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Response of brinjal genotypes to drought and flooding stress

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Abstract

A study was conducted to evaluate the plant responses to drought and flooding in eight genotypes of brinjal (*Solanum melongena* L. cvs. I.I.H.R.3, BMG-1, BPLH-1, Arka Kesav, Arka Neelkanth, Arka Nidhi, Arka Shirish, Mattu Gulla) and a wild type *Solanum macrocarpon*. The results indicated the greater sensitivity of stomata under flooding compared to drought in brinjal genotypes. Genotype BMG-1 performed photosynthetically better under drought, while under flooding Arka Nidhi and Arka Keshav has shown higher photosynthetic rate. The closure of stomata in drought was gradual, while during flooding the closure was quick as shown the differential response of stomatal conductance in brinjal genotypes under these two conditions. During flooding, the better water balance was maintained by Arka Shirish and Arka Neelkanth, while during drought, Arka Keshav and Arka Neelkanth had the better water balance as indicated by greater RWC and osmotic potential values. The study further envisage that apart from the plant performance during stress, the recovery potential is an important aspects and particularly in flooding where the recovery process seems to be very slow as compared to drought. The better recovery after releasing flooding was found in Arka Keshav, Arka Neelkanth, IIHR-3 and BPLH-1 followed by *S. macrocarpon* and Mattu Gulla, while after releasing the drought stress, better recovery was observed in BMG-1, Arka Shirish, Arka Neelkanth, Arka Nidhi, *S, macrocarpon*, and BPLH-1.

Keywords: Brinjal, drought, flooding, photosynthesis

Introduction

Abiotic stresses such as drought, flooding, high, low temperatures and salinity, severely impairs plant growth and productivity worldwide. Due to climate change, erratic climate conditions pose a huge challenge to mankind as it results in the occurrence of flooding and drought situations. Furthermore, in view of various climatic change models scientists suggested that in many regions of world, crop losses due to increasing water shortage and flooding will further aggravate its impacts. The horticultural crops in general and vegetable crops in particular are sensitive to both drought and flood. Therefore, the damages caused to the standing crops by unseasonal rains or drought needs to be minimised. Although the genetic enhancement under the different breeding programmes is going on in various laboratories for developing a tolerant varieties to drought and flood, there is a need to adopt the amelioration strategies to minimize the effect of these environmental stress on horticultural crops. One such management strategy is to modify the plants root system to identify a suitable plant type or enhance or improve the tolerance to abiotic stresses in fruit and vegetable crops through grafting. However, selection of suitable rootstock is the most important aspect of grafting. In solanaceous vegetables, brinjal is found to be most hardy crop plant and commonly used as a rootstock for grafting to enhance the tolerance to both biotic and abiotic stresses. Interspecific hybrids are found to be of a high quality rootstock increasing the genetic diversity of the rootstock (King *et al*., 2010). Therefore, rootstocks are generally selected based on their morphological, physiological & biochemical response for developing a compatible graft, tolerant to abiotic and biotic stresses (King *et al*., 2010; Khah *et al*., 2011). The present study was carried out with an objective to evaluate the response of brinjal genotypes to flooding and drought stresses before using them as rootstock.

Materials and Methods

Rootstock genotypes of brinjal (*viz.* I.I.H.R.3, BMG-1, BPLH-1, Arka Kesav, Arka Neelkanth, Arka Nidhi, Arka Shirish, Mattu Gulla) and wild species *Solanum*

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macrocarpon were selected for the study and raised in portrays. Forty days old seedlings were transplanted in bigger plastic pots (12" dia.) containing garden soil and farmyard manure in the ratio 3:1 (v/v); each pot contained a single brinjal seedling. Plants were irrigated regularly and recommended practices were followed during rearing the plants. The plants were subjected to flooding and drought at flowering stage (35 days after transplanting). During the study, the day temperature varied between 25 and 28°C, whereas the night temperature was between 13 and 18°C. The maximum and minimum relative humidity (RH) varied between 45 and 65%.

The plants were divided into three groups at flowering stage. One group of potted plants was subjected to flooding by submerging them in fabricated tank filled with water. The water level was maintained at 2-3cms above the pot soil surface. The flooding was imposed for a period of 8 days. At the end of this period, the pots were removed from the tank and were allowed to recover. The second set of plants was subjected to drought by withholding the irrigation for a period of 10 days. The soil moisture during the drought stress was measured using soil moisture monitoring system (MP 406). The soil moisture was recorded 8 to 10% at the time of releasing drought stress. The third group of plants were grown under normal conditions as control.

The fully expanded healthy leaf (4th from top) was used for measurement of gas exchange with an open gas exchange system (WALZ Gas Exchange Fluorescence System, model GFS – 3000). The system was calibrated prior to measurement. The observations were recorded at a constant light intensity of 1500 µmol m^{-2} s^{-1}. The gas exchange parameters like net photosynthetic rate (P_N), stomatal conductance (g_s), intercellular CO_2 concentration (Ci) and transpiration rate (AE) were determined between 10:00 and 11:30h at 1200 ìmol m^{-2} s^{-1} µ photosynthetic photon flux density (PPFD using a red-blue LED light source built into the leaf chamber. During measurement the ambient CO_2 concentration varied between 370 and 380 ppm.

Plant water relation was studied by measuring osmotic potential and relative water content. The fully expanded 4th leaf from top was used for determining the leaf osmotic potential ($ø_s$). Leaf samples were collected from flooded, drought and control plants and were kept in deep freezer. After a week, the thawed leaves were squeezed and the extract was used in measuring OP using Wescor Osmometer (Wescor, 5200). All observations were made between 10.00 and 11.30 h. Relative water content was determined following the protocol described by Flower and Ludlow, 1986. Briefly, after determining the fresh weight (FW), samples were immediately hydrated, by floating on de-ionized water in a closed Petri dish, to full turgidity for 4 h under normal room light and temperature and turgid weight (TW) was obtained. Samples are then oven dried at 80 °C until they reach constant weight to determine dry weight (DW). RWC was calculated using the formula:

RWC (%) = [(FW " DW)/(TW " DW)] × 100

Results and Discussion

There was a difference in the pattern of P_N response when plants were subjected to flooding and drought (Fig 1). Under the flooding, there was recorded slight decrease in P_N initially up to day 2 and afterwards there was a sharp reduction P_N. The reduction in P_N during flooding was less in IIHR-3, Arka Nidhi, Arka Keshav and Arka Neelkanth as compared to other genotypes such as BMG-1, BPLH-1, Mattu Gulla, Arka Shirish and *S. macrocarpon*. The higher P_N was maintained by Arka Nidhi and Arka Keshav during the flooding. Under drought stress, there was a gradual reduction in P_N up to day 6 in all the genotypes. However, after day 6, there was a sharp decrease in P_N in IIHR-3, BPLH-1, Mattu Gulla and *S. macrocarpon* indicating the photosynthetic sensitivity in these cultivars to drought stress. The P_N was relatively higher in BMG-1 followed by Arka Keshav, IIHR-1 and Arka Nidhi at day 10 of stress. However, the effect of drought stress was almost similar in IIHR-3, Arka Nidhi, Arka Keshav, Arka Neelkanth and S. *macrocarpon* and Arka Shirish. The highest rate of P_N was maintained by BMG-1during drought.

The reduction in P_N was associated with concomitant reduction in g_s. The effect of flooding on g_s was greater compared to drought stress as indicated by the difference in quantum of reduction in g_s under these two conditions (Fig 2). The reduction in P_N was more sharper as compared to g_s under both the conditions (flooding and drought). There was a gradual reduction in internal CO_2 (Ci) in most of the genotypes under flooding, while under drought stress the decrease was high up to day 6 and again it increased in most of the genotypes except for IIHR-3 and BMG-1 (Fig 3). The AE rate has decreased considerably in flooding as well as drought in all the genotypes. The reduction in AE was higher under flooding than drought (Fig 4).

The RWC in control plants ranged between 78.3 and 89.4%, while in flooded plants there was a considerable increase in RWC and ranged from 85.3 to 98.0% and after that it decreases and ranged between 45.0 to 89.0% (Table 1). Among the genotype, the highest RWC was found in Arka Shirish and Arka Neelkanth during flooding. The lowest RWC was observed in BPLH-1 (45.0%) followed by Mattu Gulla (50.8%). However, when these cultivars were subjected to drought stress, there was no considerable change in RWC up to 4 day stress but at 10 days stress there was a significant decrease in RWC. The highest level of RWC was maintained by Arka Keshav and Arka Neelkanth (62.0-63.0%) followed by BMG-1, Arka Nidhi, S. *macrocarpon* (53-57%7) under drought. The lowest values of RWC was maintained by BPLH-1 Mattugulla Arka Shirish (42 -48%) under drought. The $ø_s$ in control plants ranged between -1.0 and -1.2MPa (Table 2). Similar to RWC, there was an increase in $ø_s$ value when plant were subjected to flooding up to 3 day, afterwards there was a decrease in $ø_s$ and ranged between -1.24 and -2.33 MPa. The maximum decrease in $ø_s$ was observed in BMG-1, BPLH-1 Arka Keshav and Mattu Gulla. In the plants subjected to drought stress, there was no substantial change in $ø_s$ at 4 days stress, while at 10 days stress there was significant decrease in $ø_s$ in almost all the genotypes and ranged between -1.94 (Arka keshav and Arka Neelkanth) and -2.63 MPa (Mattu Gulla).

Table 1. Effect of flooding and drought on relative water content (% RWC) of brinjal genotypes

Genotype	Control	Flooding	Drought	Control	Flooding	Drought
IIHR-3	83.6	98.9	81.4	82.0	66.5	44.6
BMG-1	86.8	85.3	85.3	83.0	53.3	53.3
BPLH-1	85.0	92.6	87.7	75.3	45.0	48.5
Arka Nidhi	86.8	92.4	84.8	79.1	70.1	53.0
Arka Keshav	89.4	94.7	87.0	84.0	54.3	63.2
Arka Neelkanth	85.7	94.7	88.0	80.5	88.1	62.0
Mattu Gulla	86.3	94.3	87.4	78.8	50.8	42.0
Arka Shirish	78.3	96.3	85.1	63.1	89.0	46.6
Solanum macrocarpon	89.2	91.3	93.6	86.7	77.3	57.3
SEm	1.092	1.240	0.904	2.193	4.245	1.955
CD(0.05)	3.245	3.684	2.686	6.515	12.613	5.808

Table 2. Effect of flooding and drought on osmotic potential (-MPa) of brinjal genotypes

Genotype	Control	Flooding	Drought	Control	Flooding	Drought
IIHR-3	1.03	0.86	1.23	1.30	1.66	2.55
BMG-	1.08	0.92	1.21	1.27	2.16	2.22
BPLH-1	1.00	0.85	1.22	1.33	2.12	2.43
Arka Nidhi	1.17	0.85	1.20	1.33	1.66	2.03
Arka Keshav	1.11	0.84	1.15	1.27	2.26	1.94
Arka Neelkanth	1.20	0.84	1.20	1.26	1.24	1.95
Mattu Gulla	1.19	0.89	1.17	1.26	2.33	2.63
Arka Shirish	1.18	0.84	1.14	1.32	1.27	2.45
Solanum macrocarpon	1.23	0.97	1.17	1.35	1.90	2.27
SEm	0.011	0.009	0.011	0.009	0.016	0.024
CD(0.05)	0.034	0.026	0.034	0.026	0.047	0.072

The physiological recovery in the flooded plants was very slow as indicated by the response of P_N, Ci and g_s (Table 3). Among the genotypes, the better recovery in P_N after releasing flooding was found in Arka Keshav, Arka Neelkanth, IIHR-3 and BPLH-1 followed by *S. macrocarpon* and Mattu Gulla. However, the P_N recovery was not on par with control plants even after 4 days of releasing the flooding. Cultivar Arka Nidhi did not recover after releasing flooding. The recovery in AE rate was very slow. The recovery in P_N was better in the plants after releasing the drought stress in all the genotypes. The best recovery was observed in BMG-1, Arka Shirish, Arka Neelkanth, Arka Nidhi, *S, macrocarpon*, and BPLH-1. There was an increase in AE in the plants after releasing water stress. The higher Ci values in flooded plants as compared to drought stress also indicate the slow recovery rate in flooded plants. The results indicated that the recovery in drought stressed plants was better than the plants subjected to the flooding.

The earliest detectable physiological symptoms of flooding stress include decreased P_N, g_s, and AE (Schaffer *et al.*, 1992). The results in the present study indicated that brinjal genotypes respond differentially to flooding and drought, and there was a genotypic variation in its response to both the stress conditions. There was a genotypic variation in the maintenance of leaf water status as indicated by a significant difference in RWC of the plants during flooding. Though, there was a decrease in RWC in all the genotypes after day 3, some of the genotype such as Arka Keshav and Arka Neelkanth maintained relatively the higher RWC and $ø_s$ during flooding. Similar results have been reported in citrus rootstock seedlings during short-term flooding period in citrus rootstocks (Garcia-Sanchez *et al.*, 2007). However, it was not the same in all the genotypes in the present study. For instance, in Arka Shirish, there was significant decrease in g_s during flooding though it has higher RWC during the flooding (Fig 3). Though the partial stomatal closure and reduced AE rate of leaves generally considered among the early responses of plants to soil water logging (Jackson *et al.*, 1978; Bradford and Hsiano, 1982) and have been reported in many other vegetable crops such as tomato, pepper and beans (Pezeshki, 1994), we have not found this response in all the genotypes of brinjal. Except for Arka Shirish, Mattu Gulla and *S. macrocarpon*, in other genotypes the reduction in stomatal conductance by day 2 was slow. It may be attributed to the maintenance of water status as indicated by high RWC and $ø_s$ during initial period of flooding. Huang *et al.*, (1994a) reported significant reduction in $ø_w$ and g_s in water logging

Table 3. Recovery of net photosynthesis (P_N), transpiration (AE), stomatal conductance (g_s) and internal carbon dioxide (Ci) in brinjal genotypes after releasing flooding and drought stress

Genotype	Pn ($\mu molm^{-2}s^{-1}$)			AE ($mmolm^{-2}s^{-1}$)			g_s ($mmolm^{-2}s^{-1}$)			Ci (ppm)		
	Control	Flooding	Drought	Control	Flooding	Drought	Control	Flooding	Drought	Control	Flooding	Drought
IIHR-3	12.27	12.65	17.03	3.66	2.59	3.43	0.106	0.242	0.242	243	203	213
BMG-1	21.35	2.25	29.18	6.12	0.60	5.10	0.205	0.364	0.364	245	276	210
BPLH-1	19.88	11.69	19.96	4.95	2.64	4.09	0.165	0.355	0.355	231	272	222
Arka Nidhi	26.12	N.R.⊗	20.76	6.71	N.R.⊗	5.05	0.234	0.389	0.389	232	288	222
Arka Keshav	23.57	13.62	18.88	6.17	2.69	4.10	0.207	0.445	0.445	231	284	188
Arka Neelkanth	19.66	12.76	24.78	5.15	2.25	6.90	0.157	0.407	0.407	218	279	235
S.Macrocarpon	14.05	7.75	20.06	3.94	1.69	5.36	0.109	0.628	0.628	220	294	212
Mattu Gulla	18.32	5.22	17.86	4.96	1.47	5.27	0.145	0.416	0.416	219	288	221
Arka Shirish	13.61	2.26	24.22	3.90	1.10	6.61	0.110	0.337	0.337	222	254	210

V Plants did not recover

sensitive cultivar but not in tolerant cultivar of wheat. However, in some cases under flooding, stomatal closure occurs without significant reduction in leaf water status (Zhang and Davies, 1986). In such cases, Zhang and Davies (1987) suggested that root-sourced ABA may be mainly responsible for the early stomatal closure following water logging. Tolerance to flooding results from an ability to maintain P_N and high g_s when flooded, and to avoid oxygen shortage in roots (Caudle and Maricle, 2012). In the present study, there was slight decrease in P_N by day 2. The reduction of P_N is one of the most important responses of plants to soil flooding which could be caused by stomata and non-stomata limitations to P_N and lead to severe yield reduction (Yordanova and Popova, 2007). However, Singh *et al.* (1991) found that the decline in P_N after 1 day of flooding, was independent of the g_s reduction and the association of P_N with the decrease in g_s was manifested at a later time. With prolonged flooding stress, the involvement of non-stomatal limitation could not be ruled out in P_N reduction. The non-stomatal limitation is mainly caused by the damage of photosynthetic apparatus and lower biochemical reactions efficiency of the P_N (Singh *et al.*, 1991).

The recovery of plants after the relieving flooding is very important aspect for flood tolerant genotypes. The recovery in P_N after releasing the flooding and water stress was associated with the concomitant recovery in the g_s. The recovery in P_N was slow and could not completely recover to the control level after 4 d of relieving flooding. The recovery was better in IIHR-3, BPLH-1, Arka Neelkanth, arka Keshav and *S. macrcarpon*. Similar observation was recorded by Singh *et al.* (1991) in snap beans. The higher internal Ci values in flooded plants as compared to water stress also indicate the slow recovery rate in flooded plants. The results indicated that though there was good recovery of photosynthetic characteristics in brinjal after releasing the stress, the recovery was slow in the plants subjected to flooding compared to the drought stressed plants.

When plants were subjected to drought stress, there was 80.0 to 93.0% reduction in net photosynthetic rate of all the genotypes at 10 day after stress except for BMG-1, which had 55% reduction in P_N. The maximum reduction in P_N in BPLH-1 and Mattu Gulla indicates the sensitivity of photosynthesis in these genotypes under stress. Stomatal closure is one of the first response to drought and is considered to be the main cause of impaired P_N induced by drought, as stomatal closure limits CO_2 availability to the mesophyll (Chaves, 1991). In view of this, a decrease in P_N under drought depends more on the availability of CO_2 in the chloroplast than on the $ø_w$ (Sharkey, 1990). In the present study, the decrease in g_s was greater as indicated by 94.0 to 97.0% decrease in g_s in almost all the genotypes except for BMG-1 which has about 86.0% reduction during drought. Apart from a reduction in P_N the decrease in g_s results in a considerable reduction in AE rate during drought as shown by 73 to 83.0% decrease in AE rate in almost all the genotypes except for BMG-1 which had 57.0% reduction in AE rate at 10 day of drought. According to Baker, (1993) there is a direct relationship between reduced Ci due to stomatal closure and decreases in P_N. As stomata close, the Ci, initially declines with increasing stress and gradually increases as drought becomes more severe (Lawlor, 1995). Initially, there was a decrease in Ci during stress. However, in all the genotypes except IIHR-3 and BMG-

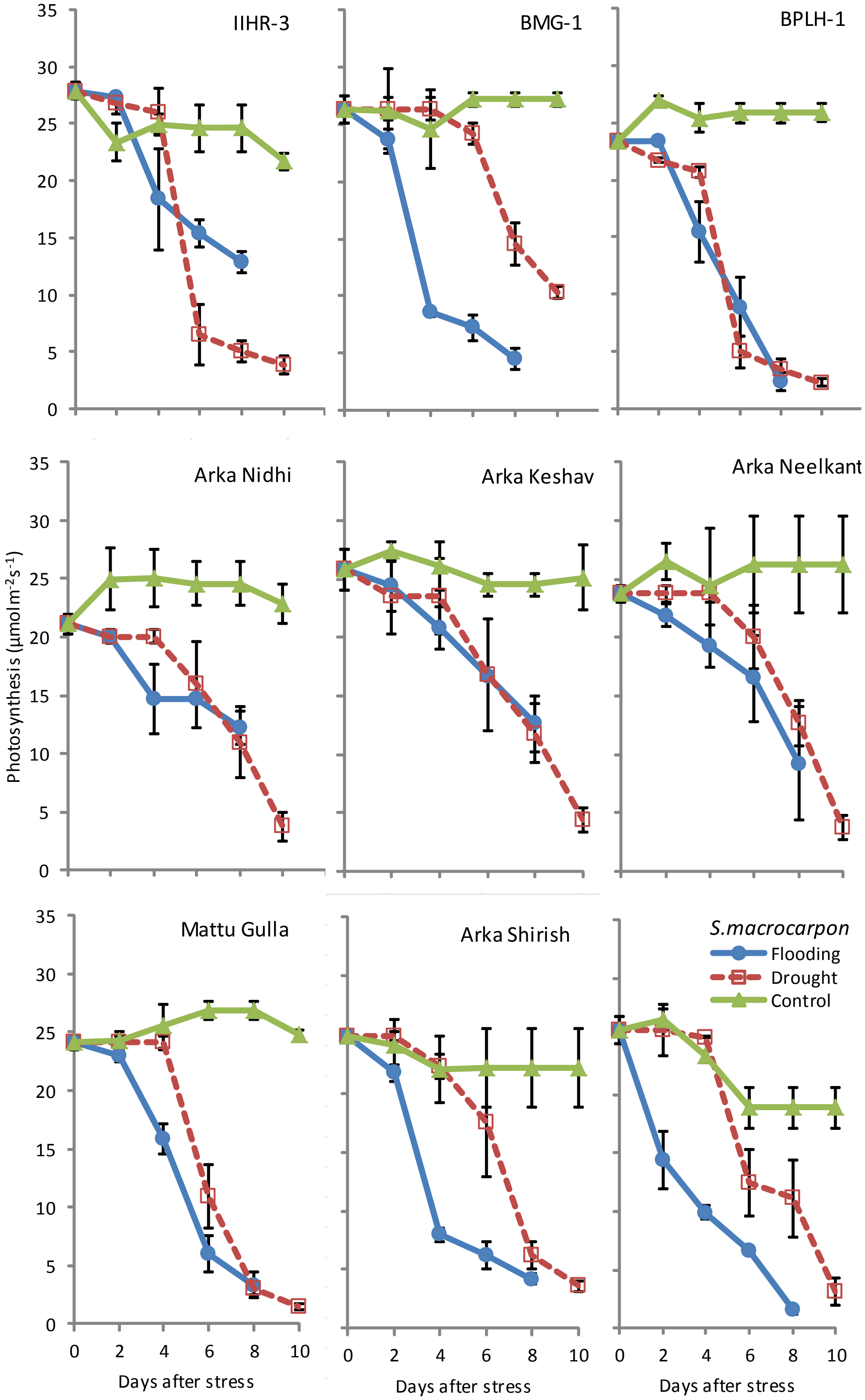

Fig. 1 Photosynthesis response of brinjal genotypes to drought and flooding

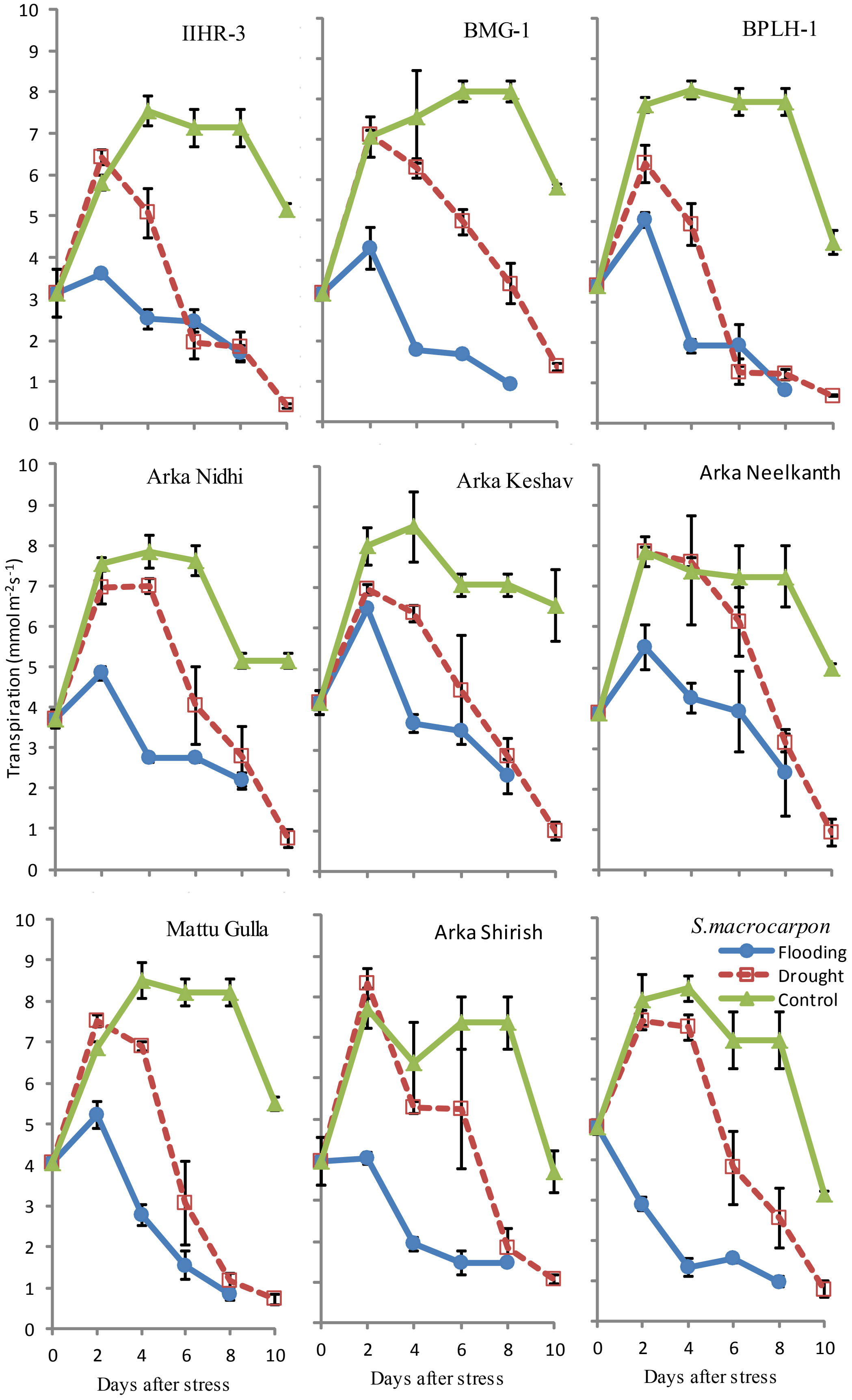

Fig. 2 Transpiration response of brinjal genotypes to drought and flooding

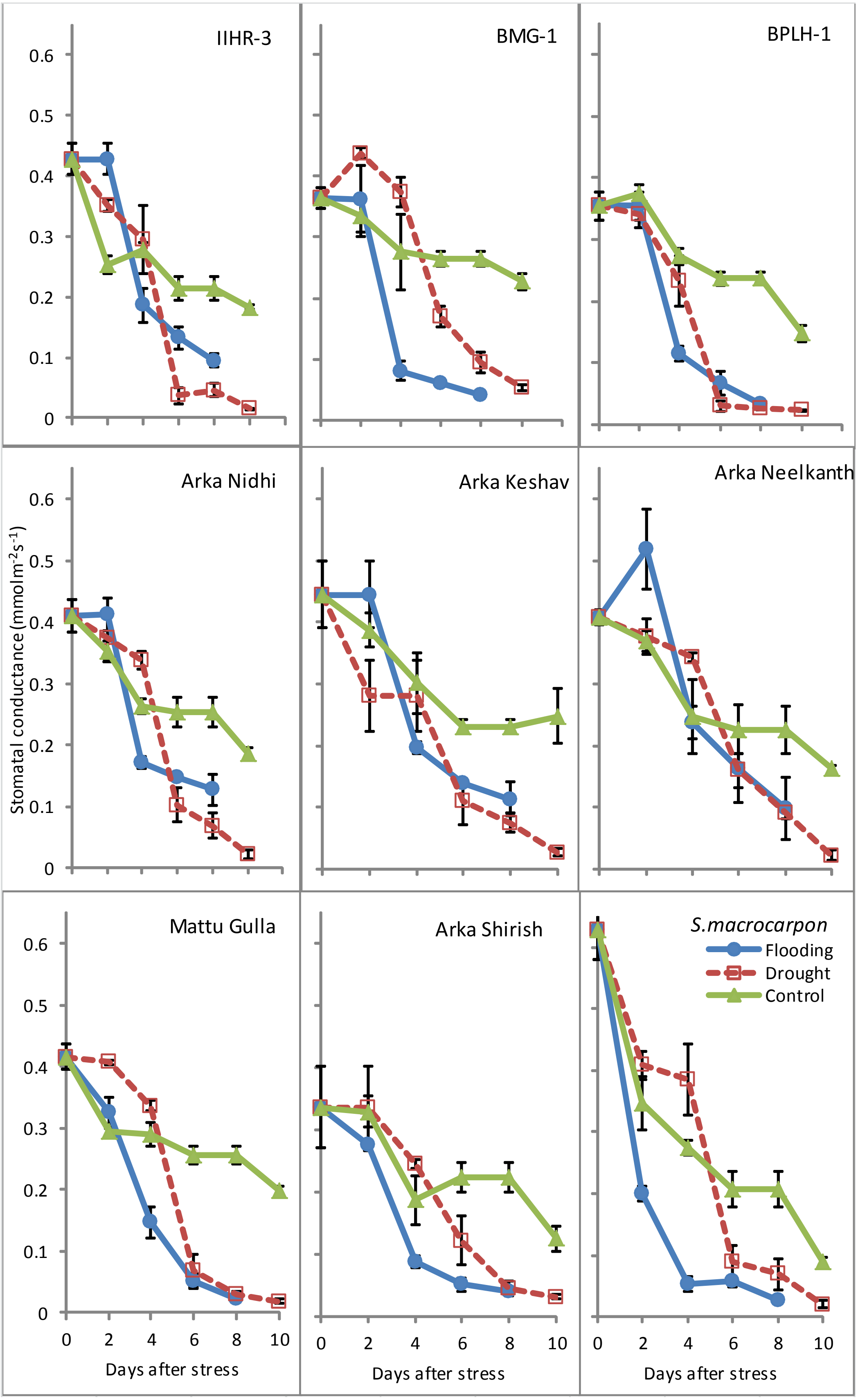

Fig. 3 Stomatal conductance response of brinjal genotypes to drought and flooding

1, there was an increase in Ci after 6 day drought stress. The decrease in Ci indicates the stomatal limitations dominate, with moderate drought, irrespective of any metabolic impairment. However, the increase in Ci after day 6 indicates the involvement of non stomatal limitations to photosynthesis in these genotypes. The decrease in P_N is, therefore, a result of both stomatal and non-stomatal limitations under drought (Yordanov *et al.*, 2003). The ability to maintain the functionality of the photosynthetic machinery under water stress, therefore, is of major importance in drought tolerance. The decrease in P_N under drought and flooding was associated to stomatal and non-stomatal mechanism (Del Blanco *et al.*, 2000; Samarah *et al.*, 2009). The nonstomatal factors involved during drought include photophosphorylation (Meyer and Genty, 1999), ribulose-1,5- bisphosphate (RuBP) regeneration (Lawlor, 2002), rubisco activity (Medrano *et al.*, 1997) and ATP synthesis. The RWC and $ø_s$ were not affected significantly up to day 4 of drought, indicating the maintenance of leaf turgidity in all the genotypes. However, after wards both the parameters decreased significantly in all the genotypes except for Arka Keshav and Arka Neelkanth which have high values of these parameter. Decrease in RWC has been known to induce stomatal closure which results in a parallel decrease in photosynthesis (Cornic, 2000). The RWC and $ø_s$ are important characteristics that influence plant water relations under drought. RWC is considered a measure of plant water status and used as an important index for drought tolerance. A decrease in the RWC in response to drought stress has been noted in wide variety of plants (Nayaar and Gupta, 2006). The decrease in relative water potential may also influence the leaf temperature (Siddiqe *et al.*, 2001). These parameters plays an important role in maintain P_N rate and the tolerance of the plant (Anjum *et al.*, 2011). Our study indicates that the higher RWC content during drought in genotypes such as Arka Keshav and Arka Neelkanth may be due to the accumulation of leaf osmolytes as indicated by more negative values of $ø_s$ in these two genotypes (Table 2). There was above 100.0% recovery in P_N and g_s in all the genotypes after releasing the drought stress.

The present study reveals that the environmental stresses such as flooding and drought have direct impact on the photosynthetic process in brinjal and the ability of these plants to acclimate to flooding and drought stresses is directly and indirectly associated with their ability to acclimate at the level of P_N, g_s and AE. The study further indicates that the effect of flooding was greater and faster on plants as compared to the drought stress as indicated by the gas exchange and plant water relation parameters under these two different stress conditions (Fig 1-4). Though, the stomatal closure is among the first response to drought and flooding, the closure of stomata in drought was gradual, while during flooding, the closure was quick as shown the differential response of stomatal conductance in brinjal genotypes under flood & drought conditions. The results indicated the greater sensitivity of stomata under flooding in brinjal genotypes. The genotype BMG-1 performed photosynthetically better under drought, while under flooding Arka Nidhi and Arka Keshav has shown higher P_N. The study further envisage that apart from the plant performance during stress, the recovery potential is an important aspects and particularly in flooding where the recovery process seems to be very slow as compared to drought.

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