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Heat Stress in Rice: Exploring the Role of Salicylic Acid for Sustainable Farming

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Abstract
Rice, a crucial staple crop globally, faces challenges from heat stress, which can lead to reduced growth, decreased yield, and impaired physiological processes. However, ongoing research on the use of salicylic acid (SA) to mitigate heat stress in rice offers promising solutions for sustainable farming. SA, a phenolic endogenous growth regulator, acts as a signal molecule, inducing defense mechanisms and regulating physiological and biochemical processes. Studies have shown that SA application alleviates heat stress by enhancing photosynthesis, activating antioxidant enzymes, and modulating osmotic potential and water potential. It also limits ethylene production, delaying senescence and improving yield. Moreover, SA pretreatment has been found to improve heat tolerance in rice seedlings by reducing electrolyte osmosis and oxidative stress. Foliar sprays of SA have demonstrated beneficial effects on pollen viability, seed setting, and grain quality under heat stress. Additionally, the use of SA in conjunction with other osmoprotectants has shown potential in enhancing crop resilience to heat stress. These findings highlight the potential of SA as a valuable tool in mitigating the adverse effects of heat stress on rice and improving overall productivity.

Keywords: antioxidant enzymes, heat stress, reactive oxygen species, rice, salicyclic acid

Introduction
Rice (*Oryza sativa*), is a staple crop worldwide, sustains billions with nutrition and livelihoods. As a versatile grain, its cultivation faces challenges with heat stress (Wopereis et al., 2008) but ongoing research, like the impact of salicylic acid on heat stress is necessary to enhance productivity and ensures sustainable rice farming. Heat stress usually defined as a sudden rise of 10-15°C over the normal ambient temperature (Lipiec et al., 2013). Heat stress is a significant environmental factor that can have detrimental effects on rice plants, leading to reduced growth, decreased yield, and impaired physiological processes (Hasanuzzaman, 2013). However, the application of salicylic acid (SA) has been found to alleviate the negative impacts of heat stress on rice (Lipiec et al., 2013. Here, we discussed the effects of salicylic acid on heat stress in rice and how it helps in mitigating the adverse effects.

Influence of salicylic acid in heat stress of rice
Salicylic acid is a phenolic endogenous growth regulator that plays a role in the control of physiological processes in plants. It is also known as a signal molecule that plays a role in the induction of defense mechanism (Halim et al., 2006). Under heat stress, salicylic acid, a common phenolic molecule which, enhances photosynthesis by regulating physiological and biochemical processes. On certain plant species, the ability of salicylic acid to activate superoxide dismutase (SOD) had discovered (Rao et al.,1997). Salicylic acid can also have an

activating and inhibitory effect on peroxidase activity, play a role in the regulation of the hydrogen peroxide pool and the formation of superoxide anion radicals in the presence of excess reductants. Salicylic acid has an activating effect on alternative oxidase, which alters the degree of reactive oxygen species production in mitochondria. (Pavlova et al., 2009).

Khan et al. (2013) Exogenous application of 0.5 mm salicylic acid alleviated heat stress in wheat by increasing proline production via increase in y-gletamyl kinase and a decrease in proline oxidase activity, resulting in an increase in osmotic potential and water potential, both of which are necessary for maintaining photosynthetic activity. In addition, ethylene production limited, resulting in delayed senescence, the retention of the stay green characteristic, and improved yield.

In rice, Heat stress (35 °C, 48 h) induced electrolyte osmosis delayed by pretreatment of seedlings with SA (0.5 mM), which also lowered MDA concentration and superoxide anion radical (O_2^-) production rate under HT stress. Whereas H_2O_2, Pro, soluble sugar, soluble protein, AsA, and GSH concentrations in rice seedlings rise when they pretreated with SA. These findings revealed that SA pretreatment improved rice seedling heat tolerance (Ding et al., 2010).

Wang and Li, (2006) found that spraying grape vine with a 0.1 mM SA reduced relative electrolyte leakage during heat stress. The use of exogenous SA (0.05 mM) promotes growth and protects against abiotic stressors (Shakirova et al., 2007). Foliar spray of 0.1–10 mM salicylic acid concentration minimized pollen sterility and high temperature stress at the pollen mother cell meiosis stage, resulted in significantly higher seed-setting rate and pollen viability than the non-Salicylic acid treatment. Under heat stress, the most effective Salicylic acid concentration was found to be 10 mM, and rice plants sprayed with 50 mM Salicylic acid showed no inhibition. High temperature has a negative effect on yield and yield attributes like plant height, number of effective tillers, grain yield per plant, test weight, seed, straw, biological yield, and harvest index, and these parameters can be improved with salicylic acid (150 ppm) treatment under normal and late sown conditions, this also reduces the impact of high temperature stress on yield and yield attribute characteristics in wheat genotypes, resulting in improved production. (Chouhan et al., 2017).

Rehman *et al*. (2015) noted that Hydropriming, $CaCl_2$ (2.2 % osmopriming), moringa leaf extracts (3.3 % osmopriming), and salicylic acid (50 mg L –1) were all used on maize hybrid (FH 810) seeds. In early planted maize, seeds primed with salicylic acid took less time to emerge and had higher vigour, also boosted plant height, grain rows and 1000-grain weight, grain and biological yield, and harvest index. Seadh et al. (2015) found seed soaking in 300 ppm salicylic acid resulted in the highest recorded values of growth, yield, and grain quality. Taria et al., (2015) found that Salicylic acid had shown to trigger flowering in a variety of plants, and foliar application of salicylic acid shown to improve flowering and pod production in soybeans. Fariduddin et al. (2003) reported that, lower amounts of salicylic acid sprayed on Brassica juncea, dry matter accumulation was dramatically increased. Higher salicylic acid concentrations, on the other hand, showed an inhibitory effect.

Osmoprotectants

Exogenous foliar spray of osmoprotectants like Glycinebetaine, Salicylic acid, Ascorbic acid, Citric acid, Potassium chloride, etc. has been reported to be effective in reducing the loss of yield by improving tolerance to heat stress under dry and warmer climate or due to late sowing of rice. Several studies show that these compounds protect plants from the negative effects of elevated temperatures through various mechanisms, such as preventing chlorophyll degradation and reducing electrolyte leakage, and thus help to maintain or sometimes increase pollen viability, seed setting, and crop yield. (Das et al., 2020). Plants produce osmolytes like proline, which work as low-molecular-weight chaperones, to counteract the effects of water deficiency. These osmolytes preserve membrane integrity and scavenge reactive oxygen species while stabilizing and protecting the structure of enzymes and proteins. Proline is one signaling or regulatory molecule that can activate a variety of processes to help in stress adaption process. (Izadi et al., 2014).

Discussion

The present study highlights the detrimental effects of heat stress on rice, including reduced growth and yield. However, it explores the potential of salicylic acid (SA) in mitigating these impacts (Das et al., 2020). SA, a phenolic growth regulator, acts as a signal molecule, inducing defense mechanisms and regulating physiological processes. Studies have shown that SA application can enhance photosynthesis, activate antioxidant enzymes, and modulate osmotic potential and water potential, thus improving heat tolerance in rice Rehman et al. (2015). The use of SA also delays senescence, improves yield, and enhances pollen viability and grain quality. These findings underscore the importance of SA as a valuable tool for sustainable rice farming, offering hope for combating heat stress and increasing overall productivity in the face of climate change (Seadh et al., 2015).

Conclusion

In conclusion, the use of salicylic acid (SA) shows great potential in mitigating the detrimental effects of heat stress on rice. SA acts as a signal molecule, activating defense mechanisms and regulating physiological processes, thereby improving heat tolerance. It enhances photosynthesis, antioxidant activity, and osmotic potential, while delaying senescence and improving yield. These findings highlight the significance of SA as a valuable tool for sustainable rice farming, offering opportunities to overcome the challenges imposed by heat stress and ensure the productivity and resilience of rice crops in a changing climate.

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