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Research Paper

Adverse effects of climate change-induced temperature and water stress on growth and yield of rice (*Oryza sativa* L.) variety *Suwandel*

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Abstract: Climate change due to temperature increment and fluctuations in rainfall has adverse effects on plants and animals. Due to these factors growth and yield of plants are drastically declined. The present study attempted to determine the impact of temperature stress water stresses that would occur as a result of climate change on rice (*Oryza sativa* L.), selecting the variety *Suwandel AC 579* as the model plant. The growth and yield parameters of *Suwandel* were measured at harvest to determine the impact of temperature stress and water stress, after exposing the rice plants to four treatments, *viz*. T1: temperature stress, no water stress, T2: temperature stress, water stress, T3: no temperature stress, no water stress (control), and T4: no temperature stress, water stress. The rice plants exposed to temperature stress showed significantly low values ($P<0.05$) for the height (T1: 75.7±2.68cm and T2: 69.34±3.5 cm) and chlorophyll content (T1: 32.66±0.97 and T2: 24.32±2.53). The yield parameters such as number of productive tillers per plant, number of grains per plant, number of filled grains per plant and test weight showed a significant decline on exposure to temperature and/or water stress further revealing that the rice variety *Suwandel* will not grow and yield successfully under the predicted climate change. As rice is the staple food of majority of people in the world, in order to meet the demand, high yielding new varieties which are able to overcome the expected climate changes such as increase in temperature and water scarcity have to be developed through breeding programmes.

Keywords: Climate Change, Temperature Stress, Water Stress, *Oryza sativa*, Vegetative Parameters, Yield Parameters

Introduction

The global climate is rapidly changing as a result of the temperature being on the increase and the fluctuations of rain fall patterns. Sri Lanka also experiences these varying patterns of climate which are less beneficial to the plants and animals on earth. De Silva *et al*. (2007) have predicted using General Circulation Model HadCM$_3$ that the annual air temperature across Sri Lanka would increase by 1.6 °C (A$_2$ scenario) and by 1.2 °C (B$_2$ scenario) by the year 2050. Chandrapala and Fernando (1995) have shown that there has been an increase in temperature in Colombo by 0.0164 °C /year during the period 1960 to 1990. Wickramagamage (2016) also reported that there has been a downward trend in the monsoonal rains during the period of last three decades including 1981 to 2010. The author further reported that this decline was faster during the period of concern.

Increase in the environmental temperature and its adverse side effects, caused many damages to the cultivations of the country. The increase in the temperature and the decrease in the rainfall would affect growth and development of plants because plants would be subjected to temperature and water stress due to increase in evapotranspiration.

Rice (*Oryza sativa* L.) is a plant which is heavily affected by the climate change. Rice is the most economically important cultivated species of the family Poaceae, providing 35%-75% calories for approximately three billion people in Asia (Khush, 2005). It is the staple food of a large human population (Ilahi *et al.,* 2005). According to Amarasinghe (2009), rice is one of the most important cereals in the world which is consumed by more than half of the population of the world. However, there is a severe impact of drought and high temperature on growth and yield of rice. This semi-aquatic plant depends heavily on rainfall and the temperature in the growing area. There are many traditional varieties of rice in Sri Lanka, out of which variety '*Suwandel*' is preferred by many consumers due to exquisite aroma, milky taste and medicinal properties.

Although there are various research projects carried out on the impact of drought stress and temperature stress on growth and yield of many varieties of rice, there is hardly any literature available on the impact of climate change on the rice variety "*Suwandel*'. Hence, this study intended to determine whether the rice variety '*Suwandel*' would be able to grow and yield successfully under the impact of temperature stress and water stress that is predicted to occur due to climate change.

Materials and Methods

This study was carried out in Nawala in a temperature regulated poly tunnel and a plant house. *Oryza sativa* L. var. *Suwandel AC 579* seeds were collected from the Rice Research and Development Institute at Batalagoda, Sri Lanka. The seeds were planted in natural field soil in pots with 40 cm diameter and 50 cm height. Bottom of the pots were clogged with polythene to prevent the leakage of water from the pots before planting seeds. The plants were thinned to have four plants in each pot. There were three sets of plants per treatment, each set having four pots and each pot containing four plants.

The plants in the poly-tunnel were subjected to a high temperature stress by maintaining a maximum temperature of 35 °C with the aid of a sensory system and exhaust fans. However, the temperature within the tunnel was below 35 °C during early morning and late evening to represent the diurnal variation outside. The plants in the plant house were maintained under a maximum ambient temperature (27-30 °C). In each location, there were six pots each containing four rice plants. The pots in each location were divided in to two equal groups and one set was watered to the 100% of soil moisture content and the other set was under water stress due to being watered to 50% soil moisture content. The treatments were: T1: temperature stress without water stress, T2: temperature stress with water stress, T3: no temperature stress without water stress (control), and T4: no temperature stress with water stress. All plants were maintained under complete randomized design with 12 replicates, in a factorial structure in which the temperature and the water regimes were used, as the factors. The plants were watered daily to meet their respective soil moisture contents after measuring soil moisture, with tension-meters fixed in the pots. There was no significant difference in the conditions such as humidity and light intensity in the two locations.

The growth parameters such as height of plant and leaf chlorophyll content (SPAD meter; OPTI SCIENCES CCM-200+, USA), and yield parameters such as number of ear-bearing tillers per plant, panicle length, total number of grains per plant, total number of filled grains per plant were recorded at harvest. Sterility percentage was calculated using the Equation 1. The test weight was assessed by taking the weight of 1000 seeds per treatment.

The ANOVA was carried out on the parameters related to growth and yield using SAS software package. All analysis was carried out in duplicate.

Sterility % = (Total number of sterile grains / Total number of grains) x 100 ……… Equation 1

Results and Discussion

Growth parameters:

Plant height: A significant reduction was observed in the growth parameters on exposure to temperature stress and/or water stress. As observed in Figure 1 and the ANOVA, the temperature stress is the only factor that had a significant influence on plant height. In the absence of temperature stress, the plant height was significantly higher (P<0.05). The water stress and the interaction effect of both stresses did not exert a significant influence on plant height (P>0.05). However, Rahman *et al*. (2002) reported a decrease in plant height of rice plants with water stress.

The phenological responses to temperature differ among crop species throughout their life cycle. For each species, a defined range of maximum and minimum temperatures form the boundaries of observable growth. The vegetative development, mainly the node and leaf appearance rate, increases as temperature rise to the species-optimum level (Hatfield and Prueger, 2015). However, as there was a significant decline in height of rice plants due to temperature stress, it can be presumed that the imposed temperature stress has exceeded the optimum temperature required for the growth of the rice variety selected. Further, as stated by Krishnan *et al*. (2011), after transplanting, the aerial growth of rice plants has increased linearly from 18 °C to 33 °C and growth was reported to decrease above or below this temperature range.

Kondo and Okamura (1931) and Osada *et al*. (1973) also reported that the plant height increased with the rise of temperature within the range of 30 °C to 35 °C. High temperature stress may cause severe damage to the proteins, disturb their synthesis, inactivate major enzymes and damage membranes. Heat stress could also have major effects on the process of cell divisions (Smertenko *et al*., 1997). All these damages can seriously limit the plant growth and also favour the oxidative damage.

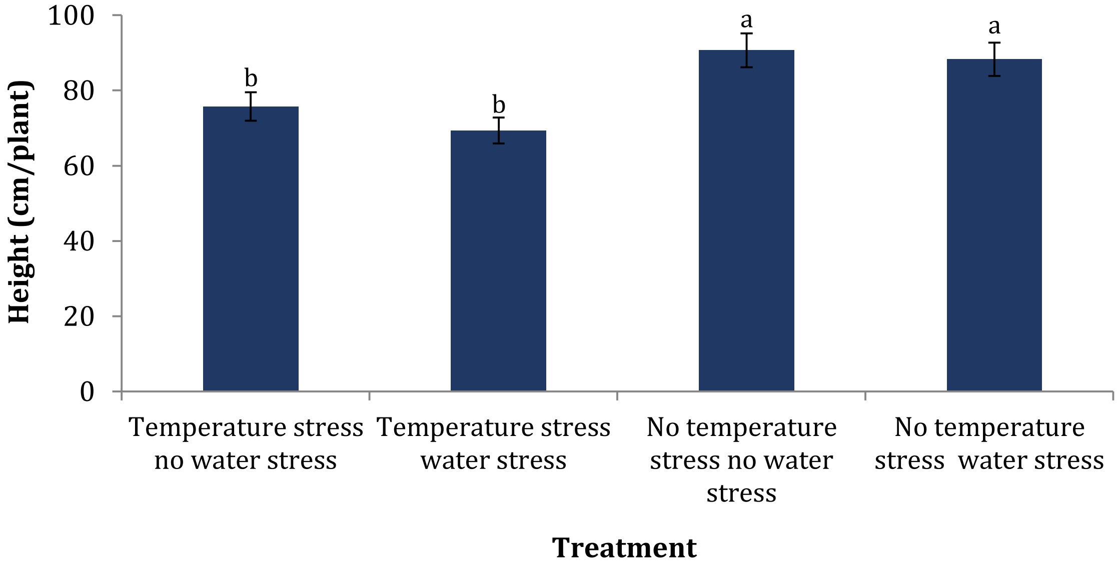

Figure 1. Effect of temperature stress and water stress on plant height of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Chlorophyll content: Figure 2 illustrates that the highest amount of chlorophyll was found in paddy plants with no temperature stress and no water stress (P<0.05), while the lowest in those exposed to temperature stress and water stress (P<0.05). This study revealed that the chlorophyll content has reduced under the stresses imposed. According to the ANOVA both temperature stress and water stress have contributed for a significant difference (P>0.05) on the chlorophyll content, however, the interaction effect was not significant (P>0.05).

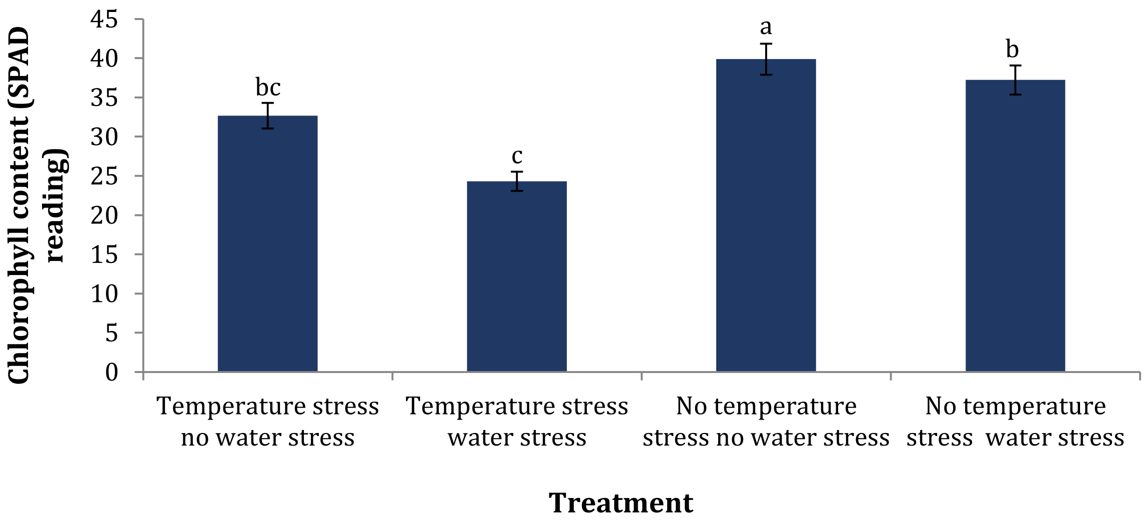

Figure 2. Effect of temperature stress and water stress on chlorophyll content of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Chlorophyll is a major chloroplast components for photosynthesis and relative chlorophyll content has a positive relationship with photosynthetic rate. Chen *et al.* (2007) noted that assessment of pigment content has become an effective means of monitoring plant growth and estimating photosynthetic productivity. According to Sikuku *et al.* (2010), the total chlorophyll and protein content decline with increasing water deficit. Alberte *et al.* (1977) reported that water stress reduced the leaf chlorophyll content. Smirnoff (1995) has reported that the decrease in chlorophyll under drought stress is mainly the result of damage to chloroplasts caused by active oxygen species. Tewari *et al.* (1998) suggested that temperature stress affected chlorophyll biosynthetic enzymes, there by reduction in chlorophyll content in wheat and cucumber. The decline in the chlorophyll content in the present study also could be due to one or more of the above reasons.

<u>Yield parameters:</u>

Panicle length: As depicted in Figure 3, there was no significant difference (P>0.05) among treatments on the panicle lengths indicating that the yield parameter of the variety *Suwandel AC 579* was not affected by the stresses imposed. The results of the present study, however, are in contrary to those of Shatpathy *et al*. (2015) who observed a significant reduction in panicle length of rice varieties selected due to moisture stress imposed.

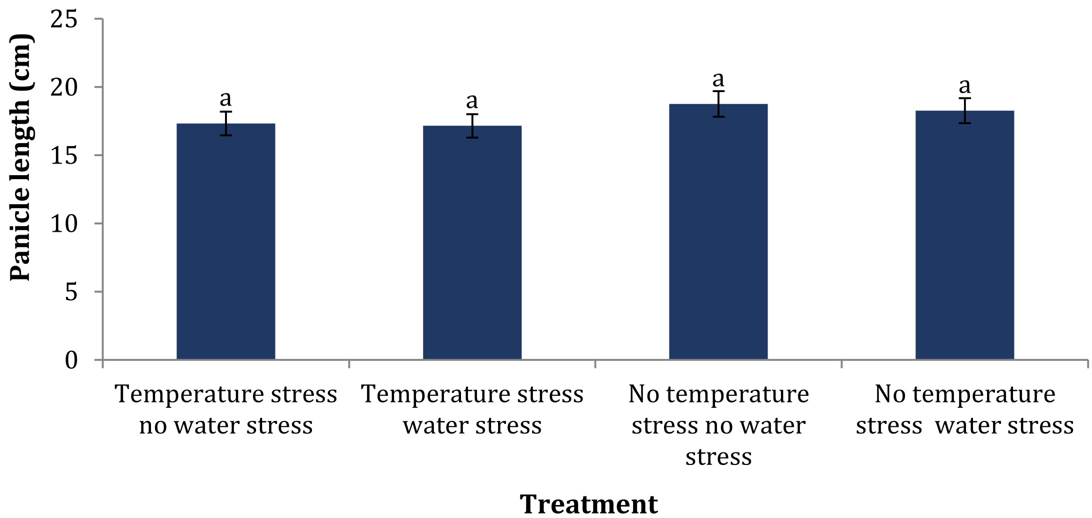

Figure 3. Effect of temperature stress and water stress on panicle length of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Number of productive tillers: The importance of fertile tillers is evident as they directly affects the final grain yield. The highest number of productive tillers was observed in paddy plants with no temperature and no water stress (Figure 4; P<0.05). Temperature stress and water stress have resulted in the lowest number of productive tillers per plant. Shatpathy *et al*. (2015) have also reported similar results in paddy plants under imposed moisture stress. Mostajeran and Rahimi-Eichi (2009) reported that the number of tillers per hill decreased with decreased moisture level and the reduction of tiller production under lower moisture levels (water stress), could be main factor due to which plants were not able to produce enough assimilates.

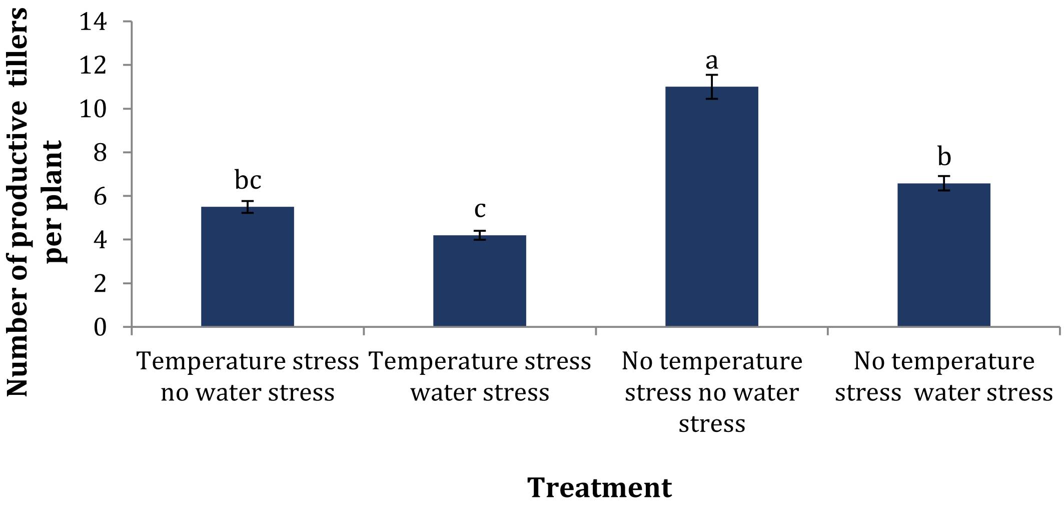

Figure 4. Effect of temperature stress and water stress on productive tillers of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Number of grains per plant: Figure 5 illustrates that the highest number of grains per plant was observed in the absence of both the temperature stress and no water stress. Water stress with no temperature stress had the lowest grain yield per plant (P<0.05). The results indicate that temperature stress and water stress have a marked negative influence on the number of grains per plant.

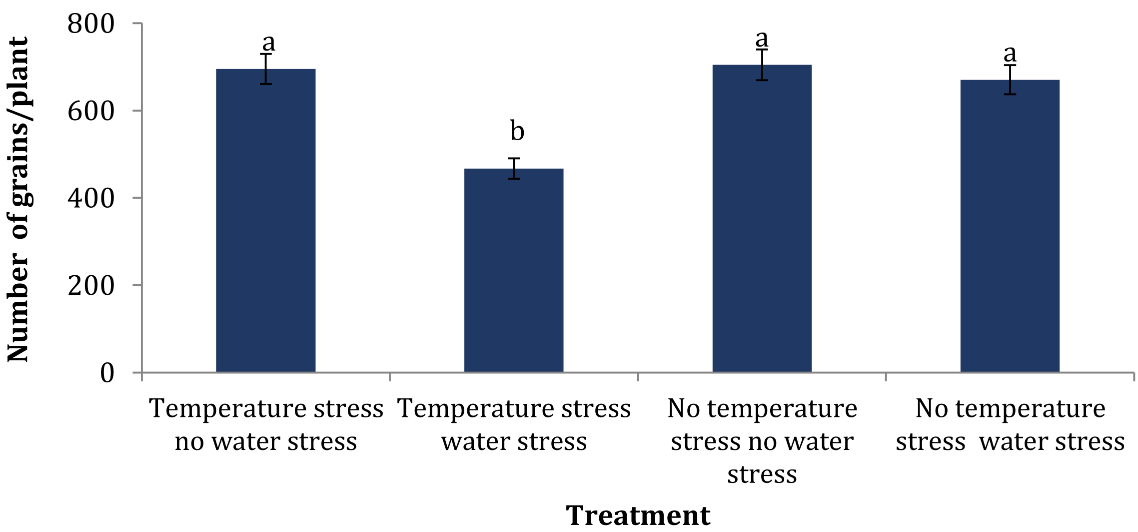

Figure 5. Effect of temperature stress and water stress on number of grains/plant. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Water stress was the only factor that contributed significantly on the number of grains per panicle (P<0.05). Temperature stress had no significant impact on the said parameter. However, the interaction effect of water stress and temperature stress has contributed significantly on the number of grains per panicle (P<0.05). This agrees with those obtained by Shatpathy *et al*. (2015) whose study has demonstrated a reduction in the number of grains per plant due to moisture stress.

Number of filled grains per panicle: As illustrated in Figure 6, absence of temperature and water stresses has resulted in the highest number of filled grains (P<0.05). Treatment without temperature stress but with water stress resulted in the lowest number of filled grains (P<0.05) indicating a negative impact on the yield or the number of filled grains in rice variety *Suwandel AC 579*.

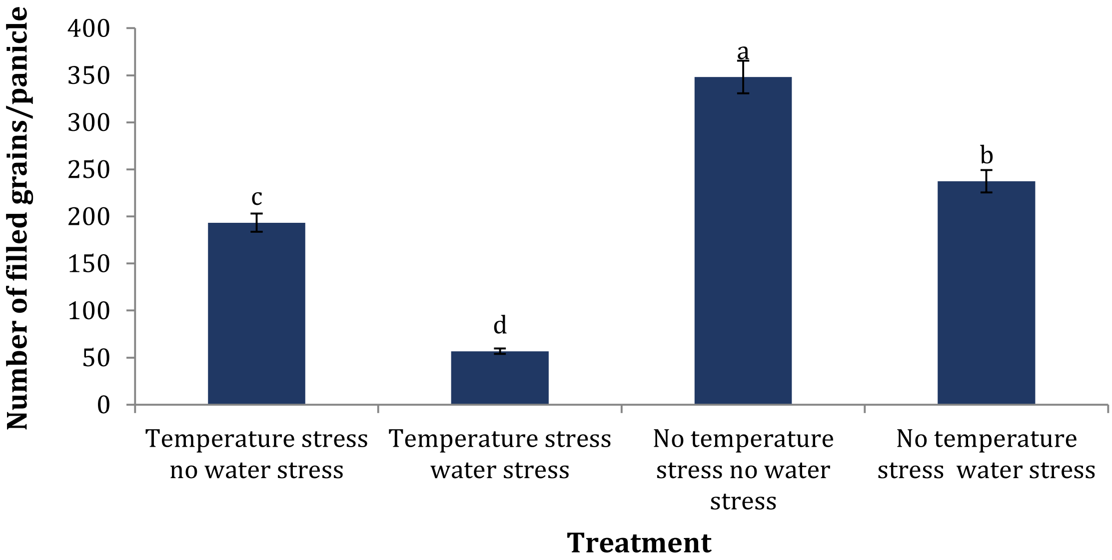

Figure 6. Effect of temperature stress and water stress on number of filled grains/panicle. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

The interaction effect of water and temperature stresses has contributed for significant differences on number of filled grains. Rahman and Yoshida (1985) have observed that water stress, by affecting the rate of grain filling, decreased the rice yield per panicle by 29-40% in the small-seeded variety IR747 (L) and by 19-32% in the large-seeded variety PPR 13-12-3. They also reported that water stress may affect both the division and expansion of the endosperm cells there by reducing the grain filling. Rahman *et al*. (2002) reported that the number of filled rice grains per panicle decreased with water stress resulting from limited translocation towards the grains of the plants stressed at flowering and booting stages.

Sterility percentage: According to Figure 7, the treatment with no temperature stress and no water stress has shown the lowest sterility percentage and it was significantly different from all other treatments. The treatment with no temperature stress but with water stress has shown the highest sterility percentage and it was significantly different from all the other treatments. According to the ANOVA for sterility percentage, both factors the temperature stress and water stress have significantly influenced the variation of the sterility percentage and also the interaction factor was significant (P<0.05). Nakagawa *et al.* (2003) have found that temperatures higher than the optimum induced floret sterility and thus decreased rice yield. According to Matsui *et al.* (1997), spikelet sterility was greatly increased at temperatures higher than 35 °C. It has also been found that exposure of pollen grains to high temperature resulted in loss of pollen viability within 10 minutes (Song *et al.,* 2001). Yang *et al.* (2019) have reported that when the rice was exposed to severe drought stress at the flowering stage, the significant increase in spikelet sterility and grain yield reduction were observed. In an experiment to find out the effect of high temperature and water stress on pollen germination and spikelet fertility in five genotypes rice, high-temperature stress has been found to cause the highest sterility in all five genotypes although, all three stress treatments resulted in spikelet sterility (Rang *et al.,* 2011). A key mechanism of high-temperature-induced floret sterility in rice is the decreased ability of the pollen grains to swell, resulting in poor anther dehiscence and low pollen production and hence low numbers of germinating pollen grains on the stigma (Matsui *et al*., 2000).

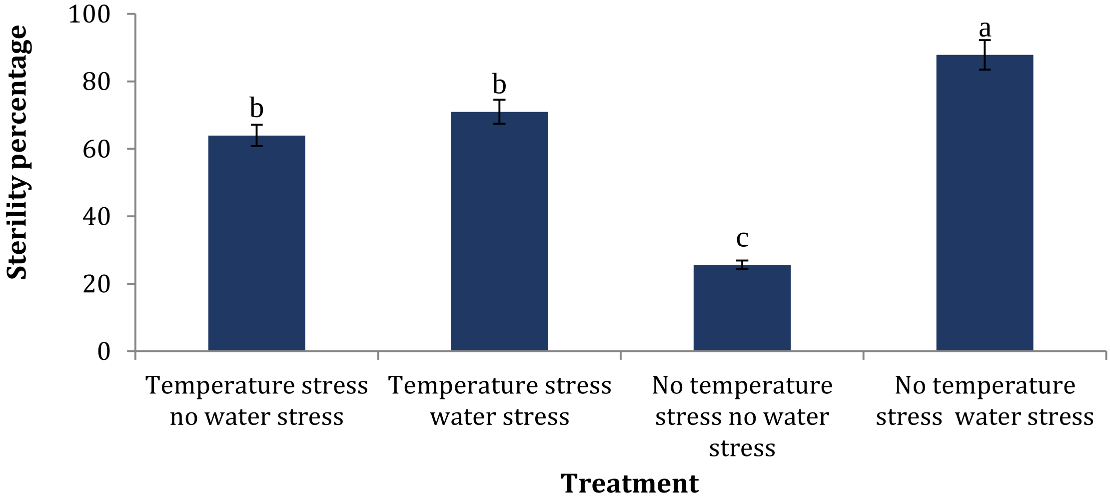

Figure 7. Effect of temperature stress and water stress on sterility percentage of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Test weight: The test weight is the weight of thousand seeds. Figure 8 illustrates that in the absence of temperature and water stress, the test weight recorded was the highest. This result was significantly different ($P<0.05$) to those exposed for water stress without temperature stress, and also from treatment with both temperature stress and water stress. The treatment with water stress without temperature stress recorded the lowest test weight. The ANOVA for test weight revealed that only water stress influenced the test weight of the rice variety tested. The effect of temperature stress and the interaction effect have not affected the test weight ($P>0.05$).

These results are in agreement with those of Shatpathy *et al.* (2015), Cattivelli *et al*. (2008) and Pantuwan *et al*. (2002) who observed that the test weight has reduced drastically when the plants were under water stress. According to the above authors, this occur when the flowering stage of the rice plants were exposed to water stress. Sarvestani *et al*. (2008) also have observed a reduction in test weight under water stress in all rice cultivars tested and the water stress at flowering stage had a greater grain yield reduction than at other times. They further explained that the yield reduction under drought stress at the flowering stage mostly resulted in from reduction in total grain number per panicle (increase in unfilled grain and a reduced proportion of filled grain) and test weight, respectively. Similar results on test weight under water stress at booting and flowering stages were reported by Islam (1999) and Islam *et al*. (1994). Stress during different growth stages might decrease translocation of assimilates to the grains, thus lowering the grain weight and increasing empty grains.

Most of the yield parameters, except the panicle length, showed a decline with the exposure to temperature and/or water stress. The present study revealed that the water stress is more influential on rice yield than the temperature stress. Furthermore, the water stress and the interaction of the temperature stress and the water stress could have a remarkable negative impact on the yield or the number of filled grains.

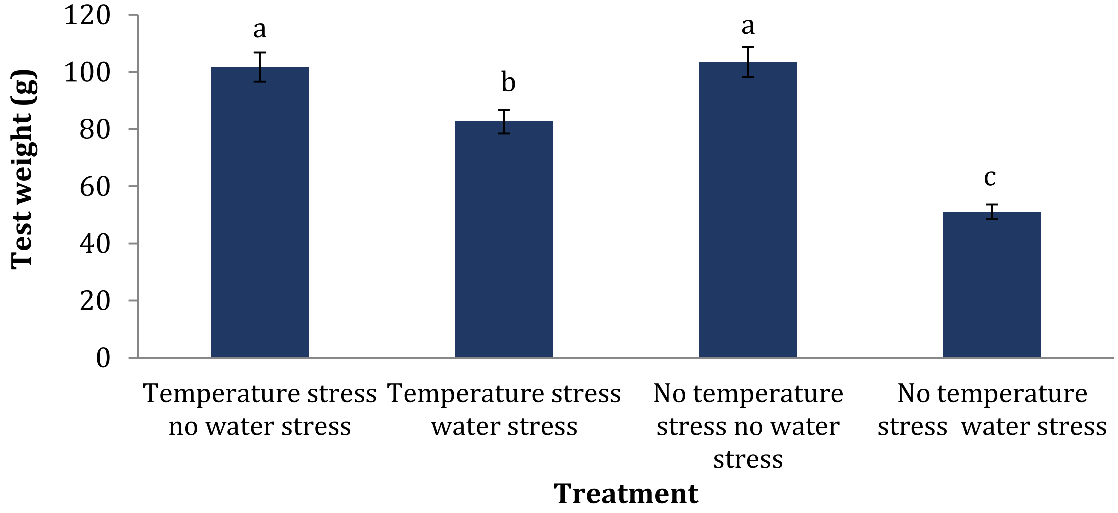

Figure 8. Effect of temperature and water stress on test weight of rice. Vertical lines indicate the standard error of the means. Bars represented by the same letter are not significantly different at P=0.05.

Similar results have been reported by Shatpathy *et al.* (2015), who reported that well-watered plants produced more yield compared to those subjected to a water deficit. Bouman and Toung (2001) concluded that rice plants are susceptible to water stress resulting in substantial yield losses in many countries. Yeo *et al.* (1997) also have observed that water deficit reduce the yield in rice plants.

Moreover, rice being water-loving and semi-aquatic plant, it is inevitable to produce substantially low yield under stressful conditions. The previous research findings have revealed that flowering stage is the critical stage that decides the harvest. Thus, imposition of stress at flowering stage will negatively affect the yield of rice. However, if irrigation water could be provided to the rice plants even when they are under temperature stress, final grain yield could be improved (De Silva *et al.,* 2007). Flowering (anthesis and fertilization), and to a lesser extent booting (microsporogenesis) were the most susceptible stages of development to temperature stress in rice (Farrell *et al*., 2006; Satake and Yoshida, 1978).

Conclusion

The results revealed that rice variety *Suwandel* is susceptible to the temperature and water stresses imposed resulting in a significant decline in yield parameters such as number of productive tillers, number of grains per plant, number of filled grains per plant and test weight. Further, the sterility percentage has increased on exposure to temperature and/or water stresses. Thus, this variety would not be a successful crop to face the increase in temperature and water stress conditions as predicted to occur with climate change. These adverse effects could be tackled to some extent with adequate irrigation. This variety could be further improved through breeding programmes to withstand stresses this is a preferred variety of farmers and consumers.

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