Effect of Temperature Variations on Growth and Development of Rice

¹Dr. Babita Yadav

¹Associate Professor, Nehru College Chhibramau, Kannauj

Received: 10 July 2022, Accepted: 20 July 2022, Published with Peer Reviewed on line: 31 July 2022

<u>Abstract</u>

Global food security is seriously threatened by heat stress (HS), which is a result of the earth's temperature quickly rising. Over half of the world's population depends on rice (*Oryza sativa L.*), a crop whose productivity and quality are frequently decreased by HS. Rice cultivars with increased heat tolerance must be bred immediately. Under HS, rice plants exhibit a variety of morphological and physiological signs. The selection of top germplasm and the discovery of thermotolerance genes depend on a precise investigation of the symptoms (phenotyping). Rice plants respond to HS by starting a chain of events and activating intricate transcriptional regulatory networks. Rice thermotolerance particularly depends on protein homeostasis under HS, which is influenced by protein quality control, efficient removal of harmful proteins, and translational regulation. Rice has adopted certain agronomic and genetic techniques for increasing heat tolerance, but the molecular processes underlying rice response to HS remain obscure, and breeding efforts to create rice thermotolerance have met with only patchy success. In this review, we discuss the effects of HS on rice and the developments in the study of signal cascades and heat-stress sensing, and we suggest methods for enhancing rice thermotolerance in the future.

Keyword- Effect, Temperature Variations, Growth and Development of Rice.

Introduction

One of the most important variables affecting the seasonal growth and geographic dispersion of crops is the ambient temperature (Li et al., 2018). Global warming has become an issue that cannot be disregarded due to population increase and industrial development (Quint et al., 2016). According to the IPCC's fifth assessment report (IPCC, 2014), the average global temperature increased by 0.85 C between 1880 and 2012 and is expected to rise by 3-5°C in Southeast Asia by 2100. The data from 23 global climate models also show a high (greater than 90%) probability that temperatures during the growing season in the tropics and subtropics by the end of the 21st century will exceed the most extreme seasonal temperatures recorded from 1900 to 2006 (Battisti et al., 2009). Heat waves will occur more frequently and persist longer than we anticipate due to global warming (Xu et al., 2018). The production of agricultural crops throughout the world is affected by global warming (Janni et al., 2020). The yields of wheat, rice, maize, and soybeans are predicted to decrease by 6.0%, 3.2%, 7.4%, and 3.1%, respectively, with every 1°C increase in the world mean temperature without CO₂ fertilisation, successful adaptation, and genetic improvement (Zhao et al., 2017). According to FAO data, the major grain crops' relative rates of production growth are decreasing. However, in order to maintain food security as the population grows, agricultural output must rise. According to estimates (Bita et al., 2013), a 70% increase in food production would be required to fulfil the demand of the predicted 9 billion people in 2050.

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL Vol. 5, Issue 02, July 2022

Over half of the world's population depends on rice (Oryza sativa L.), a crop with a harvest area of 167 million hectares and an output of more than 782 million tonnes in 2018. In Southeast Asia, which is expected to warm up the fastest (Fitzgerald et al., 2009), where 76% of the population's caloric intake comes from rice. Heat stress (HS), which is typically described as an increase in temperature over a threshold level for a specific length of time that harms plant growth and development irreparably, is brought on by a rapidly changing climate. According to Shi et al. 2015, post-heading HS caused a 1.5%-9.7% drop in rice output in four South Chinese planting locations between 1981 and 2010. According to Lyman et al. [15], paddy output decreased by 6.2% for every 1°C rise in average temperature throughout the rice growing season, total milled rice yield decreased by 7.1%-8.0%, head rice yield decreased by 9.0%–13.8%, and total milling income decreased by 8.1%–10.0 %. Rice has to be bred quickly to be thermotolerant due to its importance to global food security and the impact of climate change on rice yield. For thermotolerance breeding, it is crucial to identify the physiological and biochemical traits of rice that respond to HS, the genes and proteins responsible for heat tolerant, and the molecular pathways underpinning HS response (Raza et al., 2020). In this review, we discuss potential methods for analysing the regulatory network of the HS response and enhancing rice adaptation to global warming. We also summarised HS-caused morphological and physiological symptoms of rice and progress in elucidating molecular mechanisms underlying rice response to HS.

Growth and developmental effects of heat stress

Vegetative stage

Seedling vigour is heavily influenced by germinability and early seedling growth. Temperature elevation for an extended period of time reduces seed germination potential, resulting in a low germination rate and seedling vigour (Liu et al., 2019). At the seedling stage, the ideal temperature for rice growth is 25-28°C. Heat stress (42-45°C) causes increased water loss, withered and yellow leaves, impaired seedling and root growth, and even seedling death (Liu et al., 2018). Rice plant resistance to HS varies with genetic background at the seedling stage. Seedlings of the japonica cultivar Nipponbare are nearly all wilted after 72 hours of HS exposure, whereas seedlings of the indica cultivar HT54 can tolerate up to 48°C for 79 hours. Plants exposed to HS during the tillering stage exhibit a variety of morphological symptoms, including leaf wilting, curling, and yellowing, as well as a reduction in tiller number and biomass. Under HS (40°C day/35°C night) for 15 days, rice had a 35% lower panicle number and an 86% lower total yield per plant than at 28°C. HS has a greater impact on tiller and panicle number in japonica rice than in indica rice. Tiller number under HS is frequently used to select thermotolerant rice cultivars.

Reproductive stage

Rice plants are more susceptible to HS during the reproductive stage, which includes panicle initiation, male and female gametophyte development, pollination, and fertilisation. HS interferes with panicle initiation and spikelet development, resulting in deformed floral organs and decreased spikelet number and size (Xu *et al.*, 2020). The spikelet number of indica cultivar IR64 decreased by 66% after 15 days of pre-flowering exposure to HS (40°C day/35°C night) compared to normal growth conditions (28°C). Spikelet reduction is primarily caused by spikelet degeneration at panicle tips (Wu et al., 2016). Anther development and pollen viability within the floret are more sensitive to high temperatures than the ovule. HS during anther development, particularly at the pollen mother cell meiosis stage, may cause premature degradation and disintegration of the tapetal cells, impairing microspore nutritional supply and pollen wall formation, and causing pollen-grain abortion (Liu et al., 2020). When rice plants were

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL Vol. 5, Issue 02, July 2022

subjected to HS (40°C day/30°C night) at the pollen mother cell meiosis stage for 10 days, pollen viability and seed-setting rate decreased by 78.8% and 48.5%, respectively, when compared to the values under normal conditions (30°C day/24°C night). Following meiosis, the early microspore stage is the most sensitive to HS, and spikelet fertility is completely lost after 7 days of HS stress (39 °C day/30 °C night) (Endo et al., 2009). HS during anthesis causes altered anther shape, decreased anther dehiscence, poor pollen viability, decreased pollen number on stigma, decreased pollen swelling, poor germination of pollen grains on the stigma, inhibited elongation of pollen tubes, and decreased stigma length, all of which severely impair pollination and fertilisation, eventually reducing spikelet fertility (Shi et al., 2018). After double fertilisation, a short period of HS (39°C for 48 h) can cause abnormal cellularization of early endosperm development and impair endosperm establishment. The presence of HS during the reproductive stage reduced rice spikelet fertility by up to 80%. However, susceptibility to HS varies according to genetic background. High temperature (38°C), for example, reduced the number of pollen grains on the stigma by 55% in the Aus type N22 and 86% in the japonica type Moroberekan, but not in the indica type IR64. Because of the differences in organ temperatures, the number of grains on the stigmas of superior spikelets is more sensitive to HS than that of inferior spikelets.

Grain-filling stage

Grain filling is the process by which crop plants complete their growth and development by transporting and synthesising carbohydrates, proteins, and lipids in seeds. Following exposure to HS at the grain-filling stage, the grain-filling rate increased and the total grain-filling duration decreased by 21.3%-37.1% for different genotypes. Heat stress (35°C for 72 hours) hampered endosperm and embryo development during the early stages of seed development (Begcy et al., 2018). HS also causes altered kernel size, as well as decreased grain weight and yield. Grain weight was reduced by 24.6% and 39.1% for N22 and IR64, respectively, after 20 days of exposure to high temperatures (38°C day/30°C night) during grain filling, compared to normal conditions (31°C day/23°C night). HS at the grain-filling stage results in poor rice quality, as expressed by reduced palatability, undesirable grain appearance, and increased grain chalkiness (Nevame et al., 2018). The most visible symptoms of HS at the grain-filling stage are chalky kernels. Chalkiness is the opaque portion of the translucent white endosperm that degrades rice grain quality. When japonica cultivar Koshihikari was subjected to HS (33°C day/27°C night) for 3-35 days after flowering, 90.2% of the kernels showed combined chalk, including milkywhite and white-back kernels. With an increase in high temperature and prolonged duration at the early grain-filling stage, the chalkiness rate increased while the brown rice rate, milled rice rate, and head rice rate decreased. Several studies suggest that HS causes non-uniform filling and inhibits starch biosynthesis, resulting in irregular and smaller starch granules and the deposition of loosely packed starch granules, which increases the formation of chalky kernels. Amylose content is lower under HS (16.1%) than under normal conditions (19.8%), implying that lower amylose synthesis activity may be involved in chalk formation.

Physiological effects of heat stress Membrane damage

HS-induced growth and development retardation is frequently associated with disrupted physiological and metabolic processes in plant cells. Biomembranes are the most heat-sensitive components of the plant cell because they serve as the primary barrier and have highly ordered structures composed of lipids and proteins (Niu et al., 2018). Elevated temperatures can impair plasma membrane structure and function, alter the ratio of saturated to unsaturated fatty acids, and cause protein

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL Vol. 5, Issue 02, July 2022

denaturation, resulting in increased fluidity and permeability, compromised membrane integrity, and increased ion leakage from cells (Shen et al., 2015). Elevated temperature also reduces the activity of fatty acid desaturases, affecting the unsaturation degree of fatty acid chains and thus plant adaptation to HS.

Reactive oxygen species accumulation

Under HS, intracellular reactive oxygen species (ROS) levels skyrocket. When rice plants are subjected to HS (38°C day/30°C night) during the meiosis stage, the ROS content in anthers is more than three times that of normal temperature (28 °C day/22 °C night). HS also causes a ROS burst in rice pistils, which could be attributed to HS-induced upregulation of a number of Respiratory Burst Oxidase Homolog (RBOH) genes (Zhang et al., 2018). Simultaneously, HS reduces the activity of antioxidant enzymes, particularly superoxide dismutase (SOD) and catalase (CAT). Increased OsANN1 expression promotes thermotolerance by increasing CAT and SOD activity (Qiao et al., 2015). When plants are subjected to severe HS, intracellular ROS levels rise, disrupting ROS homeostasis and causing oxidative damage such as cell death, growth retardation, grain chalkiness, and even seedling death and spikelet sterility. Excessive ROS, in particular, will exacerbate membrane lipid peroxidation and protein oxidation, resulting in an increased content of intracellular malondialdehyde (MDA), which can impair the normal function of proteins and nucleic acids. As a result, electrolyte leakage, ROS levels, antioxidative gene transcript abundance, antioxidant enzyme activities, and MDA content are frequently used as indicators of membrane and oxidative damage and reflect plant thermotolerance. Due to their high antioxidant enzyme activities, heat-tolerant rice cultivars such as NERICA-L-44 and Nagina 22 have high membrane stability and lower ROS and MDA contents (Bahuguna et al., 2015).

Photosynthesis damage

Photosynthesis is extremely temperature sensitive. HS causes thylakoid membrane permeability to be destroyed or even thylakoid grana disintegration, causing a decrease in chlorophyll content and altering photochemical reactions with a decrease in the ratio of variable fluorescence to maximum fluorescence (Fv/Fm) and photosynthetic rate (Wang et al., 2018). The most sensitive component of the photosynthesis apparatus is photosystem II (PSII). The dissociation of the oxygen-evolving complex (OEC) in PSII caused by HS-induced oxidative stress inhibits electron transport from OEC to the acceptor side of PSII. When rice seedlings were exposed to HS, the levels of three OEC proteins decreased in vivo. The activity of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) is inhibited by high temperatures, primarily due to the inactivation of Rubisco activase. Transgenic rice plants with higher levels of Rubisco activase grew faster and had higher photosynthetic rates than wild-type (WT) plants. Similarly, overexpression of thermotolerant Rubisco activase from wild rice improved cultivated rice growth and grain yield after HS exposure, implying that engineering Rubisco activase may be an effective method for thermotolerance breeding.

Disturbance of carbohydrate metabolism and partitioning

In plants, HS disrupts carbohydrate metabolism and photoassimilate partitioning. When rice cells were exposed to high temperature (44°C), the abundance of two key enzymes in the glycolytic pathway, phosphoglucose isomerase and phosphofructokinase, was very low, and the abundance of phosphoglycerate mutase was also reduced, indicating impaired energy generation in cells. When rice plants experience HS during anthesis, the sugar content of the anthers is disrupted, impairing normal pollen development nutrition supply (Islam et al., 2019). Susceptible rice cultivars showed high expression of the Carbon Starved Anthers (CSA) gene in floral organs under HS, whereas tolerant

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL Vol. 5, Issue 02, July 2022

cultivars showed high expression of the sugar transporter gene MST8 and cell wall invertase gene INV4 in floral organs, implying that sugar starvation is a factor in spikelet sterility under HS. Similarly, a heat-tolerant rice cultivar expressed more of the sucrose transporter gene OsSUT1 than a sensitive cultivar, resulting in a greater supply of photoassimilates to filling kernels (Miyazaki et al., 2013). HS during the filling stage decreased the expression of a number of genes encoding starch synthesis-related proteins such as granule-bound starch synthase I and branching enzymes, potentially inhibiting starch accumulation and increasing grain chalkiness (Yamakawa *et al.*, 2007).

Phytohormone imbalance

HS disrupts phytohormone balance. HS decreased active cytokinin (CTK), gibberellin (GA), and indole-3-acetic acid (IAA) levels in rice spikelets and developing kernels, impairing cell proliferation and panicle formation and decreasing spikelet number, pollen fertility, and kernel weight (Tang et al., 2007). When exposed to HS, heat-susceptible cultivars showed a marked inhibition of CTK transportation rate and CTK synthesis enzymes, but increased cytokinin oxidase/dehydrogenase (CKX) activity, possibly accounting for a reduction in panicle CTK abundance. Heat-induced damage to spikelet fertility, spikelet number, and kernel weight is alleviated by exogenous application of 6-benzylaminopurine (6-BA), a synthetic CTK. Similarly, exogenous application of brassinosteroids (BR), salicylic acid (SA), and ethylene precursors to rice plants improved heat-induced oxidative damage and morphological symptoms, indicating the importance of these phytohormones in heat stress response (HSR). In contrast, HS causes an increase in abscisic acid (ABA) levels in anthers and seeds, which results in pollen abortion and inhibition (Wu *et al.*, 2019).

Effect of Cold Stress

Photosynthesis and Respiration

Photosynthesis is an important phenomenon that contributes significantly to plant growth and development. The rate of photosynthesis in cold sensitive plants is highly dependent on temperature conditions, and cold stress significantly reduces photosynthesis rate (Li et al. 2004), by increasing the concentration of soluble sugars and decreasing starch content in all organs. Cold stress has a negative impact on two major photosynthesis properties: chlorophyll content and fluorescence. Cold stress reduces the photosynthesis rate in rice by affecting the florescence and chlorophyll content (Kanneganti and Gupta 2008). Cold stress also reduces photosynthetic activity by inhibiting chlorophyll synthesis, increasing membrane permeability, damaging the chloroplast, and ultimately decreasing photosynthetic activity. Cold stress decreased the activity of the dark reaction, the activity of the light dependent reaction in the thylakoid membrane, and the activity of carbon dioxide (CO2) assimilation in the chloroplast stroma. Cold stress also inhibits electron transmission and reduces Hill reaction activity. Low temperature changed the respiratory rate of chilling sensitive crops, resulting in the destruction of mitochondrial structure and also reducing the activity of some enzymes by reducing the kinetic energy (Munro et al. 2004). Cold stress reduces the cytochrome path of electron transport and increases alternative respiratory pathways during the early stages of development (Ribascarbo et al. 2000). In short, cold stress reduces photosynthesis activity in rice by decreasing chlorophyll content and inflorescence. Furthermore, more research is needed to determine whether cold stress had a direct effect on photosynthetic rate and chlorophyll inflorescence parameters.

Grain Development and Yield Formation

Under cold stress, inferior spikelets and delayed flowering result in poor grain development and low grain yield. Poor grain development is often attributed to a lack of carbohydrates, but this may not

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL

Vol. 5, Issue 02, July 2022

be the only reason, as vital enzymes are involved in carbon metabolism. The increase or decrease in amylose concentration in rice is dependent on cultivar, but amylose production is higher at low temperatures than at high temperatures (Ahmed *et al.* 2008). A low temperature of 15-20 °C increased the amylose concentration in grain of several japonica rice cultivars. Cold stress causes partial and late maturation of grain during grain development (Oliver *et al.* 2007), and grain development is regulated by a source-sink relationship that is negatively affected by temperature. Cold stress reduces grain filling period and rate, resulting in small grain size (Oliver *et al.* 2007). However, plant hormones such as ABA and cytokinins (CKTs) also influence grain development in rice (Oliver *et al.* 2007). Stomatal closure occurs as a result of increased ABA concentration in leaves, limiting photosynthesis due to low carbon dioxide (CO2) within cells. In conclusion, under cold stress conditions, the concentration of amylose in grain increases. Cold stress shortens the duration and rate of grain filling, resulting in shrivelled grains. Rice grain development is primarily regulated by plant hormones such as ABA and CTKs. ABA

Conclusions and Future Studies

Temperature stresses cause significant yield loss in rice. Heat stress affects almost every stage of rice development, from emergence to harvesting. Heat stress has a negative impact on seed growth, emergence, and development. Heat stress shortens the coleoptile and radicle lengths, as well as the radicle weight, germination rate, leaf-elongation duration, and biomass in rice. Heat stress causes anther indehiscence and reduces pollen dispersal during the reproductive stage. Heat stress causes flowering to be delayed and has an impact on post-fertilization development. It may increase grain filling rate, but it shortens grain filling period and results in significant yield loss. Heat stress during the ripening stage results in chalky grains that are round and irregular in shape. Cold stress also impairs rice growth and reproduction by delaying panicle initiation, affecting anther respiration, increasing sucrose accumulation, and causing protein denaturation. Low temperatures cause pollen sterility and impair pollination by inhibiting anther dehiscence, resulting in a reduction in rice grain yield. Cold stress also shortens the period for grain filling, reducing grain size and overall productivity (Hussain *et al.*, 2018). High temperature stress has a negative effect on mitosis in rice; its role in encouraging pollen abortion during mitosis via its effects on the tapetum is not well understood and needs to be investigated further. To improve rice production, response and tolerance mechanisms must be investigated at the molecular level, and a functional genomics approach should be used to understand the molecular basis of rice response to thermal stress tolerance. Various ecophysiological and genomics studies may aid in understanding the interaction between temperature stress and genotypes. To reduce yield losses, new rice varieties with heat and cold tolerance at various stages are required. Despite advances in temperature stress tolerance, heat and cold stresses continue to reduce rice yield, particularly in areas where indica rice cultivars are grown. Different rice cultivars, fortunately, have widespread adaptation to low temperature stress, and cold-tolerant ecotypes are presented for breeding purposes. To identify the fundamental mechanisms of cold tolerance, an all-inclusive approach is required. Different crop management strategies, such as balanced crop nutrient use and changing planting time, should be investigated further in the future to improve rice tolerance to temperature stresses.

References-

 Ahmed, N., Maekawa, M., Tetlow, I.J. (2008). Effect of low temperature on grain filling, amylosecontent and activity of starch biosynthesis enzymes in endosperm of basmati rice. Aust J Agric Res 59, 599–604.

- 2- Bahuguna, R.N., J. Jha, M. Pal, D. Shah, L.M.F. Lawas, S. Khetarpal, K.S.V. Jagadish. (2015). Physiological and biochemical characterization of NERICA-L-44: a novel source of heat tolerance at the vegetative and reproductive stages in rice, Physiol. Plant. 154, 543–559.
- 3- Battisti, D.S., R.L. Naylor. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat, Science 323, 240–244.
- 4- Begcy, K.,J. Sandhu, H. Walia. (2018). Transient heat stress during early seed development primes germination and seedling establishment in rice, Front. Plant Sci. 9, 1768.
- 5- Bita, C.E., T. Gerats. (2013). Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops, Front. Plant Sci. 4, 273.
- 6- Endo, M., T. Tsuchiya, K. Hamada, S. Kawamura, K. Yano, M. Ohshima, A. Higashitani, M. Watanabe, M. Kawagishi-Kobayashi. (2009). High temperatures cause male sterility in rice plants with transcriptional alterations during pollen development, Cell Physiol 50, 1911–1922.
- 7- Fitzgerald, M.A.,S.R. McCouch, R.D. Hall. (2009). Not just a grain of rice: the quest for quality, Trends Plant Sci. 14, 133–139.
- 8- Fu, G., B. Feng, C. Zhang, Y. Yang, X. Yang, T. Chen, X. Zhao, X. Zhang, Q. Jin, L. Tao. (2016). Heat stress is more damaging to superior spikelets than inferiors of rice (Oryza sativa L.) due to their different organ temperatures, Front. Plant Sci. 7, 1637.
- 9- Hussain, H.A., Hussain, S., Khaliq, A., Ashraf, U., Anjum, S.A., Men, S., Wang, L. (2018). Chilling anddrought stresses in crop plants: implications, cross talk, and potential management opportunities. Front Plant Sci 9, 393.
- 10- IPCC. (2014). Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change, Synthesis report, Geneva, Switzerland.
- 11- Islam, M.R., B. Feng, T. Chen, W. Fu, C. Zhang, L. Tao, G. Fu. (2019). Abscisic acid prevents pollen abortion under high-temperature stress by mediating sugar metabolism in rice spikelets, Physiol. Plant. 165, 644–663.
- 12- Janni, M., M. Gullì, E. Maestri, M. Marmiroli, B. Valliyodan, H.T. Nguyen, N. Marmiroli, C. Foyer. (2020). Molecular and genetic bases of heat stress responses in crop plants and breeding for increased resilience and productivity, J. Exp. Bot 71, 3780–3802.
- 13- Kanneganti V., Gupta, A.K. (2008). Overexpression of OsiSAP8, a member of stress associated protein (SAP) gene family of rice confers tolerance to salt, drought and cold stress in transgenic tobacco and rice. Plant Mol Biol 66(5), 445–462.
- 14- Li, B.,K. Gao, H. Ren, W. Tang. (2018). Molecular mechanisms governing plant responses to high temperatures, J. Integr. Plant Biol. 60, 757–779.
- 15- Li, X.G., Wang X.M., Meng Q.W., Zou, Q. (2004). Factors limiting photosynthetic recovery in sweet pepper leaves after short-term chilling stress under low irradiance. Photosynthetica 42(2), 257–262.
- 16- Liu, G., Z. Zha, H. Cai, D. Qin, H. Jia, C. Liu, D. Qiu, Z. Zhang, Z. Wan, Y. Yang, B. Wan, A. You, C. Jiao. (2020). Dynamic transcriptome analysis of anther response to heat stress during anthesis in thermotolerant rice (*Oryza sativa* L.), Int. J. Mol. Sci. 21, 1155.
- 17- Liu, J., M. Hasanuzzaman, H. Wen, J. Zhang, T. Peng, H. Sun, Q. Zhao. (2019). High temperature and drought stress cause abscisic acid and reactive oxygen species accumulation and suppress seed germination growth in rice, Protoplasma 256, 1217–1227.

Vol. 5, Issue 02, July 2022

- 18- Liu, J., X. Sun, F. Xu, Y. Zhang, Q. Zhang, R. Miao, J. Zhang, J. Liang, W. Xu. (2018). Suppression of OsMDHAR4 enhances heat tolerance by mediating H2O2- induced stomatal closure in rice plants, Rice 11, 38.
- 19- Miyazaki, M., M. Araki, K. Okamura, Y. Ishibashi, T. Yuasa, M. Iwaya-Inoue.(2013). Assimilate translocation and expression of sucrose transporter, OsSUT1, contribute to high-performance ripening under heat stress in the heattolerant rice cultivar Genkitsukushi, J. Plant Physiol. 170,1579– 1584.
- 20- Munro, K.D., Hodges, D.M., DeLong, J.M., Forney, C.F., Kristie, D.N. (2004). Low temperature effects on ubiquinone content, respiration rates and lipid peroxidation levels of etiolated seedlings of two differentially chilling-sensitive species. Physiol Plant 121(3), 488–497.
- 21- Nevame, A.Y.M., R.M. Emon, M.A. Malek, M.M. Hasan, M.A. Alam, F.M. Muharam, F. Aslani, M.Y. Rafii, M.R. Ismail. (2018). Relationship between high temperature and formation of chalkiness and their effects on quality of rice, Biomed Res. Int. 2018, 1653721.
- 22- Niu, Y.,Y. Xiang. (2018). An overview of biomembrane functions in plant responses to high-temperature stress, Front. Plant Sci. 9, 915.
- 23- Oliver, S.N., Dennis, E.S., Dolferus, R. (2007). ABA regulates apoplastic sugar transport and is a potential signal for cold-induced pollen sterility in rice. Plant Cell Physiol 48, 1319–1330.
- 24- Peng, S., J. Peñuelas, A.C. Ruane, D. Wallach, T. Wang, D. Wu, Z. Liu, Y. Zhu, Z. Zhu, S. Asseng. (2017). Temperature increase reduces global yields of major crops in four independent estimates, Proc. Natl. Acad. Sci. U. S. A. 114, 9326–9331.
- 25- Qiao, B., Q. Zhang, D. Liu, H. Wang, J. Yin, R. Wang, M. He, M. Cui, Z. Shang, D. Wang, Z. Zhu. (2015). A calcium-binding protein, rice annexin OsANN1, enhances heat stress tolerance by modulating the production of H2O2, J. Exp. Bot. 66, 5853–5866.
- 26- Quint, M., C. Delker, K.A. Franklin, P.A. Wigge, K.J. Halliday, M. van Zanten. (2016). Molecular and genetic control of plant thermomorphogenesis, Nat. Plants 2, 15190.
- 27- Raza, Q.,A. Riaz, K. Bashir, M. Sabar. (2020). Reproductive tissues-specific meta-QTLs and candidate genes for development of heat-tolerant rice cultivars, Plant Mol. Biol. 104, 97–112.
- 28- Ribascarbo, M., Aroca, R., Gonzalez-Meler, M.A., Irigoyen, J.J., Sanchezdiaz, M. (2000). The electron partitioning between the cytochrome and alternative respiratory pathways during chilling recovery in 2 cultivars of maize differing in chilling sensitivity. Plant Physiol 122(1), 199–204.
- 29- Scafaro, A.P., B.J. Atwell, S. Muylaert, B.V. Reusel, G.A. Ruiz, J.V. Rie, A. Gallé.(2018). A thermotolerant variant of Rubisco activase from a wild relative improves growth and seed yield in rice under heat stress, Front. Plant Sci. 9, 1663.
- 30- Shen, H., X. Zhong, F. Zhao, Y. Wang, B. Yan, Q. Li, G. Chen, B. Mao, J. Wang, Y. Li, G. Xiao, Y. He, H. Xiao, J. Li, Z. He. (2015). Overexpression of receptor-like kinase ERECTA improves thermotolerance in rice and tomato, Nat. Biotechnol. 33, 996–1003.
- 31- Shi, P., L. Tang, L. Wang, T. Sun, L. Liu, W. Cao, Y. Zhu, D. Hui. (2015). Post-heading heat stress in rice of South China during 1981–2010, PLoS ONE 10, e0130642.
- 32- Shi, W., X. Li, R.C. Schmidt, P.C. Struik, X. Yin, S.V.K. Jagadish. (2018). Pollen germination and in vivo fertilization in response to high-temperature during flowering in hybrid and inbred rice, Plant Cell Environ. 41, 1287–1297.

A BI-ANNUAL, OPEN ACCESS, PEER REVIEWED (REFEREED) JOURNAL Vol. 5, Issue 02, July 2022

- 33- Tang, R.S., J.C. Zheng, Z.Q. Jin, D.D. Zhang, Y.H. Huang, L.G. Chen. (2007). Possible correlation between high temperature-induced floret sterility and endogenous levels of IAA, GAs and ABA in rice (Oryza sativa L.), Plant Growth Regul. 54, 37–43.
- 34- Wang, Q.L., J.H. Chen, N.Y. He, F.Q. Guo. (2018). Metabolic reprogramming in chloroplasts under heat stress in plants, Int. J. Mol. Sci. 19, 849.
- 35- Wei, H., J. Liu, Y. Wang, N. Huang, X. Zhang, L. Wang, J. Zhang, J. Tu, X. Zhong. (2012). A dominant major locus in chromosome 9 of rice (Oryza sativa L.) confers tolerance to 48^oC high temperature at seedling stage, J. Hered. 104, 287–294.
- 36- Wu, C., K. Cui, W. Wang, Q. Li, S. Fahad, Q. Hu, J. Huang, L. Nie, S. Peng. (2016). Heatinduced phytohormone changes are associated with disrupted early reproductive development and reduced yield in rice, Sci. Rep. 6:34978..
- 37- Wu, Y.S., C.Y. Yang. (2019). Ethylene-mediated signaling confers thermotolerance and regulates transcript levels of heat shock factors in rice seedlings under heat stress, Bot. Stud. 60, 23.
- 38- Xu, J., A. Henry, N. Sreenivasulu. (2020). Rice yield formation under high day and night temperatures-A prerequisite to ensure future food security, Plant Cell Environ. 43, 1595–1608.
- 39- Xu, Y., V. Ramanathan, D.G. Victor. (2018). Global warming will happen faster than we think, Nature 564, 30–32.
- 40- Yamakawa, H., T. Hirose, M. Kuroda, T. Yamaguchi. (2007). Comprehensive expression profiling of rice grain filling-related genes under high temperature using DNA microarray, Plant Physiol. 144, 258–277.
- 41- Zhang, C., G. Li, T. Chen, B. Feng, W. Fu, J. Yan, M.R. Islam, Q. Jin, L. Tao, G. Fu. (2018). Heat stress induces spikelet sterility in rice at anthesis through inhibition of pollen tube elongation interfering with auxin homeostasis in pollinated pistils, Rice 11, 14.
- 42- Zhao, C., B. Liu, S. Piao, X. Wang, D.B. Lobell, Y. Huang, M. Huang, Y. Yao, S. Bassu, P. Ciais, J.L. Durand, J. Elliott, F. Ewert, I.A. Janssens, T. Li, E. Lin, Q. Liu, P. Martre, C. Müller,