

Experimental site and plant material

The experiment was conducted in *Rabi* season of 2024-25 at the Central Horticultural Experiment Station, Aiginia, Bhubaneswar (India), located at approximately 20°24′N latitude and 85°47′E longitude at an elevation of about 30 m masl. The experiment was conducted in an environmentally controlled polyhouse, maintained at a 14-h photoperiod, 85–90% relative humidity, and day/night temperatures of 30°C/25°C throughout the crop growth period. The region has a warm humid tropical climate with distinct monsoonal rainfall patterns, which often create conditions conducive to temporary soil water saturation. Twelve contrasting genotypes were selected from a prior screening of forty accessions based on tolerance score, growth vigor, and stress symptom severity (Bal *et al.*, 2025).

Experimental design and crop establishment

The experiment was conducted as a pot culture study using a completely randomized design with two treatments *i.e.,* control (well-drained condition), and waterlogging stress. Each genotype × treatment combination was replicated three times. Each replication consisted of two pots with one plant pot^{-1}, resulting in six plants genotype^{-1} treatment^{-1}. Pot culture enabled uniform stress imposition and precise phenotypic evaluation under controlled environmental conditions, which is widely adopted in stress physiology studies for comparative genotypic assessment (Setter and Waters, 2003; Bailey-Serres *et al.,* 2012). Seeds were first grown in nursery trays and the seedlings at 4-6 leaf stage were transplanted into 15 L plastic pots containing a sterilized mixture of soil, sand, and farmyard manure in a 2:1:1 (v/v) ratio. Detailed physicochemical characterization of potting substrate was not performed for the present study; a standard sterilized potting mixture (soil, sand, and farmyard manure in a 2:1:1 ratio) was used uniformly across all the treatments to minimize substrate-related variability among pots. This potting mixture provides suitable aeration and nutrient availability for vegetable crop growth (Kramer and Boyer, 1995). One plant was maintained pot^{-1} and all plants were grown under recommended agronomic practices (Dhaliwal, 2017) until the reproductive stage.

Imposition of waterlogging stress

Waterlogging stress was imposed at the onset of flowering, a critical stage for reproductive development in eggplant. Pots assigned to the stress treatment were placed in waterproof tanks and water level was maintained approximately 5 cm above the soil surface for six consecutive days, creating temporary root-zone hypoxia similar to the field waterlogging conditions (Setter and Waters, 2003; Sasidharan *et al.*, 2018). The six-day duration was based on preliminary observations showing consistent onset of visible stress symptoms without genotype mortality, and corresponds to short-duration flooding spells typically recorded during monsoon rainfall events in coastal Odisha (Government of Odisha, 2021). Water levels were monitored and maintained twice daily to ensure uniform stress exposure. Control plants were irrigated normally without water stagnation.

Sampling procedure and growth measurements

Growth observations were recorded before stress imposition and immediately after the six-day waterlogging period. Plants were carefully uprooted and washed to remove adhering soil particles. Plant samples were separated into leaves, stems, and roots. Leaf area was measured using a leaf area meter and expressed as cm^2 $plant^{-1}$. Plant components were oven-dried at 70°C until constant weight to determine leaf dry weight, root dry weight, and total plant dry weight, following standard plant growth analysis procedures (Hunt, 1990).

Growth analysis

Growth indices were calculated using dry weight and leaf area data obtained before and after stress imposition. and

$$\text{Crop growth rate (CGR)} = (W_2 - W_1) / (t_2 - t_1)$$

$$\text{Relative growth rate (RGR)} = (\ln W_2 - \ln W_1) / (t_2 - t_1)$$

$$\text{Net assimilation rate (NAR)} = (W_2 - W_1)(\ln A_2 - \ln A_1) / [(t_2 - t_1)(A_2 - A_1)]$$

Where, W_1, W_2 = plant dry weight (g) at time t_1 and t_2 respectively; A_1, A_2 = leaf area at time t_1 and t_2, respectively.

These indices are widely used for evaluating plant growth responses under environmental stress conditions (Radford, 1967; Hunt, 1990).

Reproductive traits

The effect of waterlogging stress on reproductive development was assessed through flower drop percentage and fruit set percentage. Flower buds and flowers present at the onset of stress were tagged and monitored throughout the experimental period, while newly emerged flowers during the stress and recovery period were excluded from the analysis. Flower drop was recorded immediately after completion of the six-day waterlogging stress period by counting the number of tagged flowers that abscised during the stress treatment. Fruit set was recorded seven days after removal of the waterlogging treatment to allow sufficient time for pollination, fertilization and early fruit development.

$$\text{Flower drop percentage} = \frac{Total\ tagged\ flower\ buds - flower\ bud\ retained}{Total\ tagged\ flower\ buds} \times 100$$

$$\text{Fruit set percentage} = \frac{Number\ of\ Fruits\ formed}{Total\ tagged\ flowers} \times 100$$

These parameters are widely used indicators of reproductive stability under abiotic stress conditions (Blum, 2011).

Statistical analysis

The experimental data were analyzed using two-way analysis of variance (ANOVA), with genotype, treatment, and their interaction as sources of variation, appropriate for a completely randomized design. Mean comparisons were performed using Tukey's test at $p \leq 0.05$. All statistical analyses were conducted using R statistical software. Data were tested for normality before analysis.

RESULTS AND DISCUSSION

Growth and biomass response

Two-way ANOVA revealed highly significant genotype × treatment interactions for all measured growth parameters (leaf area: F=23.24, p<0.001; root dry weight: F=4.95, p<0.001; CGR: F=85.66, p<0.001; RGR: F=146.18, p<0.001; NAR: F=159.47, p<0.001), confirming that genotypes differed substantially in their response to waterlogging rather than showing a uniform decline, and justifying the genotype-wise interpretation presented below.

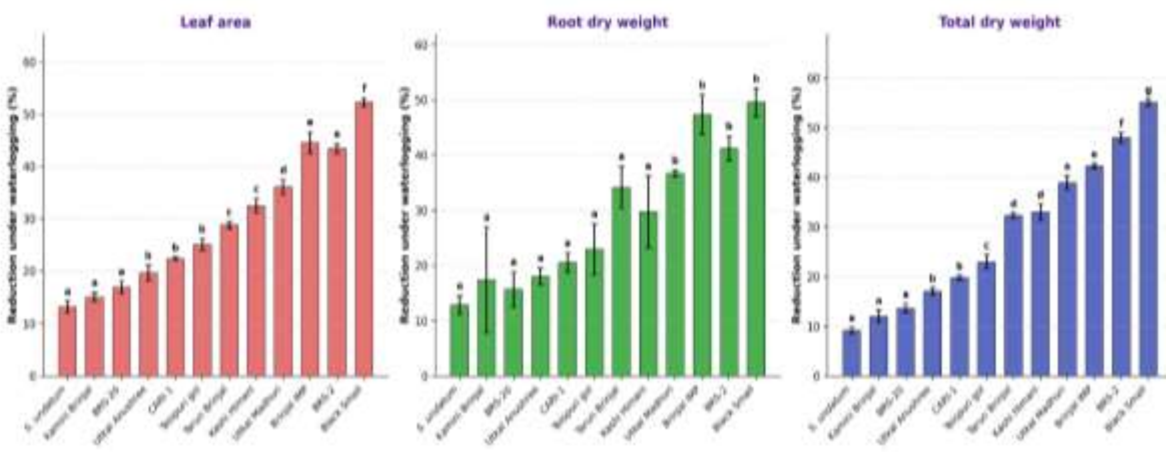

Fig. 1: Percentage reduction in leaf area, root dry weight and total dry weight of eggplant genotypes after six days of waterlogging imposed at the flowering stage relative to corresponding control values. Bars represent mean ± SE (n = 3).

Waterlogging imposed at the flowering stage significantly affected vegetative growth and biomass accumulation of eggplant genotypes, as reflected in changes in leaf area, root dry weight and total dry weight (Table 1). The magnitude of reduction varied considerably among genotypes, indicating differential responses to excess soil moisture (Fig. 1). Leaf area declined in all genotypes following the stress treatment, although the extent of reduction differed markedly (Table 1).

Genotypes such as '*S. undatum*', 'Kamini Brinjal' and 'BRS-20' showed relatively smaller reductions, whereas 'Black Small', 'Brinjal IMP' and 'BRS-2' exhibited pronounced decreases (Fig. 1). Reduced leaf development under waterlogged conditions is likely associated with oxygen deficiency in the root zone, which may restrict root respiration and nutrient uptake, and ultimately suppresses leaf expansion and possibly reduced photosynthetic capacity. Similar inhibition of canopy development under flooding conditions has been reported in several crops (Setter and Waters, 2003; Bailey-Serres *et al.,* 2012). Root dry weight also declined across all genotypes under waterlogging (Table 1). However, tolerant genotypes such as '*S. undatum*' and 'BRS-20' maintained comparatively higher root biomass than susceptible ones (Fig. 1). The reduction in root growth presumably attributed to hypoxic soil conditions and that might have limited aerobic respiration and energy production in root tissues, thereby restricting root development and nutrient acquisition (Setter and Waters, 2003; Sasidharan *et al.,* 2018). Consequently, total plant dry weight decreased under waterlogging stress in all genotypes (Table 1). Genotypes that maintained relatively higher leaf area and root biomass also showed smaller reductions in total dry matter (Fig. 1), suggesting better physiological adjustment to temporary soil saturation. Reduced biomass accumulation under such conditions is consistent with decreased photosynthetic activity and impaired assimilate production, as commonly reported under waterlogging stress in other crops (Bailey-Serres *et al.,* 2012). Overall, the observed variation among genotypes in maintaining leaf area and biomass indicates differences in their ability to sustain growth during transient soil saturation.

Table 1: Effect of waterlogging on leaf area, root dry weight and total dry weight of eggplant genotypes at the flowering stage

Genotypes	Leaf area ($cm^2 plant^{-1}$)		Total dry weight ($g\ plant^{-1}$)		Root dry weight ($g\ plant^{-1}$)	
	Control	Stress	Control	Stress	Control	Stress
Black Small	6415.52 ± 215.51^{def}	3065.78 ± 53.68^{a}	135.46 ± 0.86^{g}	60.89 ± 0.95^{a}	20.67 ± 0.23^{cdef}	10.43 ± 0.52^{a}
Brinjal IMP	4174.89 ± 83.72^{b}	2315.82 ± 86.32^{a}	127.54 ± 2.48^{fg}	73.63 ± 0.62^{b}	19.8 ± 0.26^{bcde}	10.43 ± 0.71^{a}
BRS-2	8287.58 ± 273.65^{ghi}	4689.7 ± 78.76^{b}	178.83 ± 2.41^{jk}	93.06 ± 1.86^{c}	25.9 ± 0.15^{ghij}	15.23 ± 0.58^{b}
BRS-20	6937.89 ± 139.33^{ef}	5765.01 ± 79.88^{cd}	213.38 ±1.13^{n}	184.32 ±1.98^{kl}	31.87 ± 0.43^{l}	26.87 ± 1.01^{ghijk}
CARI-1	10982.43 ± 185.32^{jk}	8523.32 ± 31.41^{ghi}	190.48 ± 1.20^{l}	152.83 ± 0.91^{h}	28.6 ± 0.17^{hijkl}	22.73 ± 0.49^{defg}
Kamini Brinjal	10252.11 ± 104.07^{j}	8708.08 ± 89.69^{hi}	209.35 ± 1.30^{mn}	184.28 ± 2.66^{kl}	30.5 ± 0.6^{jkl}	25.2 ± 2.92^{fghi}
Kashi Himani	8171.29 ± 163.9^{gh}	5514.51 ± 110.74^{c}	173.62 ± 1.22^{ij}	116.25 ± 2.78^{de}	26.37 ± 0.48^{ghij}	18.53 ± 1.71^{bcd}
S.undatum	6428.65 ± 67.41^{def}	5580.85 ± 70.66^{c}	168.78 ± 1.28^{i}	153.36 ± 1.10^{h}	26.2 ± 0.17^{ghij}	22.83 ± 0.43^{defg}
Tarun Brinjal	8730.82 ± 82.13^{hi}	6217.86 ± 58.49^{cde}	183.3 ± 1.25^{kl}	124.09 ± 0.98^{ef}	28.1 ± 0.15^{hijkl}	18.5 ± 1.06^{bcd}
Teispuri gol	7857.49 ± 114.38^{g}	5885.25 ± 87.76^{cd}	149.04 ± 0.82^{h}	114.82 ± 2.12^{d}	22.27 ± 0.49^{defg}	17.17 ± 1.03^{bc}
Utkal Anushree	11210.54 ± 232.95^{k}	9007.17 ± 166.37^{i}	202.01 ± 1.13^{m}	167.57 ± 1.47^{i}	29.9 ± 0.4^{ijkl}	24.5 ± 0.44^{efgh}
Utkal Madhuri	11030.21 ± 245.86^{k}	7049.74 ± 157.14^{f}	206.38 ± 1.44^{mn}	126.08 ± 2.84^{f}	31.27 ± 0.49^{kl}	19.8 ± 0.17^{bcde}

Values represent mean ± standard error (SE) of three replicates. Means followed by different letters within a column differ significantly at $p \leq 0.05$ according to Tukey's test.

While direct measurements of photosynthetic rate, stomatal conductance, and chlorophyll content were not included in the present study, the observed reductions in leaf area, biomass accumulation, and growth rate indices (CGR, RGR, NAR) under waterlogging are consistent with documented physiological responses including decreased photosynthesis, impaired nutrient uptake, and restricted carbon assimilation reported in previous studies on solanaceous crops under similar stress conditions (Bailey-Serres *et al.*, 2012; Yin *et al.,* 2023). However, direct measurement of these parameters in future studies would provide more definitive insights into the physiological basis of the observed growth responses.

Growth rate dynamics

Waterlogging stress imposed at flowering stage markedly influenced growth rate parameters of eggplant genotypes, as reflected in the changes CGR, RGR and NAR (Table 2). Considerable variation among genotypes was observed in their ability to maintain these physiological growth indices under excess soil moisture conditions.

Table 2: Effect of stress on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) of different brinjal genotypes under control and stress conditions

Genotypes	CGR (g plant^{-1} day^{-1})		RGR ($\times 10^{-2}$ g g^{-1} day^{-1})	NAR ($\times 10^{-3}$ g cm^{-2}day^{-1})	
	Control	Stress	Stress	Control	Stress
Black Small	1.88 ± 0.01^{f}	-10.63 ± 0.25^{a}	-11.944 ± 0.328^{a}	0.30 ± 0.01^{g}	-2.47 ± 0.09^{a}
Brinjal IMP	1.77 ± 0.03^{f}	-7.37 ± 0.33^{b}	-7.837 ± 0.270^{c}	0.43 ± 0.01^{g}	-2.46 ± 0.10^{a}
BRS-2	2.48 ± 0.03^{f}	-11.95 ± 0.55^{a}	-9.523 ± 0.458^{b}	0.31 ± 0.01^{g}	-1.99 ± 0.10^{b}
BRS-20	2.96 ± 0.02^{f}	-1.86 ± 0.17^{de}	-0.978 ± 0.093^{fg}	0.44 ± 0.01^{g}	-0.30 ± 0.03^{def}
CARI-1	2.64 ± 0.02^{f}	-3.71 ± 0.27^{c}	-2.269 ± 0.166^{e}	0.25 ± 0.00^{g}	-0.39 ± 0.03^{de}
Kamini Brinjal	2.91 ± 0.02^{f}	-1.49 ± 0.55^{e}	-0.793 ± 0.294^{fg}	0.29 ± 0.00^{g}	-0.16 ± 0.06^{ef}
Kashi Himani	2.41 ± 0.02^{f}	-7.25 ± 0.55^{b}	-5.303 ± 0.448^{d}	0.30 ± 0.01^{g}	-1.10 ± 0.09^{c}
S.undatum	2.34 ± 0.02^{f}	-0.26 ± 0.28^{e}	-0.171 ± 0.183^{g}	0.37 ± 0.00^{g}	-0.05 ± 0.05^{f}
Tarun Brinjal	2.55 ± 0.02^{f}	-7.38 ± 0.31^{b}	-5.088 ± 0.210^{d}	0.30 ± 0.00^{g}	-1.02 ± 0.05^{c}
Teispuri gol	2.07 ± 0.01^{f}	-3.71 ± 0.49^{c}	-2.956 ± 0.407^{e}	0.27 ± 0.01^{g}	-0.57 ± 0.08^{d}
Utkal Anushree	2.81 ± 0.02^{f}	-3.18 ± 0.40^{cd}	-1.797 ± 0.226^{ef}	0.26 ± 0.00^{g}	-0.32 ± 0.04^{de}
Utkal Madhuri	2.87 ± 0.02^{f}	-10.64 ± 0.55^{a}	-6.834 ± 0.410^{c}	0.27 ± 0.01^{g}	-1.26 ± 0.07^{c}

Values represent mean ± standard error (SE) of three replications. Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to Tukey's HSD test. RGR under control conditions was 1.45 ($\times 10^{-2}$ g g^{-1} day^{-1}) for all genotypes and did not differ significantly and therefore is not shown in the table. CGR = crop growth rate; RGR = relative growth rate; NAR = net assimilation rate.

CGR showed substantial decline in all genotypes following waterlogging. Under control conditions, CGR values ranged from 1.77 to 2.96 g plant^{-1} day^{-1} among the genotypes, whereas under stress conditions the values declined sharply and became negative in most cases (Table 2). The magnitude of reduction differed markedly among genotypes. Genotypes 'S. undatum', 'Kamini Brinjal' and 'BRS-20' exhibited comparatively lesser reductions in CGR, indicating their ability to sustain biomass accumulation under temporary soil saturation. In contrast, genotypes 'Black Small', 'BRS-2' and 'Utkal Madhuri' showed higher reductions in CGR, reflecting greater sensitivity to waterlogging stress. Reduction in CGR under flooded conditions is primarily associated with restricted root aeration and impaired nutrient uptake, which ultimately reduce photosynthetic activity and biomass production (Setter and Waters, 2003; Bailey-Serres *et al.*, 2012). CGR under control conditions did not differ significantly among genotypes, indicating that growth differences observed under stress were primarily associated with differential tolerance to waterlogging. Negative CGR values observed under stress conditions indicate a net reduction in plant biomass during the waterlogging period, reflecting severe inhibition of growth processes in susceptible genotypes.

RGR also declined under waterlogging stress in all genotypes (Table 2). The reduction was particularly pronounced in susceptible genotypes *viz*., 'Black Small' and 'BRS-2', whereas tolerant genotypes including 'S. undatum', 'Kamini Brinjal' and 'BRS-20' maintained relatively higher RGR values under stress. Since RGR represents the rate of biomass accumulation relative to existing plant biomass, the observed reduction suggests that waterlogging disrupted normal metabolic activity and growth efficiency. Oxygen deficiency in root zone limits mitochondrial respiration and energy production, thereby constraining growth processes and reducing relative growth rates (Sasidharan *et al.*, 2018). The relatively smaller decline in RGR in tolerant genotypes indicates their greater capacity to maintain metabolic functioning during transient hypoxic conditions.

NAR followed a similar trend and decreased substantially under stress conditions (Table 2). NAR reflects the efficiency of leaf area in producing assimilates, and its decline under waterlogging indicates impairment of photosynthetic performance and assimilate production. Susceptible genotypes 'Black Small' and 'Brinjal IMP' recorded the highest reduction in NAR, whereas tolerant genotypes 'S. undatum', 'Kamini Brinjal' and 'BRS-20' exhibited comparatively lesser declines. Reduced NAR under waterlogging stress has been attributed to stomatal closure, reduced chlorophyll content and limitations in carbon assimilation caused by root oxygen deficiency (Bailey-Serres *et al.*, 2012; Sasidharan *et al.*, 2018). Collectively, the magnitude of decline in CGR, RGR and NAR clearly distinguished tolerant and susceptible genotypes. Tolerant genotypes '*S. undatum'*, 'Kamini Brinjal' and 'BRS-20' exhibited only marginal reductions in growth indices, whereas susceptible genotypes 'Black Small', 'BRS-2' and 'Utkal Madhuri' showed drastic declines, indicating severe disruption of biomass accumulation and assimilatory efficiency under waterlogging stress.

Overall, the results indicated that genotypic variation existed with respect to the ability of eggplant plants to maintain growth rate parameters under temporary waterlogging. Genotypes that sustained relatively higher CGR, RGR and NAR under stress conditions also maintained greater biomass accumulation (Table 1), suggesting better physiological adaptation to hypoxic soil environments. Such genotypes may possess traits that enable more efficient maintenance of root function and carbon assimilation during short-term flooding.

Reproductive performance

Waterlogging stress imposed at the flowering stage significantly affected reproductive development of eggplant genotypes, as reflected in differences in flower drop percentage and fruit set percentage (Table 3). Considerable genotypic variation was observed in the ability of plants to retain flowers and successfully set fruits under excess moisture conditions. Flower drop ranged from 13.38 to 61.41% among the genotypes. The lowest flower drop was recorded in '*S. undatum'* (13.38%), followed by 'Kamini Brinjal' (18.36%) and 'BRS-20' (23.5%), revealing better reproductive stability under stress conditions. In contrast, susceptible genotypes 'Black Small' (61.41%), 'BRS-2' (52.40%) and 'Utkal Madhuri' (50.03%) exhibited substantially higher flower abscission (Table 3). Increased flower drop under waterlogged conditions is commonly associated with reduced assimilate supply, hormonal imbalance and impaired root function caused by oxygen deficiency in the root zone (Setter and Waters, 2003; Bailey-Serres *et al.*, 2012). Fruit set showed a reverse trend and varied from 20.59 to 75.57% among the genotypes. The highest fruit set was observed in '*S. undatum'* (75.57%), followed by 'Kamini Brinjal' (63.53%) and 'BRS-20' (56.96%), whereas susceptible genotypes such as 'Black Small' (20.59%), 'BRS-2' (24.46%) and 'Utkal Madhuri' (26.50%) recorded markedly lower fruit set. Higher fruit set in tolerant genotypes indicated their greater ability to maintain reproductive development despite temporary soil saturation.

Table 3: Effect of waterlogging stress on flower drop (%) and fruit set (%) of eggplant genotypes

Genotypes	Flower drop (%)	Fruit set (%)
S. undatum	13.38 ± 2.86^{f}	75.57 ± 2.44^{a}
Kamini Brinjal	18.36 ± 5.84^{ef}	63.53 ± 10.36^{ab}
BRS-20	23.51 ± 5.6^{def}	56.96 ± 2.78^{ab}
CARI-1	29.11 ± 1.33^{cdef}	54.17 ± 1.04^{abc}
Teispuri gol	37.06 ± 5.21^{bcde}	43.57 ± 5.17^{bcd}
Utkal Anushree	39.97 ± 7.40^{abcde}	41.8 ± 7.91^{bcde}
Kashi Himani	42.8 ± 2.25^{abcd}	29.52 ± 1.98^{de}
Tarun Brinjal	45.71 ± 2.41^{abc}	31.57 ± 3.4^{cde}
Brinjal IMP	49.13 ± 3.40^{abc}	31.00 ± 2.49^{de}
Utkal Madhuri	50.03 ± 5.03^{abc}	26.50 ± 2.28^{de}
BRS-2	52.40 ± 2.59^{ab}	24.46 ± 0.96^{de}
Black Small	61.41 ± 3.34^{a}	20.59 ± 1.10^{e}

Values represent mean ± standard error (SE) of three replications. Means followed by different letters within a column differ significantly at $p \leq 0.05$ according to Tukey's HSD test.

Yield and yield-attributing traits followed the same pattern as flower retention (Table 4). Number of fruits plant^{-1} declined most sharply in 'Black Small' (80.98% reduction) and 'BRS-2' (77.66%), while '*S. undatum'* (53.58%), 'BRS-20' (60.00%), and 'Kamini Brinjal' (60.94%) showed comparatively lower reduction. Fruit yield plant^{-1} showed the same trend, with '*S. undatum'* recorded the lowest yield reduction (51.31%), followed by 'BRS-20' (58.78%) and 'Kamini Brinjal' (59.43%), against 'Black Small' (82.66%), 'BRS-2' (80.99%), and 'Brinjal IMP' (80.06%) at the susceptible end. Average fruit weight was comparatively less affected across genotypes (4.83-9.54% reduction). Notably, genotype × treatment interaction was significant for fruit number and yield plant^{-1} ($p<0.05$) but not for average fruit weight, indicating that yield loss under waterlogging was driven primarily by genotype-dependent reductions in fruit number rather than fruit size.

Table 4: Effect of moisture stress on the number of fruits, mean fruit weight, and yield plant^{-1} in eggplant genotypes (T_2, stress condition)

Genotype	No. of fruits plant^{-1} (% reduction)	Mean fruit wt in g (% reduction)	Yield (g) plant^{-1} (% reduction)
S. undatum	17.33^{a} (53.58)	100.97^{a} (4.83)	1722.00^{a} (51.31)
Utkal Anushree	16.33^{a} (65.75)	92.94^{a} (6.35)	1573.33^{a} (64.24)
BRS-20	15.33^{a} (60.00)	92.93^{a} (6.59)	1621.33^{a} (58.78)
Kamini Brinjal	13.67^{a} (60.94)	78.79^{b} (5.47)	1183.33^{a} (59.43)
CARI-1	13.33^{a} (66.94)	95.46^{a} (5.24)	1343.33^{a} (61.80)
Black Small	13.00^{a} (80.98)	34.97^{c} (9.54)	457.67^{b} (82.66)
Teispuri gol	10.00^{b} (67.03)	75.70^{b} (5.68)	856.00^{b} (64.72)
Brinjal IMP	8.67^{b} (74.75)	70.84^{b} (8.55)	529.00^{b} (80.06)
Tarun Brinjal	8.00^{b} (75.76)	84.99^{b} (6.64)	796.67^{b} (73.33)
Utkal Madhuri	7.67^{b} (75.52)	86.35^{b} (7.73)	663.33^{b} (76.70)
BRS-2	7.00^{b} (77.66)	87.99^{a} (8.99)	550.67^{b} (80.99)
Kashi Himani	6.67^{b} (75.26)	108.93^{a} (5.63)	796.67^{b} (74.49)
S.Em±/$CD_{0.05}$			
Treatments	0.392/ 1.114	1.192/ 3.391	32.232/ 91.650
Genotypes	0.960/ 2.729	2.921/ 8.305	78.951/ 224.495
Interaction	1.357/ 3.860	4.131/ ns	111.654/ 317.483

Values in parentheses indicate percentage reduction under stress relative to control. Means followed by different superscript letters within a column differ significantly (Tukey's HSD, $p \leq 0.05$).

The variation noted in reproductive traits among genotypes was closely associated with their capacity to sustain physiological activity and biomass accumulation under stress conditions. Genotypes that maintained higher growth rates and biomass production under waterlogging also showed lower flower drop and higher fruit set, suggesting that maintenance of assimilate supply plays a crucial role in sustaining reproductive development. Similar relationships between growth maintenance and reproductive stability under flooding or hypoxic conditions have been reported in several crop species (Bailey-Serres *et al.,* 2012; Sasidharan *et al.,* 2018). Overall, the results indicate that excess moisture stress significantly disrupts reproductive processes in eggplant; however, tolerant genotypes are capable of maintaining lower flower abscission and higher fruit set. Among the evaluated genotypes, '*S. undatum'*, 'Kamini Brinjal' and 'BRS-20' consistently exhibited superior reproductive performance, highlighting their potential as promising genetic resources for breeding programs aimed at improving waterlogging tolerance in eggplant**.**

While the present study did not evaluate the underlying biochemical or anatomical basis of genotypic tolerance, mechanisms such as enhanced antioxidant defense, adventitious root formation, aerenchyma development, and anaerobic metabolic adjustment have been reported to confer waterlogging tolerance in other Solanaceous crops (Bailey-Serres *et al.*, 2012; Yin *et al.*, 2023) and may plausibly contribute to the superior performance of '*S. undatum'*, 'Kamini Brinjal' and 'BRS-20' observed here. Direct evaluation of these mechanisms in the identified tolerant genotypes represents an important direction for future work.

Relationships between growth and reproductive traits

Correlation analysis revealed strong and significant relationships between growth performance and reproductive stability under waterlogging stress (Table 5). Total dry weight, leaf area, and CGR were strongly correlated with each other (r = 0.88–0.94, $p < 0.01$), and each showed a strong negative correlation with flower drop (r = −0.84, −0.76, and −0.79, respectively; $p < 0.01$) and a strong positive correlation with fruit set (r = 0.87, 0.79, and 0.81, respectively; $p < 0.01$). Flower drop and fruit set were themselves strongly negatively correlated (r = −0.92, $p < 0.01$), consistent with their inverse relationship as measures of reproductive success. These results provide

Table 5: Correlation coefficients among parameters under waterlogging

Parameters	Dry weight	Leaf area	CGR	Flower drop	Fruit set
Dry weight	1.00				
Leaf area	0.91**	1.00			
CGR	0.94**	0.88**	1.00		
Flower drop	-0.84**	-0.76**	-0.79**	1.00	
Fruit set	0.87**	0.79**	0.81**	-0.92**	1.00

direct quantitative evidence that genotypes able to sustain biomass accumulation and growth rate under waterlogging also retained more flowers and set more fruit, confirming that growth maintenance is a key determinant of reproductive resilience in this genotype set.

Mechanistically, the close association between vegetative growth and reproductive performance observed here is consistent with source–sink theory: water-logging-induced reductions in root function and canopy growth constrain the assimilate supply available to developing flowers and fruits, triggering hormonally-mediated abscission under carbohydrate limitation (Bailey-Serres *et al.*, 2012). Ethylene accumulation under hypoxic conditions is known to promote flower and fruit abscission by weakening the pedicel abscission zone, a response exacerbated when assimilate supply from source tissues is already compromised (Yin *et al.*, 2023). Genotypes that sustained greater biomass and growth rate under stress may therefore have maintained a more favorable carbon balance between vegetative and reproductive sinks, reducing hormonally-triggered organ shedding and supporting continued fruit development.

Limitations of the study

The present experiment was conducted under pot culture conditions which, despite enabling precise stress control, may not fully replicate the field conditions wherein root systems develop without spatial restrictions. Root confinement may alter root architecture and growth patterns compared to the field conditions, and soil physicochemical dynamics in pots may differ from natural field environments. Additionally, microclimate conditions under controlled settings may not fully capture field variability. Therefore, the results may be interpreted as comparative genotypic responses under standardized controlled conditions. Consequently, multi-location and multi-season field validation across diverse soil environments especially varied drainage conditions are necessary before finalizing any breeding recommendation. The study also focused on short-term waterlogging responses and early reproductive outcomes, with recovery assessed only through fruit set and soil redox potential. The dissolved oxygen was indirectly measured during stress imposition; standardized water-level control (5 cm above soil surface, monitored twice daily) was used instead of ensuring the comparable hypoxic exposure across genotypes. Multivariate approaches such as PCA, cluster analysis, and composite stress tolerance indices, along with post-stress recovery of vegetative growth parameters and fruit quality assessment, were considered beyond the specific scope of this growth-and-reproduction-focused study and have been addressed separately for this genotype set.

Conclusion: The present study demonstrated that short-term waterlogging imposed at the flowering stage significantly affects growth dynamics and reproductive performance of eggplant genotypes. Considerable genotypic variation was observed in the ability of plants to maintain biomass accumulation, growth rate parameters and reproductive stability under excess moisture conditions. Tolerant genotypes such as *S. undatum*, Kamini Brinjal and BRS-20 exhibited comparatively smaller reductions in leaf area, root biomass and growth rate indices (CGR, RGR and NAR), along with lower flower drop and higher fruit set under stress. In contrast, susceptible genotypes including Black Small, BRS-2 and Utkal Madhuri showed pronounced reductions in growth parameters and severe reproductive losses. These results indicate that maintenance of growth and assimilatory capacity plays a critical role in sustaining reproductive development under waterlogged conditions. Under the controlled conditions of this study, *S. undatum*, Kamini Brinjal, and BRS-20 demonstrated superior tolerance to short-term waterlogging at the flowering stage. These genotypes warrant further evaluation through multi-location field trials across diverse environments and seasons to confirm their breeding value for developing waterlogging-resilient cultivars. The quantitative relationships between growth maintenance and reproductive stability identified in this study provide a framework for selecting stress-resilient genotypes in breeding programs.

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