Azarian J. Agric. VOL (4) ISSUE 5, 2017: 157-168

Azarian Journal of Agriculture

www.azarianjournals.ir

Azarian Journals

Research article **ISSN:2383-4420**

Heat stress remediation of rice (*Oryza sativa* L.) growth and development, and nutrients uptake through fertilizers management in tropics

Mohammad Taghi Karbalaei Aghamolki[2], Mohd Khanif Yusop[2], Shahram Mahoud Soltani[1*], Hawa Zee Jaafar[2], Jalal Karbalaei Aghamolki[3], Mohamed Hanafi Musa[2]

Article Info

Accepted:
3 Nov. 2017

Keywords:
Rice, heat stress, fertilizers management, uptake

ABSTRACT

Increased evidences have shown that agricultural crop production to be constrained by heat stress that can significantly reduce crop growth and development as well as nutrients uptake. Nitrogen and potassium are two macro-essential nutrients that influence a number of biochemical and physiological processes that involve in crop production, and also contribute to the survival of crop exposed to high temperature tension. Therefore, the current glasshouse experiment was conducted to explore the effect of nitrogen and potassium fertilizers application on the resistance of rice against heat stress. The highest decrease in morphological and physiological characteristics were observed in aborted spikelets per panicle about 2 time, chlorophyll content by 4.23% and plant height by 2.43% over control, meanwhile the fertile spikelets per panicle by 38.5%, grain yield by 25.25%, the numbers of tillers per hill by 10.76% and effective tillers per hill by 9.1% decreased in heat stress pots. In case of macronutrients uptake, the highest decreased in N uptake was observed in straw by 12.45% and followed by total (12.21%) and grain (11.68%), meanwhile K uptake was decrease in order of grain(28.96%)> total (18.26%)>straw (13.43%) ($P<0.05$). The highest rate of single N application in both sources remediated the morphological characters between 15 to 63%, meanwhile the single K application increased them about 2%. Also, the fertilizers management remediated the negative effect of heat stress in order of: yield (<2 times), fertile spikelets (< 2 times), effective tillers (57.6%) and 1000 grains weight (about 4%) compare to control in applied heat treatments. With respect to single application of N and K that increased the N and K uptake (grain, total and straw) averagely about 2.2 and 1.2 times more than control at heat stress pots, respectively, the highest levels of urea and applied K, increased all uptake parameters averagely about 2-3 times.

INTRODUCTION

Temperature acts as a main driving force of plant growth and development from emerging to ripening. An on-going temperature prediction survey of international panel on climate change indicated that the average of earth's surface temperature has increased by about of 2–4 °C at the end of 21th century (IPCC 2007), as a result of both natural and progressing anthropogenic elements (Eitzinger et al. 2010). But high temperature as a part of heat stress will changes the optimum growth conditions and adversely affects plant growth and yield in all crop production sites, especially in tropics and subtropics (Poli et al. 2013) where by the end of the 21st century are predicted to exceed the most extreme seasonal temperatures (Battisti and Naylor 2009).

Rice (*Oryza sativa* and *Oryza glaberrima*) is one of the important cereals crop grown across the world paddy fields (Nagai and Makino 2009). Almost all rice varieties are currently grown in close to optimum mean temperatures' regions for

[1]Department of soil and water, Rice research institute of Iran, Agricultural research, education and extension organization, Rasht, IR Iran.
[2]Department of Crop Science, Faculty of Agriculture, University Putra Malaysia, 43400, Serdang, Selangor, Malaysia
[3] Faculty of agriculture, Tehran University, Karaj, Iran

*Email: shmsoltani@gmail.com

rice production. Despite of heavily outweigh effect of temperature increasing in cool weather, but by any further increasing and/or supra-optimal temperatures in short period of sensitive stages, may cause considerable reduction in its grains yield by 41% by the end of the 21st Century (Ceccarelli et al. 2010). For wheat, maize and barley, there is a clearly negative response of global yields to increased temperatures. Based on these sensitivities and observed climate trends, we estimate that warming since 1981 has resulted in annual combined losses of these three crops representing roughly 40 Mt or $5 billion per year, as of 2002 (Lobell and Field 2007). High temperature (degree in combination of high light intensity) stress can cause serious problems on plant anatomy (Zhang et al. 2005), morphology and (Giaveno and Ferrero 2003), as well as physiological and biochemical processes in crop, such as water relations (Cabañero et al. 2004; Morales et al. 2003; Simões-Araújo et al. 2003), hormonal activities (Maestri et al. 2002), compatible osmolytes compounds accumulation (Hare et al. 1998; Sakamoto and Murata 2002), cell membrane thermostability and permeability (Martineau et al. 1979a; Martineau et al. 1979b; Somerville 1991), and photosynthesis mechanism (Mittler 2002; Posmyk and Janas 2007; Sharkova 2001; Wise et al. 2004) through membrane disruptions, metabolic alterations and generation of oxidative stress (Mittler 2002; Posmyk and Janas 2007). In rice, high temperatures (>35°C) induces spikelet sterility (Jagadish et al. 2007; Matsui et al. 1997a), reduction of the number of germinating pollen grains on the stigma (Jagadish et al. 2007; Matsui et al. 1997a; Matsui et al. 1997b; Matsui et al. 2000; 2001a; b), yield reduction in experimental paddy fields (Oh-e et al. 2007), significant losses in seed set at flowering (Tian et al. 2007), decreased anther dehiscence, poor shedding of pollen, poor germination of pollen grains on the stigma and decreased elongation of pollen tubes (Prasad et al. 2006a; Prasad et al. 2008; Prasad et al. 2006b) . Analysis of the temperature and rice yield during 1992–2003 at International Rice Research Institute (IRRI) showed that rice grain yield declined by 10% for each 1^0C increase in minimum temperature of growing season (Peng et al. 2004).

Mineral nutrition of plants plays a critical role in increasing plant resistance to environmental stresses (Marschner 1995). Also, better plant nutrition can effectively alleviate the adverse effects of temperature stress by a number of mechanisms. Temperature stress (high and low) results in increased generation of the reactive oxygen species (ROS) due to energy accumulation in stressed plants which increases the photo-oxidative effect and damage the chloroplast membrane. Application of nutrients like N, K, Ca and Mg reduce the toxicity of ROS by increasing the concentration of antioxidants like superoxide dismutase (SOD); Catalase (CAT) and peroxidise (POD) in the plant cells (Huang et al. 2004).

Nitrogen as a first essential element (in amount), among the mineral nutrients, is crucial to survive agricultural crop against the biotic and abiotic stresses, especially in temperature stress tolerance. Of the mineral nutrients, nitrogen due to its vital responsibility in utilization of absorbed light energy and photosynthetic carbon metabolism can justified stresses negative effect on plant growth (Kato et al. 2003; Huang et al. 2004). This is severely occurs in N-deficient leaves, where it leads to a high risk of photo-oxidative damage. When rice crop exposed to high light intensity, N deficiency is associated with enhanced lipid peroxidation (Huang et al. 2004). Kato et al. (2003), reported that plants grown under high-intensity light with a high N supply had greater tolerance to photo-oxidative damage and higher photosynthesis capacity than those grown under similar high light with a low N supply.

Potassium is a macronutrient required in large quantities by plants and is the most abundant cation in plant cells. Compared to other macro nutrients, potassium is not metabolized or incorporated into other macromolecules. The concentration of K in the cytoplasm has consistently been found between 100 and 200 mM (Shabala and Pottosin 2010), and apoplastic K concentration may vary between 10 to 200 or even reach up to 500 mM (White and Karley 2010). K plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmo-regulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance (Marschner 1995). Numerous studies have shown that the application of K fertilizer mitigates the adverse effects of drought on plant growth (Andersen et al. 1992; Sangakkara et al. 2001). It was also found that potassium fertilization under water stress conditions at the reproductive stage could minimize drought stress effects such as reduction in net photosynthesis, stomatal conductance and transpiration rate (Fukai and Cooper 1995). Heat stress can affect many of the processes involved in the inhibitions of growth, enzyme activities, photosynthesis, and acceleration of leaf senescence (Huang et al. 2004). In addition, heat stress may also lead to direct inhibitions of nutrient uptake or even to the change of contents of basic nutrients such as N, K and P in plant tissues (Huang et al. 2001), thus it is important to understand how heat stress may be alleviated by the supply of macronutrients. In spite of accepted positive effect of heat stress (improve the crop establishment of rice) in some rice cropping areas, especially in cool weather (Nakagawa et al. 2003), but its negative effects heavily outweigh the positive (Rosenzweig and Parry 1994). Therefore, some of the easy access strategies (nutrient application) that will be targeted by researchers to mitigate of higher plant against heat stress. Due to lack of results in tropical rice, the current works was done to explore the influence of types and rates of N and K fertilizers on the morphological and physiological characters of rice in tropics.

MATERIALS AND METHODS

The current glass house study was laid out at glass houses complex of Universiti Putra Malaysia during 2012 (latitude 02°59' N, longitude 101°43 E' and altitude 64 m above the sea level). The selected soil (Selangor soil series) was silt clay loam, with pH of 5.5, 0.55% total nitrogen, 131 mg L^{-1} available phosphorus, 0.32 mg g^{-1} potassium. Four factors factorial experiment was conducted in split plot design experiment, using Randomized Complete Block Design (RCBD) with three replications. The main plot was heat stress that contributed normal growing temperature (32°C±2) and heat stress (38°C±2) during the day with same temperature at night (22°C±2) at two growth chambers separately. The subplots were nitrogen with two sources (Meister-20 (polymer coated urea) (a new N fertilizer) and Urea, both, in three rates (0, 120, 160, 120 and 160 kg ha^{-1}), and potassium in three rates (0, 60 and 90 kg ha^{-1}).

The seeds of MR219 rice variety (the most common rice variety in Malaysia) were grown in the plastic basket (40 cm length, 30 cm width and 10 cm diameter). The three 20 days old seedlings transplanted in pots containing 10 kg well puddle soil. About 3-4 cm water level was maintained until the physiological maturity. The P was applied at 60 kg ha^{-1}. The whole P, K in form of Single Super Phosphate and Muriate of potash were applied during the soil paddling. Urea was applied as a N fertilizer in three splits (40% at the transplanting-basal application), 30% at the active tillering (top dressing) and 30% in the early reproductive stage (top dressing)), but the whole Meister-20 was applied at the transplanting time due to its slow release behavior. Data observation was done by using the Standard Evaluation System for rice (SES 2002) during maturity stage (Lack et al. 2012). The number of effective tillers was determined from the average of three hills in each experimental pot. Same plants were selected to count panicles per plant. Fertile, unfertile and aborted spikelets were counted from ten randomly selected panicles in each pot. The thousand grain weight was determined by digital balance. Plants were harvested when 85 % of grain changed to yellow color (end of ripening stage) and threshed manually to determine grain yield per pot at 14% moisture content. For soil and plant N content were measurement by CNS device (Jones 2001). The SAS program was used to explore the analysis of variance (ANOVA) of all data at 5% confidence level and mean comparison was done through Duncan's test at 5% probability level.

RESULTS AND DISCUSSION

Effect of Heat stress and Role of Nitrogen on Morphological Traits of Rice

The morphological characteristics as influenced by heat stress, N fertilizers and their interaction are presented in table 1 and figure 1, respectively. The mean comparison analysis (Table 1) revealed that plant height and chlorophyll content positively and number of tillers hill negatively significantly affected by heat stress treatment alone ($P \leq 0.05$). Furthermore, the flag leaf length just numerically (not significantly) is influenced by heat stress at 5% confidence level. The maximum percentage increase in morphological characteristics was observed in chlorophyll content (4.23%) and plant height (2.43%), meanwhile the numbers of tillers per hill decreased about 10.76% in presence of heat stress (38±2 ºC).

Crop architectural adaptation, such as plant height variability, plays a positive significant role in their heat stress resistance. The more height the more leaves and panicles, therefore crops can tolerate heat stress due to transpiration cooling effect of leaves which reduces the water evaporation from anthers and thereby increases anther dehiscence (Shah et al. 2007). Increase in plant height by increasing the transpiration processes can help the crops to avoid from heat stress through cooling effect. This mechanism was observed in mung bean (Kumar et al. 2011), wheat (Hasanuzzaman and Fujita 2013), and N22 rice varieties and its mutant NH219 (more in the mutant) (Poli et al. 2013).

Exposure of crops to high temperature resulted in their reduction and consequently thermo-sensitive genotypes loss more (Zhou et al. 2012) compared to more tolerate genotypes (NH219) can increase their chlorophyll content (Poli et al. 2013). An increase in the daytime temperature from 25 to 35 °C (but not more than 40°C) enhanced the leaf chlorophyll content of three selected rice cultivars(Castilla et al. 2010; Sánchez-Reinoso et al. 2014; Yun-Ying et al. 2009; Yun-Ying et al. 2008). Conversely, temperatures higher than the optimum (heat stress) induce numbers of tillers per hill (Yoshida 1978) and consequently, is the major character contributing to the yield loss (Shah et al. 2011). Poli et al. (2013) indicated that by exposing the rice varieties to high temperature the 30 % reduction of tiller number was observed.

The rice growth morphological characters and the chlorophyll content were positively increased by increase in application rate of both nitrogen fertilizers, significantly (Figure 1). The maximum percentage increase in morphological characteristics was occurred in the number of tillers, panicle exertion, flag leaf length, and the chlorophyll content at the highest rate of N application for both of applied N sources about for 63%, 46%, 27.2%, and 22.7% , respectively. Approximately two observed characters (plant height and chlorophyll content) showed considerable difference with N fertilizer types. Urea compared to M20 at the rate of 160 $kg.ha^{-1}$ provides higher plant height (2%) and more chlorophyll content (4%).

In contrast to N, the individual effect of K application on heat stress showed three distinct patterns among morphological characters. Whereas flag leaf width, flag leaf length and panicle exertion neither at normal nor at heat stress conditions have not affected by K application, tillers per hills (numerically), and plant height and chlorophyll content (positively significantly) increased due to applied K, particularly at the rate of 60 kg ha^{-1} ($P \leq 0.05$). The maximum percentage increase was occurred in the plant height, and the chlorophyll content at the 60 kg K ha^{-1} application rate about for 2%. Similar to individual effects of N and K fertilizers on recorded morphological and physiological characters, the interaction impact of them showed three different performances at current experiment. As seen in figure 1 where N and K application levels were plotted, there were no significant treatments (applied heat, N and K) effects on flag leaf width and length (pattern 1), but plant height and chlorophyll content positively significantly increased even if at heat stress compare to normal pots ($p \leq 0.05$) (pattern 2). Furthermore, although, tillers per hill and panicle exertion positively significantly increased at both heat and no stress conditions ($p \leq 0.05$), but the plant cannot recover the heat stress damage fully. The maximum increase for all characters were observed in the highest level of applied K and N. In case of N fertilizers variation, urea was more effective than M20 at both heat and no stress pots. The fertilizers management remediated the negative effect of heat stress in order of: tiller per hill (61.2%), panicle exertion (48.65%), chlorophyll content (26.8%) and plant height (15.5%) compare to control in applied heat treatments.

Nitrogen fertilizers' type, rate and application time have vital effect on optimum rice growth factors such as rice plant height, tiller number and leaf size (Dobermann 2005). The plant height increasing through better crop response to high soluble N fertilizer (Urea) application compare to slow release one is probably due to more enhancement of N availability which promote better plant growth resulting in higher photo assimilates and consequently more dry matter accumulation and higher plant height (Chaturvedi 2005). A number of research indicated the positively significantly increase in plant growth and other morphological and physiological characters (Islam et al. 2007; Salman et al. 2012). Nitrogen plays a vital role in plant to mitigate the negative influences of abiotic stresses, especially temperature stress (Waraich et al. 2012; Waraich et al. 2011). The higher temperatures, the higher light intensity, therefore, it adversely affects crop nutrients uptake and consequently plant growth and development. Of the macro-nutrients, N is a key factor in absorbed light energy utilization and photosynthetic carbon metabolism (Huang et al. 2004; Kato et al. 2003). Across the heat treatments, the individual effect of N at both types and rates were positively significant on rice growth morphological characters and the chlorophyll content. Furthermore, as noted earlier approximately all observed characters value were higher in Urea compare to M20 treatment. Thus, the maximum percentage increase was recorded in the number of tillers per hill, panicle exertion, flag leaf length, and the chlorophyll content in the heat stress condition (38±°C) receiving 160 kg N ha^{-1} in the form of common urea about for 60%, 40%, 27.2%, and 21.% , respectively, over control. N supplying can help crops to avoid and/or tolerate heat stress through some physiological mechanism such as, scavenging the reactive oxygen species (ROS) by acting as an antioxidant (Wendehenne et al. 2001), as a signal in inducement of thermo-

Table 1. Morphological characteristics under heat stress treatments

Heat stress	Tillers per hill	Plant Height (cm)	Chlorophyll Content (SPAD)	Flag leaf width (cm)	Flag leaf length (cm)	Panicle exertion (cm)
Normal (32±2 ºC)	15.8 ᵃ	106.8 ᵇ	35.5 ᵇ	1.33 ᵃ	28.7 ᵃ	4.7 ᵃ
Heat (38±2 ºC)	14.1 ᵇ	109.4 ᵃ	37.0 ᵃ	1.33 ᵃ	28.9 ᵃ	4.7 ᵃ
LSD (%)	0.47	1.82	0.94	0.22	1.68	0.62

In each row, means followed by common letter are not significantly different at 5% probability level by LSD

Table 2. The impact of heat stress on yield and yield components of rice.

Heat stress (ºC)	Effective tillers Per hill	Fertile spikelets per panicle	sterile spikelets per panicle	Aborted spikelets per panicle	1000 grain weight (g)	Grain yield (g pot^{-1})
Normal (32±2 ºC)	14.3 ^{a}	131.4 ^{a}	58.9 ^{b}	3.5 ^{b}	22.7 ^{a}	20.2 ^{a}
Heat (38±2 ºC)	13.0 ^{b}	80.8 ^{b}	87.3 ^{a}	7.3 ^{a}	22.0 ^{b}	15.1 ^{b}
LSD (%)	1.2	21.9	10.5	3.2	0.66	2.1

In each row, means followed by common letter are not significantly different at 5% probability level by LSD.

tolerance (Song et al. 2012) and by inducing expression of gene encoding small heat shock protein 26 (HSP26) (Uchida et al. 2002).

Effect of Heat stress on yield and yield components

Although the optimum temperature (27 to 32 °C) is the major driving force of crop growth and development, but the heat stress (high temperature) negatively affected almost all the observed rice reproductive characters, except sterile spikelets per panicles and aborted spikelets per panicle (Table 2). The maximum percentage decrease was recorded in Fertile spikelets per panicle, grain yields and effective tillers per hill about 38.5, 25.25 and 9.1%, respectively, while the maximum percentage increase was done in aborted spikelets per panicle about 2 time over control.

There are consistent results regarding the long term responses of the rice varieties to N fertilizers at any rate, source and application types (Timsina et al., 2001) due to N key roles in crop growth and development (Hirzel *et al*, 2011). Applied N fertilizers in form of both Urea and M20 positively significantly increased yield and yield components at any rates, particularly 160 kg N ha^{-1}, in the normal growing conditions (32±ºC). The maximum percentage increase was found about 21 g per pot and 22.7 g by receiving the highest application rate for grain yield and 1000 grains weight. Furthermore, the fertile spikelets per panicle, effective tillers per hill, aborted spikelets per panicle averagely increased about 80, 67 and 88% over control, respectively, with no significant difference between fertilizer types (Table 3).

Despite the fact that exposure of high temperature and N fertilizers application (separately) during the rice growth stages had contradictory trends, heat stress effects on crop growth was significantly mitigated, avoid and/or tolerate through a number of physiological mechanism (Wendehenne *et al.,* 2001; Song *et al.,* 2006; Uchida *et al.,* 2002) when optimum N nutritional status was considered. Although N supply led to better growth factors performance and, consequently, higher yield in both normal and heat stress conditions compare to control. The maximum percentage increase in grain yield, 1000 grains weight, effective tillers number and fertile spikletes per panicle was 108, 1.37,64 and 74.6%, respectively. It was of interest that the number of sterile spikelets and aborted spikelets, unexpectedly, being higher in the heat stress than normal growing condition. Cao et al. (2009) also concluded that the relative high yield in heat-tolerant genotypes of rice is associated with high levels of photosynthesis rate in leaves that it significantly related to N suppling. Therefore, although the effects of short-term high temperature stress on photosynthesis and grain filling varied among genotypes and the developmental stages of plant when exposed to the stress (Restrepo-Diaz and Garces-Varon, 2013.), the optimal application of N fertilizers can help crop to survive under heat stress condition.

In contrast to N, the effect of K application (singly) on morphological and physiological characters at heat stress condition indicated two distinct patterns. Whereas effective tillers per hills and 1000 grains weight neither at normal nor at heat stress conditions have not affected by K application, fertile spikelets per panicle and grain yield (positively significantly), and sterile spikelets per panicle and aborted spikelets per panicle (negatively significantly) affected by applied K, particularly at the rate of 60 and 90 kg ha^{-1}, respectively ($P \leq 0.05$) (Table 3). In the heat stress condition, the maximum percentage increase was occurred in the fertile spikelet per panicle and grain yield at the 60 kg K ha^{-1} application rate about 21.5 and 56.7%, respectively, and also the highest decrease in observed characters was occurred in aborted spikelet per panicle about 34% at the 60 kg K ha^{-1} application rate.

The process of grain filling, the accumulation of reserve nutrients in the developing and maturing grain, is also sensitive to environmental conditions strongly affecting final yield quantitatively and qualitatively as well (Yang and Zhang 2006). Sufficient and balance macronutrients application plays a vital role in increasing crop resistance (Marschner 1995), and also effective alleviation of the adverse effects abiotic stresses. Yield and yield components as well as morphological and physiological characters showed two various patterns at current experiment not only by individual supply of N and K fertilizers but also the

Table 3. The impact of different levels of nitrogen on yield components of rice.

Heat stress (ºC)	K fertilizer (kg ha^{-1})	N fertilizer (kg ha^{-1})	Effective tillers Per hill	Fertile spikelets per panicle	sterile spikelets per panicle	Aborted spikelet per panicle	1000 grain weight (g)	Grain yield (g pot^{-1})
Normal (32±2 ºC)	0	0	9.3 ^{h}	81.0 1^{fgh}	47.0 ^{jkl}	2.3 ^{l}	22.5 $^{b-g}$	10.0 ^{mn}
		120(M20)	15.7 ^{abc}	130.0 ^{c}	41.7 ^{l}	3.7 $^{h-l}$	22.5 $^{b-g}$	19.3 ^{fgh}
		160(M20)	16.2 ^{a}	146.3 ^{ab}	52.3 $^{i-l}$	4.0 $^{h-}$l	22.8 $^{a-f}$	24.3 ^{abc}
		120(urea)	14.8 $^{b-e}$	136.0 ^{bc}	60.0 ^{hij}	4.0 $^{h-l}$	22.8 $^{a-f}$	20.9 ^{def}
		160(urea)	15.8 ^{ab}	137.0 ^{bc}	81.7 ^{def}	5.7 $^{f-h}$	22.3 $^{b-h}$	21.4 ^{def}
	60	0	9.3 ^{h}	87.7 $^{e-h}$	47.3 ^{jkl}	2.7 $^{k-l}$	22.5 $^{b-g}$	11.6 ^{m}
		120(M20)	15.0 $^{a-d}$	138.3 ^{bc}	53.0 $^{i-l}$	2.0 l	22.3 $^{b-h}$	19.8 ^{efg}
		160(M20)	16.0 ^{a}	160.3 ^{a}	51.7 $^{i-l}$	2.0 l	22.7 $^{a-f}$	26.6 ^{a}
		120(urea)	15.8 ^{ab}	141.7 ^{bc}	52.3 $^{i-l}$	5.0 $^{g-j}$	23.0 $^{a-d}$	21.4 ^{def}
		160(urea)	16.2 ^{a}	156.3 ^{a}	72.7 ^{fgh}	4.7 $^{g-k}$	23.6 ^{a}	23.1 ^{bcd}
	90	0	9.5 ^{h}	85.3 $^{e-h}$	43.3 ^{kl}	2.0 l	22.1 $^{c-h}$	11.5 ^{m}
		120(M20)	14.7 ^{def}	128.3 ^{c}	58.3 $^{h-k}$	3.3 $^{i-l}$	22.5 $^{a-g}$	19.3 ^{fgh}
		160(M20)	15.8 ^{ab}	156.7 ^{a}	65.0 ^{ghi}	3.0 $^{j-l}$	22.9 $^{a-e}$	25.3 ^{ab}
		120(urea)	14.3 ^{efg}	138.0 ^{bc}	65.0 ^{ghi}	2.7 ^{kl}	23.0 ^{abc}	22.1 ^{cde}
		160(urea)	15.8 ^{ab}	148.3 ^{ab}	92.7 $^{b-e}$	5.0 $^{g-j}$	23.3 ^{ab}	25.7 ^{a}
Heat (38±2 ºC)	0	0	9.2 ^{h}	48.3 l	74.3 ^{fgh}	5.0 $^{g-j}$	22.0 $^{c-h}$	6.7 ^{o}
		120(M20)	13.7 ^{efg}	75.0 ^{h}	77.7 ^{efg}	5.3 $^{f-i}$	21.9 $^{e-h}$	15.7 ^{kl}
		160(M20)	14.7 $^{c-f}$	94.0 ^{def}	84.0 ^{def}	5.3 $^{f-i}$	22.1 $^{c-h}$	18.2 $^{g-k}$
		120(urea)	14.3 $^{d-g}$	78.0 ^{gh}	102.7 ^{ab}	9.3 $^{a-d}$	22.1 $^{c-h}$	16.0 ^{kl}
		160(urea)	13.8 ^{efg}	97.7 ^{de}	100.3 ^{abc}	10.0 ^{abc}	21.9 $^{d-h}$	17.0 $^{h-l}$
	60	0	8.8 ^{h}	58.7 l	83.0 ^{def}	3.3 $^{i-l}$	21.9 $^{e-h}$	10.5 ^{mn}
		120(M20)	13.3 ^{g}	80.3 ^{fgh}	73.7 ^{fgh}	5.3 $^{f-i}$	21.3 ^{h}	16.6 $^{i-l}$
		160(M20)	14.5 $^{d-g}$	99.0 ^{de}	81.0 $^{d-g}$	7.3 ^{def}	22.1 $^{c-h}$	19.2 $^{f-i}$
		120(urea)	13.8 $^{d-g}$	78.0 ^{gh}	81.0 $^{d-g}$	9.0 ^{bcd}	22.1 $^{c-h}$	15.8 ^{kl}
		160(urea)	14.5 $^{d-g}$	105.7 ^{d}	84.7 $^{c-f}$	8.0 ^{cde}	22.6 $^{a-f}$	18.8 $^{f-j}$
	90	0	8.8 ^{h}	57.3 ^{i}	74.0 ^{fgh}	4.7 $^{g-k}$	21.8 ^{fgh}	8.6 ^{no}
		120(M20)	13.5 ^{fg}	76.0 ^{h}	88.00 $^{b-f}$	6.3 ^{efg}	22.1 $^{c-h}$	15.1 l
		160(M20)	14.5 $^{d-g}$	94.0 ^{def}	97.0 $^{a-d}$	8.3 $^{b-e}$	22.4 $^{b-g}$	16.4 ^{jkl}
		120(urea)	13.3 ^{g}	77.7 ^{gh}	97.0 $^{a-d}$	10.3 ^{ab}	21.5 ^{gh}	15.8 ^{kl}
		160(urea)	14.2 $^{d-g}$	92.3 $^{d-g}$	111.0 ^{a}	11.3 ^{a}	22.8 $^{a-f}$	15.9 ^{kl}
LSD (%)			1.1	13.7	14.7	2.1	0.99	2.4

interaction impacts of them. It might be due to the several mechanism involved in crop responses to abiotic stress (Chaves et al. 2003). While there were positive significant treatments (applied heat, N and K interaction) effects on 1000 grains weight, effective tiller, effective spikelets (pattern 1), but the rest positively significantly (statistically but not economically) increased at heat stress conditions compare to normal pots ($p \leq 0.05$) (pattern 2). On the other hand, although, the sterile and aborted spikelets positively significantly increased at both heat and no stress conditions ($p \leq 0.05$), but the plant cannot recover the heat stress damage fully (decrease the unfilled grains) through mineral nutrition application. The maximum increase for all characters were observed in the highest level of applied K and N. In case of N fertilizers variation, urea was more effective than M20 at both heat and no stress pots. The fertilizers management remediated the negative effect of heat stress in order of: yield (more than2 times), fertile spikelets (more than 2 times), effective tillers (57.6%) and 1000 grains weight (about 4%) compare to control in applied heat treatments (Table 3). Air temperature higher than the optimal by inducing the floret sterility can cause rice yield reduction (Nakagawa et al. 2003), especially more than 35 °C (Matsui et al. 1997b). The results of a glass house indicated that the possible rice grain yields reduction was found in both indica and japonica rice varieties. Jagadish et al. (2007) reported that the high temperature above 33.7 °C only by 1 hour exposure was sufficient for sterility increasing through reduction of pollen grains ability to swell,

Table 4. Effect of heat stress and normal temperature K and N uptakes across all potassium and nitrogen treatments

Heat stress (ºC)	K uptake (mg pot^{-1})			N uptake (mg pot^{-1})		
	Straw	Grain	Total	Straw	Grain	Total
Normal (32±2 ºC)	389.785 ^{a}	175.94 ^{a}	565.72 ^{a}	189.6 ^{a}	101.9 ^{a}	291.6 ^{a}
Heat (38±2 ºC)	337.424 ^{b}	124.99 ^{b}	462.42 ^{b}	166.0 ^{b}	90.0 ^{a}	256.0 ^{b}
LSD (%)	41.5	38.8	63.4	23.1	13.5	14.6

In each row, means followed by common letter are not significantly different at 5% probability level by LSD.

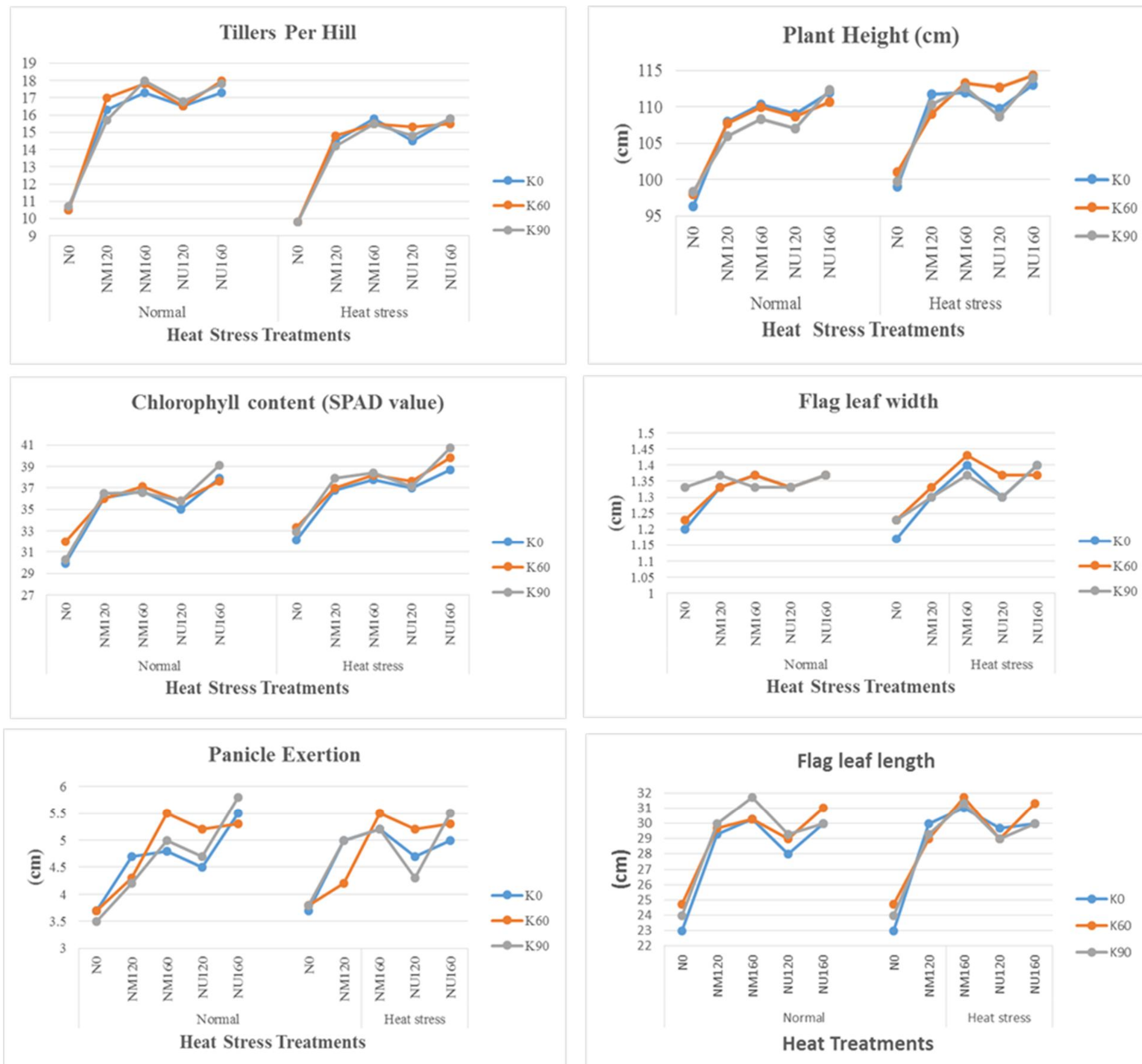

Figure 1. Morphological characteristics and chlorophyll Content under different nitrogen, potassium and heat stress levels treatments.

In each row, means followed by common letter are not significantly different at 5% probability level by LSD; M20= Meister-20 (polymer coated urea), NU=Urea N source

resulting in poor thecae dehiscence (Matsui et al. 2000).

Effect of heat stress on Nitrogen and potassium uptake

At any physiological levels (the molecular or cellular), the photosynthetic process of crop is closely related to plant N content (Rizhsky et al. 2004). Nitrogen uptake and assimilation are strongly associated to temperature and optimum N uptake and assimilation occur at the normal temperature (Rizhsky et al. 2003).When the air temperature is more than optimum for sufficient period of growth cycle, the rate of N availability, uptake, leaf N, and also N assimilation decrease sharply due to blocking or reducing the N assimilatory enzymes (Prasad et al. 2008). These changes in enzyme activities could be a result of changes in amino acid composition as altered by drought, heat, or combination of drought and heat (Rizhsky et al. 2004). Nitrate reductase activity, as an N metabolism regulator, is decreased under heat stress (Singh and Sawhney 1989). K is also essential to the performance of multiple plant enzyme functions, and it regulates the metabolite pattern of higher plants, ultimately changing metabolite concentrations (Marschner 2011). Plants that are continuously exposed to abiotic stress, their root growth and the rates of K^+ diffusion in the soil were restricted. Therefore, K adsorption,

acquisition and uptake decrease (Wang et al. 2013). The mean comparison analysis (Table 1) revealed that N and K uptake (grain, straw and total) negatively significantly affected by heat stress treatment alone ($P \leq 0.05$). The maximum percentage decrease in N uptake was observed in straw (12.45%), total (12.21%) and grain (11.68%), meanwhile K uptake was decrease in order of grain(28.96%)> total (18.26%)>straw (13.43%) in presence of applied heat stress (38±2 ºC). In case of lesser N uptake in grain compare to straw, Tahir and Nakata (2005) indicated that assimilated N partitioning in various parts of plant is affected by heat stress and (Ito et al. 2009) showed similar results for rice where high temperature caused a significant decrease in N transport from shoots to ears through phloem pathway. Moreover, high temperature stress adversely can influence the

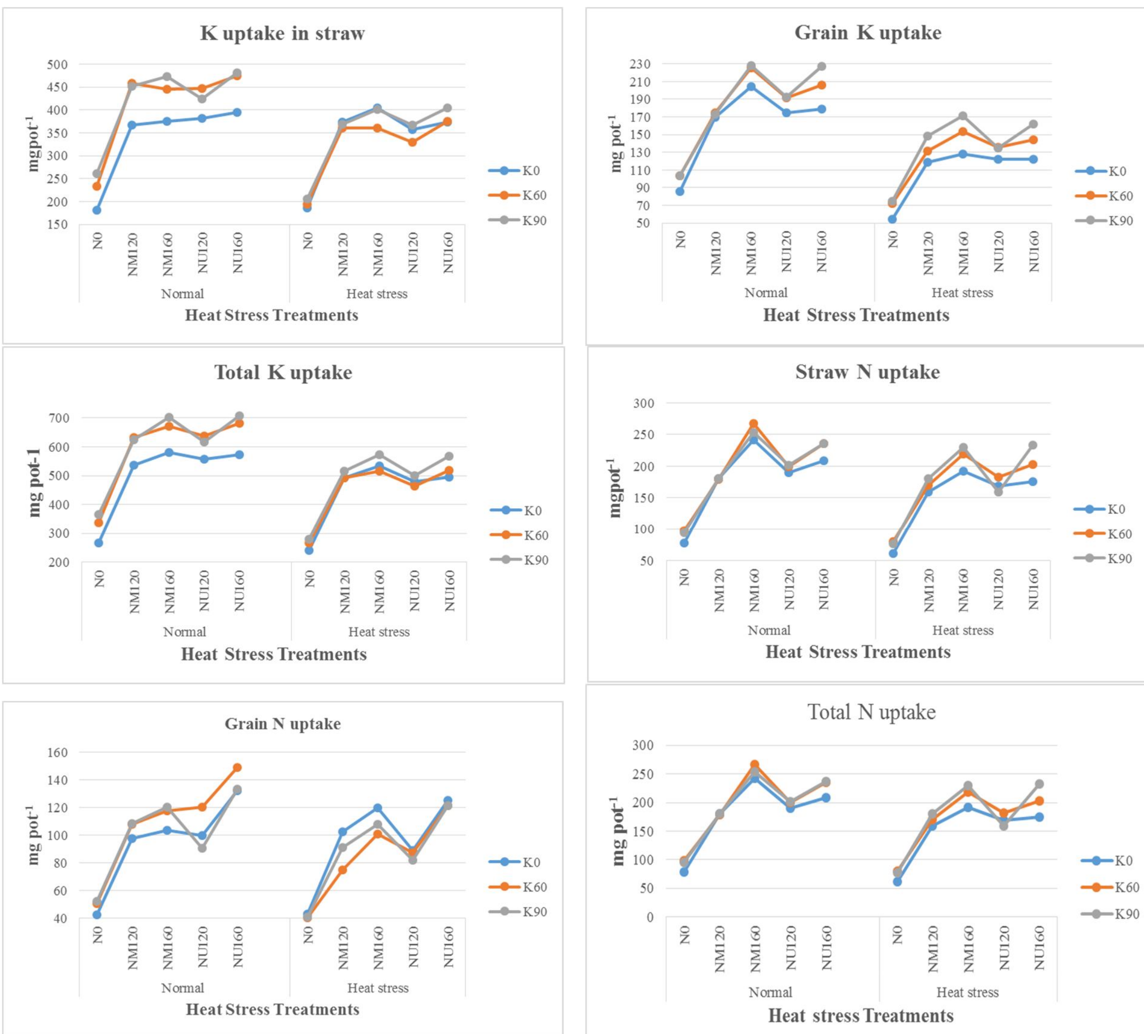

Figure 2. Effect of heat, N and K application on K and N uptake

In each row, means followed by common letter are not significantly different at 5% probability level by LSD; M20= Meister-20 (polymer coated urea), NU=Urea N source photosynthetic capacity (Wise et al. 2004), and consequently, nutrient uptake reduces through decrease in straw and grain dry weight. The results of this experiment are in line with the finding of Khalatbari et al. (2015) that showed that dry weight of straw and grain yield, and total K uptake were decreased 18.8, 25.8 and 18.2 percent compared to normal temperatures, respectively.

As efficient traditional methods, the agronomic strategies, such as adequate NPK fertilizers application, still is quick solutions to improve rice growth and grain productivity. Dupont and Altenbach (2003) indicated that the post-anthesis application of N fertilizers decreased the negative effect of heat stress on the storage protein composition. Also the higher levels of applied N not only increased leaf and grain N concentration but also led to higher free NH4+ levels in leaves and in developing ears.

In case of individual effect of N fertilizers (rates and types), the rice N and K uptake positively significantly increased in all three types of uptake (grain, straw and total) ($P<0.05$) by increasing the N rates at both fertilizers types, but urea was more effective than M20 due to its better solubility (Figure. 2). The maximum percentage increase in N uptake was occurred in the grain, total and straw at the highest rate of N application with urea sources about for 2.36, 2.21 and 2.17 times compare to control at heat stress pots, respectively. Similar with N and lesser extent, the individual effect of K application on heat stress positive significant influence on K uptake ($P\leq0.05$). The maximum percentage increase was occurred in the at the 60 kg K ha^{-1} application rate about 1.38, 1.17 and 1.10 times more than control at heat stress pots at grain, total and straw at the highest rate of K application, respectively.

Similar to individual effects of N and K fertilizers on recorded uptake in rice tissues, the interaction impact of them showed two different performances at current experiment. As seen in figure 2 where N and K application levels were plotted against uptake, there were significant effects of fertilizer rates and types on grain and straw by M20 highest level+ highest level of K (pattern 1), but the rests positively significantly increased even if at heat stress compare to normal pots ($p\leq0.05$) (pattern 2) through highest levels of urea and applied K, averagely about 2-3 times more than control. The findings are in line with Khalatbari et al. (2015) that in which the rate of increasing dry weight of straw and grain yield were more in M_{20} fertilizer related to urea fertilizer at high level of nitrogen compared to check treatment. K uptake increased in straw and grain with increasing of using N fertilizer.

CONCLUSION

Heat stress, either singly or in combination with other abiotic stresses, may cause morphological, physiological, biochemical, and molecular alterations that adversely reduce crop growth and productivity, and ultimately yield. Producing an economically significant yield under heat stress conditions depends on several agricultural management strategies that contribute to heat tolerance in the field condition, such as soil amendments addition and/or adequate and balance macro-essential nutrients application, both in right amount and right types. Nitrogen and Potassium, individually or in combination, in the current crop-nutrition research positively significantly increased the rice growth and productivity in presence of heat stress as well as normal conditions. The fertilizers management (combination application of 160 kg ha^{-1} and 60 kg K ha^{-1}) remediated the negative effect of heat stress. With respect to fertilizers type, applied N and K increased yield about 200% compare to control. The positive significant effects of applied adequate fertilizers caused the higher grain yield by around 2 times, fertile spikelets closed to 2 times, and effective tillers by 57.6% compared to control. Furthermore, the highest levels of N and K, increased their uptake parameters averagely about 2-3 times. Despite the clear and positive responses of rice to nutritional treatments, the value of morphological and physiological characters in heat stress compared to normal pots are considerably low. Therefore, investigating more details about the effect of other macro and micro nutrient, the right time and method of application, interaction of nutrient elements and, soil and plant factors are necessary.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Universiti Putra Malaysia and also acknowledge to Long Term Research Grant Scheme (LRGS) in Food Security– Enhance Sustainable Rice Production under the Ministry of High Education, Malaysia for Technical and financial support of this project. Also, the authors would like to appreciate the editor of this paper, Miss Shiva Dialami.

REFERENCES

Andersen M.N. Jensen C. Lösch R. (1992) The interaction effects of potassium and drought in field-grown barley. I. Yield, water-use efficiency and growth. Acta Agriculturae Scandinavica B-Plant Soil Sciences, 42: 34-44.

Battisti D.S. Naylor R.L. (2009) Historical warnings of future food insecurity with unprecedented seasonal heat. Science, 323: 240-244.

Cabañero F.J. Martí V. Carvajal M. (2004) Does calcium determine water uptake under saline conditions in pepper plants, or is it water flux which determines calcium uptake? Plant Science, 166: 443-450.

Castilla L. Sierra J. Pineda D. Echeverry J. Garcés G. Perafán R. Ospina J. Florez E. (2010) En: Análisis de la producción arrocera en el Tolima periodo 2009B-; 2010A.

Ceccarelli S. Grando S. Maatougui M. Michael M. Slash M. Haghparast R. Rahmanian M. Taheri A. Al-Yassin A. Benbelkacem A. (2010) Plant breeding and climate changes. The Journal of Agricultural Science, 148: 627-637.

Chaturvedi I. (2005) Effect of nitrogen fertilizers on growth, yield and quality of hybrid rice (oryza sativa L.). journal of central european agricultural. volume6.

Chaves M.M. Maroco J.P. Pereira J.S. (2003) Understanding plant responses to drought—from genes to the whole plant. Functional Plant Biology, 30: 239-264.

Dobermann A.R. (2005) Nitrogen use efficiency–state of the art.

Dupont F. Altenbach S. (2003) Molecular and biochemical impacts of environmental factors on wheat grain development and protein synthesis. Journal of Cereal Science, 38: 133-146.

Eitzinger J. Orlandini S. Stefanski R. Naylor R. (2010) Climate change and agriculture: introductory editorial. The Journal of Agricultural Science, 148: 499-500.

Fukai S. Cooper M. (1995) Development of drought-resistant cultivars using physiomorphological traits in rice. Field Crops Research, 40: 67-86.

Giaveno C. Ferrero J. (2003) Introduction of tropical maize genotypes to increase silage production in the central area of Santa Fe, Argentina. Crop Breed Appl Biotechnol, 3: 89-94.

Hare P. Cress W. Van Staden J. (1998) Dissecting the roles of osmolyte accumulation during stress. Plant, cell & environment, 21: 535-553.

Hasanuzzaman M. Fujita M. (2013) Exogenous sodium nitroprusside alleviates arsenic-induced oxidative stress in wheat (Triticum aestivum L.) seedlings by enhancing antioxidant defense and glyoxalase system. Ecotoxicology, 22: 584-596.

Huang B. Liu X.Xu Q. (2001) Supraoptimal soil temperatures induced oxidative stress in leaves of creeping bentgrass cultivars differing in heat tolerance. Crop Science, 41: 430-435.

Huang Z.A. Jiang D.A. Yang Y. Sun J.W. Jin S.H. (2004) Effects of nitrogen deficiency on gas exchange, chlorophyll fluorescence, and antioxidant enzymes in leaves of rice plants. Photosynthetica, 42: 357-364.

IPCC (2007) Climate Change, AR4 ClimateSynthesis Report, A. Allali, et al, Editors: 23-73.

Islam M.S. Peng S. Visperas R.M. Ereful N. Bhuiya M.S.U. Julfiquar A. (2007) Lodging-related morphological traits of hybrid rice in a tropical irrigated ecosystem. Field Crops Research, 101: 240-248.

Ito S.Hara T. Kawanami Y. Watanabe T. Thiraporn K. Ohtake N. Sueyoshi K. Mitsui T. Fukuyama T. Takahashi Y. (2009) Carbon and Nitrogen Transport during Grain Filling in Rice Under High temperature Conditions. Journal of Agronomy and Crop Science, 195: 368-376.

Jagadish S. Craufurd P. Wheeler T. (2007) High temperature stress and spikelet fertility in rice (Oryza sativa L.). Journal of experimental botany, 58: 1627-1635.

Jones J.B. (2001) Laboratory guide for conducting soil tests and plant analysis. CRC press LLC, Folrida.USA.

Kato M.C. Hikosaka K. Hirotsu N. Makino A. Hirose T. (2003) The excess light energy that is neither utilized in photosynthesis nor dissipated by photoprotective mechanisms determines the rate of photoinactivation in photosystem II. Plant and Cell Physiology, 44: 318-325.

Khalatbari A.M. Karbalaei Aghamolki M.T. Yusop M.K. Hanafi M.M. Jaafar H.Z.Kh. S. (2015) Impact of Heat Stress and Fertilizer Management on Yield and Potassium Uptake of Rice. International conference on sustainable development, strategies and chanllenges, Tabriz, Iran.

Kumar S. Kaur R. Kaur N. Bhandhari K. Kaushal N. Gupta K. Bains T. Nayyar H. (2011) Heat-stress induced inhibition in growth and chlorosis in mungbean (Phaseolus aureus Roxb.) is partly mitigated by ascorbic acid application and is related to reduction in oxidative stress. Acta Physiologiae Plantarum, 33: 2091-2101.

Lack S. Marani N.M. Mombeni M. (2012) The effects of planting date on grain yield and yield components of rice cultivars. Advances in Environmental Biology: 406-414.

Lobell D.B. Field C.B. (2007) Global scale climate–crop yield relationships and the impacts of recent warming. Environmental research letters, 2: 014002.

Maestri E. Klueva N. Perrotta C. Gulli M. Nguyen H.T. Marmiroli N. (2002) Molecular genetics of heat tolerance and heat shock proteins in cereals. Plant Molecular Biology, 48: 667-681.

Marschner H. (1995) Mineral Nutrition of HigherPlants.

Marschner H. (2011) Marschner's mineral nutrition of higher plants. Academic press.

Martineau J. Specht J. Williams J. Sullivan C. (1979a) Temperature tolerance in soybeans. I. Evaluation of a technique for assessing cellular membrane thermostability. Crop Science, 19: 75-78.

Martineau J. Williams J. Specht J. (1979b) Temperature tolerance in soybeans. II. Evaluation of segregating populations for membrane thermostability. Crop Science, 19: 79-81.

Matsui T. Namuco O.S. Ziska L.H. Horie T. (1997a) Effects of high temperature and CO 2 concentration on spikelet sterility in indica rice. Field Crops Research, 51: 213-219.

Matsui T. Omasa K. Horie T. (1997b) High temperature-induced spikelet sterility of Japonica rice [Oryza sativa] at flowering in relation to air temperature, humidity and wind velocity conditions. Japanese Journal of Crop Science (Japan).

Matsui T. Omasa K. Horie T. (2000) High temperature at flowering inhibits swelling of pollen grains, a driving force for thecae dehiscence in rice (Oryza sativa L.). Plant Production Science, 3: 430-434.

Matsui T. Omasa K. Horie T. (2001a) Comparison between Anthers of two Rice (Oryza saliva L.) Cultivars with Tolerance to High Temperatures at Flowering or Susceptibility. Plant Production Science, 4: 36-40.

Matsui T. Omasa K. Horie T. (2001b) The difference in sterility due to high temperatures during the flowering period among japonica-rice varieties. Plant Production Science, 4: 90-93.

Mittler R. (2002) Oxidative stress, antioxidants and stress tolerance. Trends in plant science, 7: 405-410.

Morales D. Rodríguez P. Dell'Amico J. Nicolas E. Torrecillas A. Sánchez-Blanco M.J. (2003) High-temperature preconditioning and thermal shock imposition affects water relations, gas exchange and root hydraulic conductivity in tomato. Biologia Plantarum, 47: 203-208.

Nagai T. Makino A. (2009) Differences between rice and wheat in temperature responses of photosynthesis and plant growth. Plant and Cell Physiology, 50: 744-755.

Nakagawa H. Horie T. Matsui T. Mew T. Brar D. Peng S. Dawe D. Hardy B. (2003) Effects of climate change on rice production and adaptive technologies. Rice science: innovations and impact for livelihood Proceedings of the International Rice Research Conference, Beijing, China, 16-19 September 2002. International Rice Research Institute (IRRI).

Oh-e I. Saitoh K. Kuroda T. (2007) Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. Plant Production Science, 10: 412-422.

Peng S. Huang J. Sheehy J.E. Laza R.C. Visperas R.M. Zhong X. Centeno G.S. Khush G.S. Cassman K.G. (2004) Rice yields decline with higher night temperature from global warming. Proceedings of the National Academy of Sciences of the United States of America, 101: 9971-9975.

Poli Y. Basava R.K. Panigrahy M. Vinukonda V.P. Dokula N.R. Voleti S.R. Desiraju S. Neelamraju S. (2013) Characterization of a Nagina22 rice mutant for heat tolerance and mapping of yield traits. Rice, 6: 1.

Posmyk M. Janas K. (2007) Effects of seed hydropriming in presence of exogenous proline on chilling injury limitation in Vigna radiata L. seedlings. Acta Physiologiae Plantarum, 29: 509-517.

Prasad P. Boote K. Allen L. Sheehy J. Thomas J. (2006a) Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crops Research, 95: 398-411.

Prasad P. Staggenborg S. Ristic Z. (2008) Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crop plants. Response of crops to limited water: Understanding and modeling water stress effects on plant growth processes: 301-355.

Prasad P.V. Boote K.J. Allen L.H. (2006b) Adverse high temperature effects on pollen viability, seed-set, seed yield and harvest index of grain-sorghum [Sorghum bicolor (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. Agricultural and Forest Meteorology, 139: 237-251.

Rizhsky L. Liang H. Mittler R. (2003) The water-water cycle is essential for chloroplast protection in the absence of stress. Journal of Biological Chemistry.

Rizhsky L. Liang H. Shuman J. Shulaev V. Davletova S. Mittler R. (2004) When defense pathways collide. The response of Arabidopsis to a combination of drought and heat stress. Plant Physiology, 134: 1683-1696.

Rosenzweig C. Parry M.L. (1994) Potential impact of climate change on world food supply. Nature, 367: 133-138.

Sakamoto A. Murata N. (2002) The role of glycine betaine in the protection of plants from stress: clues from transgenic plants. Plant, cell & environment, 25: 163-171.

Salman D. Morteza S. Dariush Z. Abbas G.M. Reza Y. Ehsan G.D. Reza N.A. (2012) Application of nitrogen and silicon rates on morphological and chemical lodging related characteristics in rice (Oryza sativa L.) at north of Iran. Journal of agricultural science, 4: 12.

Sánchez-Reinoso A.D. Garcés-Varón G. Restrepo-Díaz H. (2014) Biochemical and physiological characterization of three rice cultivars under different daytime temperature conditions. Chilean journal of agricultural research, 74: 373-379.

Sangakkara U. Frehner M. Nösberger J. (2001) Influence of soil moisture and fertilizer potassium on the vegetative growth of mungbean (Vigna radiata L. Wilczek) and cowpea (Vigna unguiculata L. Walp). Journal of Agronomy and Crop Science, 186: 73-81.

Shabala S. Pottosin I.I. (2010) Potassium and potassium-permeable channels in plant salt tolerance. Ion Channels and Plant Stress Responses. Springer.

Shah F. Huang J. Cui K. Nie L. Shah T. Chen C. Wang K. (2011) Impact of high-temperature stress on rice plant and its traits related to tolerance. The Journal of Agricultural Science, 149: 545-556.

Shah N.H. Ahmad N. Iqbal F. (2007) Response of rice varieties to various transplanting dates. Pakistan Journal of Plant Sciences (Pakistan).

Sharkova V. (2001) The effect of heat shock on the capacity of wheat plants to restore their photosynthetic electron transport after photoinhibition or repeated heating. Russian Journal of Plant Physiology, 48: 793-797.

Simões-Araújo J.L. Rumjanek N.G. Margis-Pinheiro M. (2003) Small heat shock proteins genes are differentially expressed in distinct varieties of common bean. Brazilian Journal of Plant Physiology, 15: 33-41.

Singh P. Sawhney S.K. (1989.) Nitrate reduction in plants. p. 93-128. In Y.P. Abrol (ed.) Nitrogen in higher plants. Research Studies Press, Somerset, UK.

Somerville C. (1991) Plant lipids: metabolism, mutants, and membranes. Science, 252: 80.

Song L. Jiang Y. Zhao H. Hou M. (2012) Acquired thermotolerance in plants. Plant Cell, Tissue and Organ Culture (PCTOC), 111: 265-276.

Tahir I. Nakata N. (2005) Remobilization of nitrogen and carbohydrate from stems of bread wheat in response to heat stress during grain filling. Journal of Agronomy and Crop Science, 191: 106-115.

Tian X. Tsutomu M. Li S. Lin J. (2007) [High temperature stress on rice anthesis: research progress and prospects]. Ying yong sheng tai xue bao= The journal of applied ecology/Zhongguo sheng tai xue xue hui, Zhongguo ke xue yuan Shenyang ying yong sheng tai yan jiu suo zhu ban, 18: 2632-2636.

Uchida A. Jagendorf A.T. Hibino T. Takabe T. Takabe T. (2002) Effects of hydrogen peroxide and nitric oxide on both salt and heat stress tolerance in rice. Plant Science, 163: 515-523.

Wang M. Zheng Q. Shen Q. Guo S. (2013) The critical role of potassium in plant stress response. International journal of molecular sciences, 14: 7370-7390.

Waraich E. Ahmad R. Halim A. Aziz T. (2012) Alleviation of temperature stress by nutrient management in crop plants: a review. Journal of soil science and plant nutrition, 12: 221-244.

Waraich E.A. Ahmad R. Ashraf M. (2011) Role of mineral nutrition in alleviation of drought stress in plants. Australian Journal of Crop Science, 5: 764.

Wendehenne D. Pugin A. Klessig D.F. Durner J. (2001) Nitric oxide: comparative synthesis and signaling in animal and plant cells. Trends in plant science, 6: 177-183.

White P.J. Karley A.J. (2010) Potassium. Cell biology of metals and nutrients. Springer.

Wise R. Olson A. Schrader S. Sharkey T. (2004) Electron transport is the functional limitation of photosynthesis in field□grown pima cotton plants at high temperature. Plant, cell and environment, 27: 717-724.

Yang J. Zhang J. (2006) Grain filling of cereals under soil drying. New phytologist, 169: 223-236.

Yoshida S. (1978) Tropical climate and its influence on rice.

Yun-Ying C. Hua D. Li-Nian Y. Zhi-Qing W. Li-Jun L. Jian-Chang Y. (2009) Effect of high temperature during heading and early filling on grain yield and physiological characteristics in indica rice. Acta Agronomica Sinica, 35: 512-521.

Yun-Ying C. Hua D. Li-Nian Y. Zhi-Qing W. Shao-Chuan Z. Jian-Chang Y. (2008) Effect of heat stress during meiosis on grain yield of rice cultivars differing in heat tolerance and its physiological mechanism. Acta Agronomica Sinica, 34: 2134-2142.

Zhang J.M. Hongo A. Akimoto M. (2005) Physical strength and its relation to leaf anatomical characteristics of nine forage grasses. Australian journal of botany, 52: 799-804.

Zhou W. Xue D. Zhang G.-p. (2012) Identification and physiological characterization of thermo-tolerant rice genotypes. Journal of Zhejiang University, 38:1-9.