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Short Communication

Physio morphological plasticity of rice (*Oryza sativa* L.) genotypes exposed to water-stress

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Abstract

Water stress conditions alter the normal plant equilibrium and lead to a series of morphological, physiological and biochemical as well as molecular changes in plants affecting growth and productivity. An experiment was conducted at the Department of Plant Physiology, College of Agriculture, Kerala Agricultural University during 2018-19 with to evaluate the physio-morphological plasticity of rice genotypes under water stress. Plants of six rice genotypes, Nagina 22, Karutha Modan (Ptb 29), Chuvanna Modan (Ptb 30), Annapoorna (Ptb 35), Jyothi (Ptb 39) and Swetha (Ptb 57) were maintained at 100 % and 50 % FC soil moisture in a rainout shelter. Physio morphological observations were recorded at the booting stage and Nagina 22, Karuthamodan and Chuvannamodan, being tolerant genotypes, exhibited better plasticity in terms of physiological and root traits towards water stress whereas, Annapoorna, Jyothi and Swetha failed to respond. In the tolerant genotypes, there was no significant reduction in Relative Water Content (RWC), Cell Membrane Stability (CMS), and Specific Leaf Area (SLA) whereas, there was a significant increase in the growth of root parameters. Biomass partitioning data revealed allocation of dry matter towards root under stress compared to control condition.

Key words: Climate change, Drought tolerance, Relative water content, Root traits, Specific leaf area.

India along with eight other countries, China, Canada, Columbia, Democratic Republic of Congo, Indonesia, Russia, and the U.S., hold around 60 per cent of the world's freshwater resources, but due to uneven distribution and improper utilization, India by the year 2019 became one of the extremely severe drought-prone countries (Wright, 2019). India witnessed nearly 17% of the drought years from 1901 to 2010 with severe impacts on agriculture, food security, water resource availability and economic status of the country (Kumar et al., 2013). Although India accounts for 4.2 % of the world's freshwater resources, nearly 80 % of fresh water is used for agricultural purposes. It is expected that 10-15 % of the water budgeted for agriculture is likely to decrease in the near future (Gautam and Bana, 2014).

As of 2019, nearly seventeen countries, home for one-fourth of the world population, are facing an extremely high incidence of drought. Every year the increasing severity of water stress was leading to disruption of agriculture, and the consequences were seen as famine. Drought causes numerous changes at physiological, metabolic and molecular levels which seriously impairs the growth and development of a plant (Zu et al., 2017). Among the cultivated crop plants, rice is the most sensitive crop for water stress conditions. Turgor pressure acts as a driving force for the enlargement of plant cells

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thereby contributing to growth which gets severely affected under water stress (Jaleel et al., 2008). Drought stress also affects physiological processes such as transpiration, ion uptake, photosynthesis, translocation, respiration, carbohydrate and nutrient metabolism in plants.

Tolerance to water stress varies not only with genotypes but also environment, and their interaction. The use of physiological traits for indirect selection would be vital in strengthening yield based selection methods (Lonbani and Arzani, 2011; Sheshshayee et al., 2011; Beena et al., 2012). The nature and characteristics of the root system are considered as the major factors affecting plant response to water stress. Root length, root density, and root diameter serve as measures to characterize the root system development of rice cultivars. Root length density also influences the potential of water uptake (Sharp and Davis, 1985). In case of rainfed lowland rice ecosystem root:shoot allocation of biomass greatly varies due to non-availability of sufficient photosynthates. The proportion at which assimilates are partitioned towards root increases under water stress conditions (Azhiri-Sigari et al., 2000). With this background, this study was conducted to analyze the changes in physio-morphological traits associated with water stress in selected drought tolerant and susceptible rice varieties.

A pot culture experiment was conducted with six rice genotypes i.e., Nagina 22, Karuthamodan (Ptb 29), Chuvannamodan (Ptb 30), Annapoorna (Ptb 35), Jyothi (Ptb 39), and Swetha (Ptb 57) at the Department of Plant Physiology, College of Agriculture, Vellayani, Kerala Agricultural University. The plants were maintained at two different moisture levels; control plants at 100 percent field capacity of soil moisture (control plants) and those at 50 per cent field capacity (stressed plants) by following gravimetric method as described by Fontenelli et al. (2016). At booting stage observations on root, and on physiological and biochemical parameters were taken.

Relative leaf water content was measured based on the method described by Turner (1981). Cell membrane stability index was estimated as per the procedure described by Blum and Ebercon (1981). Specific leaf area was calculated from plants under 100 % and 50 % FC soil moisture by selecting a fully expanded leaf.

The area of leaf was recorded with the help of graphical method. Leaf samples were oven dried at 70°C for about 48 hours until constant weight was obtained. Specific leaf area was calculated using the following equation

SLA (cm/g) = (LA / DW)

Where, LA was the leaf area; DW was the dry weight.

Plants were grown under 100 % and 50 % FC using gravimetric method as per the protocol given by Chaudhary et al. (2012). Starch accumulation in roots under control and stress condition was estimated using anthrone reagent as per the protocol given by Sadasivam and Manickam (1996).

For measuring root traits, root samples were collected from control and stressed plants at booting stage by carefully removing soil mass from pots. The adhering soil particles were removed by washing with high jet of water and mean values of the parameters root length (cm), root volume (ml) by water displacement method, root dry weight, root: shoot ratio (root: shoot ratio = root dry weight / shoot dry weight) and specific root length (specific root length = root length in cm/ root dry weight in g) were recorded. Leaf weight ratio, stem weight ratio and root weight ratio were determined after drying the samples at 80º C for 48 hours until they reached a constant weight. The following equation was used:

X weight ratio = X dry weight / Total biomass

(X : Leaf /Stem /root)

Being a sessile organism, plants encounter a wide range of adverse environmental conditions. Among these stresses curtailing crop growth and productivity, water deficit severely affects the sustainable production of a crop (Foley et al., 2011). Relative water content studies the tissue water status and is closely related to the leaf water potential (Sinclair and Ludlow, 1985). As a response to water stress, a reduction in relative water content was noticed in rice genotypes. Among the genotypes the least reduction in RWC was recorded in Nagina 22, which showed 89.34 % in control and 85.37 % under stress showing a reduction of 4.44 %, whereas among the other genotypes Annapoorna recorded severe reduction in RWC, which was 83.78 % under control condition to 71.96 % under stress showing a reduction of 14.11 % (Table 1). Prasad et al. (2017) reported similar kind of results with rice genotypes Nagina-22, NDR 97, SuskSamrat and Swarna Sub1. Nagina-22 showing a lowest reduction of 4 % under stress whereas the highest reduction was noticed in Swarna sub 1 with 25 % reduction in RWC. Nithya et al., 2020 reported that path analysis of physiological traits with yield components of 81 rice genotypes revealed that the relative water content had maximum positive direct effect on yield.

Reduction in SLA was noticed in all the genotypes under water stress condition except Jyothi. Among the genotypes the highest reduction in SLA was noticed in Nagina 22, which was 369.43 $cm^2 g^{-1}$ under control and 214.90 $cm^2 g^{-1}$ under stress, showing a reduction of 41.86 %, whereas there was no reduction in SLA in Jyothi with 181.01 $cm^2 g^{-1}$ under control to 183.73 % under stress, showing an increase in SLA by 1.5 % (Table 1). Specific leaf area (SLA) indicates thickness of leaf and density (Thomas, 1983). Wright et al. (1994) reported a significant reduction in SLA in tolerant genotypes under water stress. Higher SLA indicated more leaf area per unit biomass, resulting in higher transpiration surface and poor photosynthetic machinery due to thinner leaves. Results were in accordance in this study, where Nagina-22 and Karuthamodan recorded high SLA in control and reduced significantly values in stressed plants, favouring stress tolerance.

The results of cell membrane stability index showed a significant variation among the genotypes. Among the genotypes, Chuvannamodan recorded the highest value of cell membrane stability index with 97.10 %, followed by Karuthamodan (96.77 %), whereas genotypes Jyothi (83.11 %), Annapoorna (84.36 %) recorded the lowest values. The mean reduction in cell membrane stability index among the genotypes was 7.9 % (Table 1). Premachandra et al. (1990) reported that the relation between electrolyte leakage and the ability of plants to tolerate drought stress were well correlated with cell membrane stability measured by electrolyte leakage. In the present study, the tolerant genotype Nagina-22 expressed high cell membrane stability index (94.35 %), whereas lowest value was in Jyothi (83.11 %).

Highest leaf area was recorded in genotype Karuthamodan (674.85 cm^2) under water stress showing a decline of 13.96 % compared to control (790.35 cm^2). The lowest leaf area under water stress was recorded in Swetha (300.22 cm^2) showing a decline of 35.54 % compared to control (481.87 cm^2) (Table 1).

Table 1. Effect of water stress on RWC, SLA and CMSI of rice genotypes

Genotypes	RWC (%)		SLA ($cm^2 g^{-1}$)		CMSI (%)	Leaf area (cm^2)	
	Control	Stressed	Control	Stressed		Control	Stressed
Nagina 22	89.34	85.37	369.63	214.90	94.35±1.66	762.99	406.19
Karuthamodan	87.06	83.26	331.73	239.45	96.77±1.21	790.35	674.85
Chuvannamodan	88.22	82.94	290.47	206.18	97.10±0.83	713.43	440.23
Annapoorna	83.78	71.96	265.72	261.13	84.36±1.62	557.14	484.18
Jyothi	83.55	75.29	181.01	183.73	83.11±1.51	452.37	314.24
Swetha	84.04	76.25	308.83	256.30	84.34±1.52	481.87	300.22
C.D.(0.05)	0.84	0.28	10.39	3.54	4.43	67.21	22.89

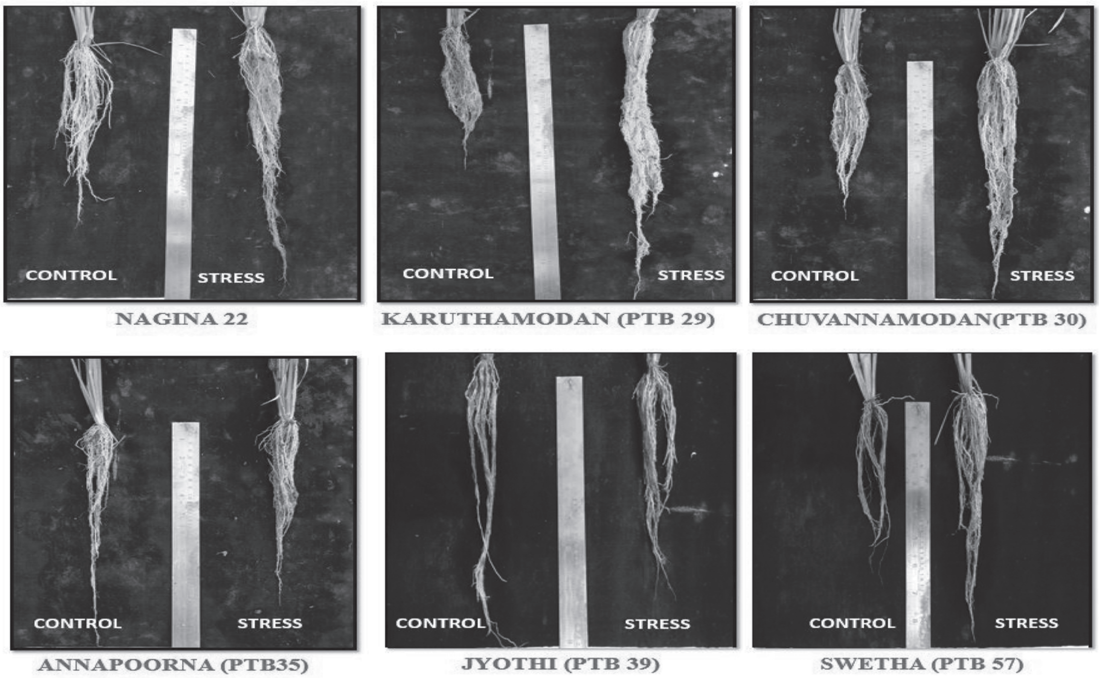

Plate 1. Effect of water stress on root length (cm) of rice genotypes at booting stage

Karuthamodan recorded the highest root length (38.46 cm) in water stress condition showing an increase of 34.57 % compared to control plants. Root system of the lowest was recorded from Annapoorna on exposure to water stress, with a root length of 14.76 cm, showing a decrease of 66.21 % compared to the control plants (Table 2).

Rice genotypes studied showed a significant variation for root volume in both control and stress conditions. In water stress condition, genotype Karuthamodan with 19.5 mL showed an increase of 54.27 % compared with control counterparts (8.91 mL). The lowest increase in root volume under stress condition was recorded in Jyothi (4.86 mL), showing an increase of 9.5 % compared to control plants (4.4 mL) (Table 2). Under control conditions highest root dry weight was recorded in Karuthamodan (2.88 g) whereas lowest value was recorded in Swetha (0.69 g). The rice genotypes produced high dry mass in exposure to stress, with highest root dry weight observed in Karuthamodan with 4.27 g having an increase of 32.52 %, and lowest root dry weight observed in Jyothi (0.56 g), with a decrease of 48.30 % (Table 2). Beena et al., 2017 also studied the genetic diversity of root traits in rice and reported that Karuthamodan posses long and thick root system.

Table 2. Effect of water stress on root parameters of rice genotypes

Genotypes	Root length (cm)		Root volume (mL)		Root dry wt. (g)		Specific root length (cm g^{-1})	
	Control	Stressed	Control	Stressed	Control	Stressed	Control	Stress
Nagina 22	27.96	37.00	8.10	13.96	1.75	2.12	24.06	27.67
Karuthamodan	25.16	38.46	8.91	19.50	2.88	4.27	22.77	36.36
Chuvannamodan	21.80	30.46	7.40	12.97	1.34	1.86	22.90	31.75
Annapoorna	24.53	14.76	3.96	4.46	0.97	0.64	16.82	15.14
Jyothi	24.63	20.66	4.40	4.86	1.08	0.56	15.17	13.07
Swetha	18.90	23.03	4.75	5.66	0.69	0.70	20.48	28.57
C.D.(0.05)	1.46	0.49	10.39	3.54	0.22	0.07	2.35	0.80

Genotype Karuthamodan recorded the highest specific root length (36.36 cmg^{-1}) in water stress condition showing an increase of 37.36 % compared with specific root length of control plants i.e., 22.77 cmg^{-1} whereas, lowest value was recorded in Jyothi (13.07 cmg^{-1}) under water stress condition, showing a decrease of 13.88 % as compared to control plants (15.17 cmg^{-1}) (Table 2).

Deep rooting is a complex trait governed by the angle of root growth and maximum length of the root (Abe and Morita, 1994). Increase in root volume directly makes root capable of mining to greater depths in search of water and is beneficial in extracting water from deeper layers of subsoil when subjected to water stress. Ingram et al. (1994) reported a greater root length density below 20/30 cm when rice crops were grown under rainfed lowland scenario. Length and volume of genotypes Nagina 22, Karuthamodan and Chuvannamodan under stress treatment were in accordance with this. Renukha et al. (2013) also reported a significant variation in root length at genotypic and treatment level, with tolerant genotype like NLR 33671 exhibiting the highest root length, followed by NLR 3010. Mean increase of 25.9 % of root dry weight was noticed under stress compared to control. Beena et al., 2018 also reported that root dry weight increases under water stress condition in tolerant rice genotypes. Kavitha (2014) reported a similar significant difference for root dry weight among the genotypes and a progressive increase in dry weight up to 60 DAS. Turner, et al. (2001) reported that specific root length (SRL) was positively correlated with increased crop productivity under water stress. Rejeth et al., 2020 also reported that root traits are positively correlated with yield under water stress condition. In this study genotypes Karuthamodan and Chuvannamodan showed a significant increase for specific root length under water stress condition, whereas Annapoorna, Jyothi and Swetha genotypes did not show any significant difference under 100 % and 50 % FC.

In general all the genotypes recorded higher leaf weight ratio and stem weight ratio than root weight ratio. Annapoorna recorded the highest leaf weight ratio (LWR) (0.48) under water stress condition whereas Nagina 22 recorded the highest LWR under control. Stem weight ratio (SWR) was found highest in Karuthamodan (0.44) under water stress condition whereas Chuvannamodan recorded highest SWR under control conditions (0.47). All the genotypes recorded an increase in root weight ratio (RWR) under stress conditions compared to control. Significant increase in RWR was observed in Karuthamodan, Nagina 22, and Chuvannamodan in stressed plants. The highest RWR was recorded from Karuthamodan under stress (0.21) whereas lowest value was recorded in Jyothi (0.11). In controlled condition the highest RWR was recorded in Karuthamodan (0.15) and lowest in Jyothi (0.10) (Table 3).

Biomass partitioning was found to be vary both at treatment and genotypic levels. The amount of assimilates that were diverted to roots was higher under stress condition than in control. Kadam et al. (2015) studied rice and wheat genotypes under stress and reported an increase in root and stem biomass, and a decrease in leaf biomass under stress. A similar trend was noticed in genotypes Nagina-

Table 3. Effect of water stress on biomass partitioning and starch in accumulation in roots of rice genotypes

Genotypes	Leaf weight ratio(LWR)		Stem weight ratio(SWR)		Root weight ratio (RWR)		Starch accumulation (mg/g)	
	Control	Stressed	Control	Stressed	Control	Stress	Control	Stressed
Nagina 22	0.46	0.44	0.42	0.37	0.11	0.18	1.99	3.04
Karuthamodan	0.42	0.39	0.42	0.38	0.15	0.21	1.50	3.52
Chuvannamodan	0.45	0.40	0.47	0.42	0.07	0.16	1.59	2.62
Annapoorna	0.45	0.48	0.46	0.42	0.08	0.09	1.33	1.35
Jyothi	0.44	0.45	0.45	0.44	0.10	0.11	1.54	1.87
Swetha	0.45	0.38	0.43	0.50	0.11	0.12	1.56	2.13
C.D.(0.05)	0.02	0.006	N/S	0.01	0.01	0.005	0.18	0.06

22, Karuthamodan and Chuvannamodan in our study. This result was also supported by Naresh et al., 2018.

Among the genotypes, a significant increase in starch was noticed in roots of Nagina 22, Karuthamodan and Chuvannamodan when exposed to water stress. In 100 % FC the highest accumulation of starch was noticed in Nagina-22 with 1.99 mg/g whereas, under stress condition Karuthamodan showed the highest accumulation with 3.52 mg/g followed by Nagina-22 (3.05 mg/g), whereas lowest value recorded in Annapoorna (1.35 mg/g) and was at par with Jyothi with 1.87 mg/g (Table 3). Stored starch in roots serves as a driving force for grain development and shows variations in accumulation in tolerant genotypes under water stress. Genotypes Nagina-22, Karuthamodan and Chuvannamodan recorded a mean increase of 43.8% under stress. These findings are in line with those of Singh et al. (2013) that susceptible genotypes BPT-5204 and Saita exhibited lowest increase in starch content in their roots under water stress.

Under water stress deep root system played a prominent role in mitigating water stress condition and this trait was noticed in Nagina-22, Karuthamodan and Chuvannamodan. Deep root system also helped in better exploration of soil water and nutrient resources. Biomass partitioning details also revealed a similar kind of result as higher dry matter was partitioned towards root under stressed situation for better root growth than well watered plants. In the present study, physiological parameters such RWC, CMSI and traits such as SLA, root length, root volume and root dry weight were found to be significantly contributing to drought tolerance in rice. The findings on RWC, CMSI, SLA, root traits and biomass partitioning in this study would help in selecting traits of importance for breeding drought tolerant rice.

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