Chapter

Characterization of Selected Drought Tolerance Rice Landraces: A Case in Kerala, India

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Abstract

Rice is a staple food of more than half of the world's population. The successful cultivation of rice depends on a variety of climatic and soil conditions. There are lot of factors both biotic and abiotic, which affect the growth and yield of crops. Drought is one of the major abiotic stresses, which leads to drastic decline in the production of rice worldwide. In the present situation of severe climatic change, the scarcity of fresh water is diminishing at an alarming rate. Due to the sensitivity of rice crop and the enormous requirement for optimum yield, drought affects rice when compared to other food crops. Rice germplasm is endowed with scores of varieties and landraces that are reservoirs of genes which is capable of withstanding various abiotic stresses. These landraces can be used to tackle this abiotic stress and can fulfill the increasing demand of food.

Keywords: abiotic stress, drought, heat shock protein, landraces, proline

1. Introduction

Human population is exploding day by day. By 2050, the world population is expected to reach the mark of nine billion, and to feed this enormous population, the food production needs to be increased by more than 50% [1]. Rice is agronomical and nutritional, one among the most important staple food satisfying the need of the calorie intake of approximately half of the population. To meet the future demand for food, anticipated from the projected world population increase, there is an urgent need to take all necessary steps to enhance the productivity of rice. The in-depth understanding of plant responses to abiotic stress needs to be achieved as the climate prediction models have demonstrated the increased rate of abiotic factors like drought, floods, salinity, and soaring temperature during the crop growing periods [2, 3]. Of the 470 Mts of worldwide production of rice, 90% is contributed from the Asian countries. The uneven pattern of rainfall has led to a marked decrease in the yield of upland cultivation. The reduction in the amount of fresh water causes serious stress to the crop production since nearly 5000 L/kg of water is required [4].

The staple food for almost two-third of the world's population, the rice is both nutritional and has medicinal values. Rice is a major source of carbohydrates, which are broken down into glucose upon digestion. Thus, it becomes a rich source of energy. The presence of resistant starch adds to its nutritive value. Since, rice lacks sodium and cholesterol; it is greatly preferred as the staple food. Rice is gluten free and rich in vitamins like thiamine, niacin, iron, and riboflavin. The absence of preservatives and gluten makes it a preferable choice. In addition to the nutritional properties, there are some notable medicinal values for rice. The resistance starch encourages the growth of beneficial bacteria, which helps in keeping the bowel healthy. The high amount of insoluble fiber present in the whole grain is believed to be protective against many varieties of cancer. In addition to being the best food in dysenteric problems, it is also considered to be tonic, fattening, and aphrodisiac [5].

The IRRI 2010 have projected that rice requirement of 496 Mt in 2020 will increase up to 555 Mt in 2035 and will see an overall increase in the future. Global rice production in 2019 has been capped at 512 million tones [6]. Global rice consumption is recorded 494.5 million tons in 2019/20 [7]. Demand for rice is estimated to be 2000 million metric tons by 2030 [8], which has to be answered by immediate promising improvement in rice production in this era of drastic climate change and drought [9]. Of the total worldwide, rice production more than 50% of the area is rainfed and which accounts one quarter of total rice production [10]. World rice production is geographically concentrated in Western and Eastern Asia. Asia is the biggest rice producer, accounting for 90% of the world's production and consumption of rice. Asian farmers still account for 92% of the world's total rice production. Around 280 major rice varieties have been reported from India. There are thousands of strains of rice today, including those grown in wild and those-which are cultivated as crop.

Rice is grown under diverse conditions such as irrigated, rainfed lowland and flood prone ecosystems. It is the only crop that is grown in most fragile ecosystems and cultivated in all the agro-climatic zones below sea levels to the hilly areas. In rainfed ecosystems, drought is the major obstacle for rice production. As it is evident, drought seems to be the major obstacle in the rainfed ecosystem and causes severe loss in grain production. Pandey et al. have cited the example of various Indian states like Jharkhand, Orissa, and Chhattisgarh, which faces severe drought that had recorded a yield loss of 40% valued more than $650 million [11]. Rice production in Kerala is tapering down, yielding just 6.3 lakh tone last year. The state produced only about 15% of its requirement in 2008 compared to 45% in 1956. The work undertaken by the Kerala Agricultural University focusing on the landraces pointed out the fact that Palakkad District contributes around one-third of the total state production [12].

2. Drought, the severe abiotic factor affecting rice production

There are various factors affecting the growth development and yield of agriculture crops which can be classified as biotic and abiotic factors. According to the International Rice Research Institute (IRRI, 1998) projection, over the next two decades, India, Pakistan, the Philippines, and Vietnam will suffer, due to the sharp decrease in per capita water availability. Drought will be the most important abiotic factor which will lead to inter sectorial competition drastically affecting the need of agricultural water [13]. In Asia, approximately 34 million ha of shallow rain-fed lowland rice and 8 million ha of upland rice, totaling approximately one-third of the total Asian rice area are subjected to occasional or frequent drought stress [14]. Continuous drought and fresh-water scarcity has led to the increase of salinity level again giving rise to a new abiotic stress [15]. As paddy crop suffers from water stress at soil water contents even above field capacity drought affects the yield output. Farmers in most rainfed ecosystems, therefore, use the less risky traditional varieties and small amounts of fertilizers which often cause low production.

Drought is the stress situation that lowers plant water potential and turgor pressure and alters the execution of normal physiological process. The challenge of drought is even greater for crops such as rice when compared with other crops such as maize and wheat due to its relatively higher water needs [16]. Around 4000 L of water is required for the production of 1 k of rice which is about double the amount needed for other crops [17]. Since rice cultivars have been grown since time memorable under flood irrigation conditions, rice is very sensitive to deficiency in soil water level as compared to many other field crops; the production systems of rice are more sensitive to drought and possess relatively weak resistances [18]. The water deficit arising with the drought can be classified as the – severe water deficit: available soil moisture 40–50%; moderate water deficit: available soil moisture 50–60%; mild water deficit: available soil moisture 60–70%.

Sarvestani et al. has reported that as a result of reduced water level in the soil, the plant root stem uptakes reduced water leading to the yellowing of leaves due to the reduction in chlorophyll content [19]. The first noticeable response in respect to drought is the rolling of leaves which can help in reducing the internal water level [20]. Henderson et al. has also reported that leaf tip drying is also observed in drought affected plants [21]. The rice genotypes that possess high leaf rolling ability can produce high yield in comparison to other genotypes [22]. Bosco et al. have sustained the fact that the decrease in yield is a result of decrease in plant height, reduction in leaf area, and tillering ability [23]. Root characteristics, leaf temperature, flowering time, panicle exertion, maturity time, and spikelet fertility also affect the crop production [24]. An additional factor occurring due to drought stress resulting in yield reduction is the closure of stomata causing a sharp decrease in carbon dioxide intake directly reducing the photosynthesis rate [25]. The duration and severity of water scarcity determines the rate of reduction of life cycle and the extent of grain filling [26].

3. Drought tolerance in rice landraces

Erratic rainfall distribution is the most limiting factor of growing upland rice in India. Identification of relevant physiological stress tolerance mechanism and the genetic improvement of drought tolerance in crop plants need great attention [27]. Traditional varieties, wild relatives, native species, and modern cultivars together represent the wide genetic resources of the agriculture cops which form the basis of global food security. Genetic diversity provided farmers, plant physiologists, plant breeders, and biotechnologists with options to develop, through the natural selection, breeding and genetic manipulation, new crops, that are resistant to pests, diseases, and adapted to changing environments (abiotic stress) [10].

Landraces are generally called as the native varieties. They harbor a great genetic potential for crop improvement. As these are not subjected to subtle selection over many decades, they are endowed with tremendous genetic variability. This heterozygosity aids in the adaptation of landraces to wide agro-ecological niches and also possess unmatched qualitative traits and medicinal properties. This rich variability of complex quantitative traits still remains unexploited. Rice cultivation in the Kerala state of India situated in the southern Western Ghats dates back to 3000 B.C. [28]. There is immense genetic diversity in the germplasm of both wild and cultivated rice. The landraces present in the state are named according to morphological features, seed color, specific uses, growing conditions, etc. South Asian region is considered as the primary center [29], and Jeypore tract of Orissa is considered as the secondary center of rice and its wild relatives [30] in addition to the humid tropical coastal and mid-lands of Kerala with innumerable wild relative together with more than 600 landraces [31].

Landraces are also important genetic resources for resistant to pest and fungal diseases. "Velluthachira," "Bengle," and "Bhumanasam" are resistant to Rice gall midge; "Thadakan" is resistant to blast,"Buhjan" and "Laka" are resistant to brown plant hopper [32]. Owing to their specific domination in geographical niches, landraces have gene of resistance to abiotic stresses, which have not been widely used or incorporated into modern varieties. The South Indian Landraces "Norungan" and "Noortripathu" are now used as donors for drought tolerance [33].

The present scenario of predicted global food security needs to be tacked with the better understanding of natural selection, germplasm, responses of plant to abiotic stress, and improved yield under stress conditions. The identification of a traditional race, which can thrive well in stress prone area and genetic manipulation of plants that can maintain higher photosynthetic rates, better foliage growth and improved yield under stress conditions requires to be attended [34, 35]. There are a number of comprehensive reviews on drought response in plants [36–38]. Kamoshita et al. have reviewed the drought responses in upland rice [39]. Drought tolerance studies of the under-utilized heterozygous landraces which are bestowed with numerous beneficial properties are the need of the hour.

4. Screening of drought tolerance in rice

One of the major phenomena encountered in almost all rice growing environments is drought. The methods to mitigate are to cultivate either the genotypes which have the capability to strive in the water scarcity or to develop new cultivars which can withstand the drought stress. The factors, which might have operated to create intra-varietal differences in the cultivated rice of Kerala can be attributed to the diverse climatic and ecological conditions which would have led to selection of varieties. The investigation was carried out to find out the best landrace with yield in both stressed and non-stressed environment which can be suggested as the best cultivar for upland cultivation. The recent approaches by functional genomics and genomics assisted breeding of abiotic stress tolerance are helpful in generating valuable information for engineering stress tolerant plants for their use in sustainable agriculture.

Exploration and collection of different accessions of landraces from different districts of Kerala were carried out. After primary screening, the following germplasm were selected to study the effect of drought and the ability of landraces to withstand it (**Tables 1** and **2**).

The seeds of selected landraces varieties were kept for germination. The approximate period for germination was recorded to be 7 days. After all the seeds were germinated, they were transferred to drought condition by withholding the water supply. The withholding resulted in the appearance of wilting signs. These seedlings were screened for their regaining capacities after re-watering. After completion of 7 days of germination, the seedlings were transferred to drought by withholding the input of water. Neither of them could survive 4 days in drought and they wilted and died. In the second phase, drought period was reduced to 3 days. After 72 hours of drought, the seedlings did show signs of wilting but once re-watered, they started to regain. The regaining capacity of the landraces showed district variation. After normal growth for 7 days the seedlings were transferred to drought condition. The areas of the leaves were recorded prior to their transfer into drought with the help of a graph paper and recorded as L1. After 3 days of drought, the leaves showed signs of wilting and started to roll. At that time, the leaf area was again calculated with the help of a graph paper and recorded, L2. Induction of heat shock proteins was done and quantified together with the total carbohydrates and proline. The healthy grains of the selected landraces along with check varieties were

SN	Name of landraces
1.	Navara punja
2.	Navara
3.	Oarkazhama
4.	Vadakan
5.	Vellaryan
6.	Malakkaran
7.	Mundakan
8.	Kuthiru
9.	Kazhama

Table 1.
Landraces selected.

SN	Landraces	Plumule	Radicle
1	Navara punja	9.425	11.27
2	Navara	9.275	11.9
3	Orkazhama	9.675	15.6
4	Vadakan	9.65	10.02
5	Vellaryan	9.7	10.85
6	Malakaran	10.975	15.02
7	Mundakan	9.75	14.27
8	Kuthiru	9.77	12.27
9	Kazhama	8.82	13.27

Table 2.
Plumule and radicle length (cm).

germinated under controlled condition by soaking in double distilled water 72 h, after germination and 50 seeds were exposed to a temperature of 42°C at uniform time intervals. The amount of protein accumulated was correlated with the level of drought tolerance of different landraces and the control and was estimated by the method of Lowry et al. [40]. Accumulation of proline is seen under stress conditions which is used as an energy source for survival and growth [41]. Proline is an osmoregulatory molecule which allows the cell to balance the osmotic strength of its cytoplasm with that of its surroundings to prevent a net loss of water. In addition to functioning as osmotic balancing agents, proline interacts with crucial macromolecules of the cell to maintain their biological activity during stress. It has been suggested that proline may also function as a sink of energy and reducing power, hydroxyl radical scavenger, a compatible solute that protects enzymes and also as a means of reducing acidity. The proline content of the drought treated samples and control seeds were analyzed according to the procedure of Bates et al. [42].

4.1 Screening of root architecture

The root and shoot lengths of all the accessions studied before and after subjection to drought were recorded. From the data obtained its seen that with the induction of drought, there is a remarkable increase in the length of radicle, and

SN	Landraces	Plumule length	Radicle length
1	Orkazhama	>10	Replaced by fibrous roots
2	Malakaran	>9	>7.8.
3	Mundakan	>8.7	>7.5
4	Kazhama	>11	Replaced by fibrous roots
5	Kuthiru	>14	Replaced by fibrous roots

Table 3.
Root performance under drought (cm).

numerous root hairs make their appearance. This might be for the increasing of the absorption area. Kuthiru has the longest shoot while Kazhama has the shortest. With respect to roots, Oarkazhama has the longest roots followed by Malakkaran and Kuthiru. Vaddakan has the smallest, and deteriorated radicle was shown by Navara. After a period of 3 days, the seedlings were watered and their regaining capacity and performance is depicted in **Table 3**. Root system architecture is one of the most important contributors to drought resistance in crops [26]. A well-developed root system is a key to ensuring stable and high yields under drought [43], and the greater root length in deeper soil layers has been shown to increase yield by allowing more water extraction [44]. Supporting to this, the current investigation also revealed the formation of dense root system on subjection to drought. Since rice is characterized by a shallower and more fibrous root system, it has limited water extraction below 60 cm [45]. The lateral root of rice showed greater development under drought [46], which would accelerate drought stress in 20 cm deep soil adverse to rice production.

Since the landraces Njavara, Njavara punja Vadakan and Vellaryan did not show any marked drought tolerance and could not withstand the initial drought stress; they were not subjected to further studies.

4.2 Estimation of leaf area

The leaf area index that reduces due to the subjective stress was compared with normal ones grown under optimum conditions. All the accessions showed decrease in leaf area, and the maximum reduction was shown by the accession, "Malakkaran" and minimum by "Kazhama." There was a clear indication that the accessions tend to reduce the leaf area during drought condition (**Table 4**).

4.3 Estimation of heat shock proteins (HSPS)

The concentration of heat shock accumulated is then found out by the method of Lowry et al. The amount of heat shock protein accumulated by induction together with the amount induced by drought is summarized in **Table 5**.

SN	Landraces	Normal	Drought induced	% Reduction
1	Oarkazhama	17.0	12.5	26
2	Malakaran	18.9	11.7	38
3	Mundakan	19.4	12.3	36
4	Kuthiru	16.9	11.0	34
5	Kazhama	20.7	17.9	14

Table 4.
Leaf area index of drought induction (in cm).

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SN	Landraces	Raw	Control	Drought induced
1	Orkazhama	139.41	169.41	181.17
2	Malakaran	116.47	110.0	199.41
3	Mundakan	104.7	173.5	194.70
4	Kuthiru	113.52	169.38	193.53
5	Kazhama	124.7	165.49	181.76

Table 5.
Heat shock proteins in rice.

The concentration of the heat shock protein increases when the seeds are subjected to drought. And the amount is the lowest in Oarkazhama and highest in Malakkaran in the case of raw seeds. Once drought is induced, it is seen that there is an increase in the Hsp's. These may help them to tolerate the advent of water stress. Plant growth regulators modulate plant response to unfavorable environment. Heat shock proteins (HSPs) are expressed at a very high rate when the cells are exposed to increased temperature, and its activity and expressions are co regulated.

The increasing global temperature and the reduction in the available water content for the crops subject them to survive in elevated temperatures. Park et al. reported that the hsp 90 genes and hsp 90 proteins are found in rice [47]. They are induced by elevated temperature stress but their levels are reasonably large even at low temperatures. These hsps provide the temperature affected rice to combat the degradative effect of heat. Yeh et al. reported that a recombinant rice of 16.9 kda heat shock protein can provide thermo protection in vitro [48]. Hsp 100 family has been directly implicated in the induction of thermo tolerance in microbial and animal cells. Jie Zou showed that rice small Hsp gene, shsps 17.7, the product which acts as molecular chaperons aid to determine the mechanism of acquisition of tolerance to drought stress by heat shock [49].

4.4 Estimation of proline

Following the procedure of Bates et al., the concentration of the basic amino acid proline, which has to play a great role in stress condition was determined. The results obtained are summarized below (**Table 6**).

The amount of proline in raw seeds is very less. The value increases only negligibly once the seedlings germinated. But the induction of drought stress remarkably contributes toward the increase of proline content which helps the seedlings to survive in stress period. The landraces Malakkaran showed the highest amount of proline in both raw seeds and also after introduction of drought. While Kuthiru and Kazhama were the landraces possessing the least amount. The landraces which had thrived well in the drought condition showed increase in the proline content.

Proline, a compatible solute and an amino acid, is involved in osmotic adjustment (OA) and protection of cells during dehydration [50]. Cell turgor is maintained due to osmotic adjustments, which allows cell enlargement and plant growth during water stress. It also enables stomata to remain partially open and CO_2 assimilation to continue at water potentials that would be otherwise inhibitory for CO_2 assimilation [51]. Proline can scavenge free radicals and reduce damage due to free radicles during drought stress. Growing body of evidence indicated that proline content increases during drought stress and proline accumulation is associated with improvement in drought tolerance in plants [50, 52].

SN	Landraces	Raw	Control	Drought induced
1	Orkazhama	0.23	0.56	0.86
2	Malakaran	0.28	0.65	0.92
3	Mundakan	0.13	0.49	0.81
6	Kuthiru	0.14	0.38	0.83
5	Kazhama	0.07	0.41	0.80

Table 6.
Proline content in rice.

From the physiological and biochemical results, it is quite clear that the increased higher accumulation of the stress amino acid proline renders Malakkaran followed by Kuthiru the ability to withstand the drought conditions. These two landraces showed more adaptability to drought stress. And if the particular seeds can withstand the severe drought condition, then they can be successfully used for cultivation purposes. From the study undertaken, it is obvious that the two landraces, Malakkaran and Kuthiru can be used for even the upland cultivation even in severe drought periods.

Drought contributes directly to an increase in the incidence and severity of poverty. It is therefore critical that we establish effective strategies to mitigate the effects of drought in order to ensure agricultural productivity and environmental sustainability. The use of landraces which can thrive well in the drastic water scarcity can result in optimum yield which would help in fulfilling the adequate food availability of the increasing human population. As the pressure on land and its resources are increasing with the population growth, there is a noticeable decrease in the low land areas suitable for rice cultivation. The practice of cultivating cultivars which have promising characteristics to tolerate the abiotic stress is the need of the hour.

5. Conclusion

The increased frequency of drought in arable region threatens rice production and demands the development of rice genotype capable of producing more from diminishing water resources. The development of rice cultivars with improved drought tolerance is thus an important element in reducing risk, increasing productivity, and alleviating poverty in communities dependent on rain-fed production. These landraces with the potential to withstand drought condition should be cultivated to harness their potential. The repository of hidden treasures of tolerant genes in the underutilized landraces present in the state of Kerala with maximum water use efficiency mitigate can prove to be the best in alleviating the drought stress.

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Conflict of interest

Nil

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