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Alleviation of Different Climatic Conditions by Foliar Application of Salicylic Acid and Sodium Nitroprusside and Their Interactive Effects on Pigments and Sugar Content of Maize Under Different Sowing Dates

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ABSTRACT

The agricultural sector is seriously impacted by climate change, leading to potential risks to food security. In terms of global food production, maize ranks third. As a result, crop production and food security depend critically on assessing the effects of climate change and developing measures to adapt maize. Regarding adaptability, changing planting dates and using different agrochemicals are more effective than other management. Crop models are part of a global decision support system to help farmers maximize yields despite unpredictable weather patterns. To mitigate yield loss and protect the ecosystem, it is essential to use efficient maize-sowing practices in the field. This experiment was carried out to identify the most favorable sowing dates that maximize yield while ensuring the crop's productivity and the integrity of the surrounding ecosystem remain intact. The main aim of this experiment was to mitigate the different climatic conditions by exogenous application of salicylic acid (SA) and sodium nitroprusside (SNP) on pigments and sugar content in maize under different sowing dates. A field experiment was carried out in the School of Agriculture, Lovely Professional University, Punjab, India, during the spring season of 2022. The experiment dealt with various maize crops, PMH-10, sourced from the Punjab Agricultural University (PAU), Punjab. The experiment was conducted in an open-air environment. The experimental setup was laid out in a split-plot design. The results stated that foliar application of salicylic acid and sodium nitroprusside successfully influenced high-temperature tolerance and low temperature at the reproductive phase and initial vegetative stages with other growing climatic conditions of maize in early and late sowings when controlled by increasing the chlorophyll index, carotenoids content, and sugar content of maize.

INTRODUCTION

Food insecurity will excessively affect the world's poor and most vulnerable communities due to climate change (Barbier & Hochard 2018). The last three decades have been the warmest since 1850 (Pachauri et al. 2014). Temperature and precipitation increases occur over the planet, although not equal (Stoker et al. 2013). Several studies (Najali et al. 2018) have examined the possible implications of future climate changes on food production on a global or continental scale. Global production systems are particularly susceptible to the effects of climate change (RK & Meyer 2014; Shafqat et al. 2019). Reduced agricultural productivity is a significant worry for food security, and this is especially true in arid and semi-arid regions (Ahmed et al. 2019). Crop growth, development, and output are already more at risk in dry areas due to the detrimental consequences of increasing temperatures and erratic rainfall patterns (Chattha et al. 2021). The most important discovery from climate change research, in terms of adjustments being made in agricultural production systems, is the variance in climatic projections. Climate change may be seen in various ways, including but not limited to long-term shifts in temperature and rainfall patterns, increases in atmospheric carbon dioxide and other gases, and a rise in the frequency of extreme weather events (Masson et al. 2021, Shafqat et al. 2021). The agricultural value of maize is substantial, especially for the provision of food in developing countries. As its use becomes more commonplace in households, businesses, and factories, the demand for biofuel is expected to continue proliferating (Asseng et al. 2015). However, climate variability makes maize production extremely susceptible to the effects of extreme weather events (Ahmed et al. 2018). The optimal development and reproductive phases can be disrupted by temperature variations, especially under extreme conditions, which can shorten the growing season and reduce crop yield

(Mubashra et al. 2019). Maize's physiological and metabolic systems require favorable environmental conditions to function correctly (Hatfiel & Prueger 2015). Reduced maize output has been linked to variations in the ideal temperature ranges. This loss is exacerbated by both higher daytime and nighttime temperatures.

High heat and dryness put a significant amount of stress on the majority of maize genotypes grown there. It also suggests that planting water-efficient crop cultivars might be an effective solution (Mina et al. 2019). Since the reproductive stages, flowering and grain-filling, are especially vulnerable to increased temperatures, pinpointing the optimal planting time is crucial for increasing productivity and diversifying the current agricultural system to ensure sustainability (Ahmed et al. 2019). Heat stress and the scarcity of critical resources like water and nutrients have become significant obstacles to the efficient production of maize, a widely important cereal crop. Rising temperatures are blamed for these problems (Babel et al. 2019). Increased atmospheric carbon dioxide (CO_2) has been linked to improved plant growth and output. It is important to remember that maize, a C4 crop, may have fewer benefits than other crops regarding photosynthetic accumulation for ultimate biomass output (Mina et al. 2019). The sustainability of maize production in the region is threatened by climate change's possible influence on maize phenology, growth, development, and yield.

Furthermore, it threatens long-term food security. The impact of different sowing dates, plant genetics, and environmental interactions on crop yields may be evaluated using crop growth models (Saddique et al. 2020a, 2020b, 2020c). The capacity of growth regulators, including salicylic acid (SA), ethylene (ET), abscisic acid (ABA), jasmonates (JA), and nitric oxide (NO) donor (SNP) to stimulate development in plants despite times of dormancy and stress has garnered much interest. Particular attention has been paid to how these regulators improve plant resistance to stress (Khan & Khan 2013). Some crops, including wheat, maize, and rice, are particularly vulnerable to high temperatures and heat stress. Scientific investigations (Rai et al. 2018, 2020) corroborate this observation. Salicylic acid (SA) and sodium nitroprusside (SNP), a nitric oxide (NO) donor, are discussed in detail as contributing factors to plant heat tolerance in their study (Prakash et al. 2021).

MATERIALS AND METHODS

Study Site

During the spring season of 2022, a research experiment was conducted at the agricultural area of Lovely Professional University (LPU), situated in Phagwara, Punjab. The objective of the experiment was to ascertain the optimal timing for maize sowing and identify the appropriate agrochemicals to maximize crop production. A field experiment was carried out in the School of Agriculture, Lovely Professional University, Punjab, India, using a single variety of maize crops, PMH-10, from Punjab Agricultural University (PAU) in Punjab. The experiment used a split-plot design, with two factors: sowing as the main plot and agrochemicals as the sub-plot. The experiment was replicated three times. Salicylic acid at 150 milligrams per liter and Sodium Nitroprusside at 250 micromoles per liter were applied as an exogenous treatment using an appropriate sprayer at different growth stages of maize. The experiment followed the recommended agronomic management practices for maize production in the Punjab area.

Data Collection

Chlorophyll index: Chlorophyll was measured using a SPAD meter at 30, 60, and 90 DAS. Chlorophyll concentration may be determined by measuring the same leaf thrice with the SPAD meter and averaging the results (Arregui 2006).

Carotenoid content (mg.mg^{-1} fresh weight): Carotenoids are extracted in 80% acetone, and the absorbance is measured at 450 m. The amount of Carotenoids is calculated using the absorbance coefficient described by Jensen (1980).

Total Soluble Sugar content (mg.mL^{-1}): Total soluble sugar in a plant sample may be quickly and easily calculated using the Anthorne reaction. Furfural is produced through the dehydration of carbohydrates in concentrated H_2SO_4. The 630 nm calorimetric measurement of the complex formed when furfural condenses with Anthorne reveals a blue-green (Sadasuvam & Manickam 1992).

Statistical Analysis

All the morphological data were statistically analyzed using variance analysis (ANOVA). Data were assessed by Statistix 10 software with Duncan 's multiple range test (DMRT) with a probability $p<0.05$.

RESULTS AND DISCUSSION

Chlorophyll Index

The Data presented in Table 1 show the effect of Salicylic acid and sodium nitroprusside on the chlorophyll index of maize when grown under different sowing dates. The results revealed that the chlorophyll index was highly affected by the application of salicylic acid, with an increase in chlorophyll index by 43.36 and 42.93 in the case of late sowing and early sowing, respectively, at 30 DAS. The results also state that the combined application of salicylic acid and sodium nitroprusside was also able to increase the chlorophyll index by 42.96 at 30 DAS. Similarly, at 60 and 90, DAS application of salicylic increased the chlorophyll index by 47.06, 46.9, and 58.18, 58.02 in late sowing and early sowing, respectively. Salicylic acid mitigated the environmental stress condition by increasing the chlorophyll index, which was created when maize is sown early and late compared to the optimum sowing time. The pigment chlorophyll is responsible for the green coloration of plants. Photosynthesis is essential for plant life because it converts the energy from the sun into the sugars and starches that plants require for survival. Chlorophyll concentration is, therefore, a reliable predictor of plant health. By affecting stomatal closure and the shape of chloroplasts and enzymes involved in photosynthesis, including ribulose 1,5-bisphosphate carboxylase/oxygenase (RuBisCo) and carbonic anhydrase, SA can control photosynthesis in plants. SA can enhance plants' antioxidant enzymes and defense mechanisms and help regulate ion channels and photosynthesis cycles. Enhanced enzyme activity associated with CO_2 absorption at the chloroplast level may be responsible for the higher photosynthetic rates seen after spray treatments of some phenolic compounds like SA rather than just a rise in stomatal opening. Similarly, it was also reported that foliar sprays of ascorbic acid (AsA), salicylic acid (SA), and hydrogen peroxide (H_2O_2) @ 20 and 40 $mg.L^{-1}$ were administered to third-leaf stage spring maize seedlings. Increased levels of superoxide dismutase (SOD), chlorophyll, and nutrients were found in plants after foliar treatment, which led to longer shoots and roots (Ahmed et al. 2013) (Table 1).

Table 1: Effect of salicylic acid and sodium nitroprusside on chlorophyll index of maize grown under different sowing dates at 30, 60, and 90 DAS.

Treatments	Chlorophyll index		
At different Interval	30 DAS	60 DAS	90 DAS
Main Plot (Sowing Date)			
SE -Early sowing	39.59	43.15	47.93
S0 -Optimum sowing	40.16	44.97	50.054
SL -late sowing	42.075	45.79	49.935
CV Alpha at 0.05	1.74	3.70	1.63
Sub Plot (Agrochemicals)			
A0- Control	38.144	43.067	42.460
A1-Sodium Nitroprusside [250 $\mu M.L^{-1}$]	39.556	44.078	50.981
A2-Salicylic acid [150$mg.L^{-1}$]	42.589	46.667	57.933
A3- Sodium Nitroprusside [250 $\mu M.L^{-1}$] + Salicylic acid [150$mg.L^{-1}$]	42.156	44.744	45.200
Alpha at 0.05			
CV (Sowing date and agrochemical)	4.10	2.80	2.82
CD (sowing)	0.79	1.86	0.90
CD (Agrochemicals)	1.64	1.23	1.37
CD (Sowing and agrochemicals)	2.59	2.60	2.24

Where DAS: Days After Sowing, Data is in the form of Mean± at $p < 0.05$, Main Plot- SE- Early, Sowing, S0- Optimum sowing, SL- Late sowing: Subplot- A0- Control, A1-Sodium nitroprusside (250 $\mu M.L^{-1}$), A2- Salicylic acid (150 $mg.L^{-1}$), A3- Sodium nitroprusside (250 $\mu M.L^{-1}$) + Salicylic acid (150 $mg.L^{-1}$)

Total Carotenoid Content

The data presented in Table 2 show the effect of salicylic acid and sodium nitroprusside on the total carotenoid content of maize when grown under different sowing dates at 30, 60, and 90 DAS. In the case of sodium nitroprusside, the total carotenoid range of maize was gradually increased by 41.45 $mg.mL^{-1}$ in late sown, followed by the application of salicylic acid of 47.02 $mg.mL^{-1}$ at 30 DAS. However, at 60 DAS, the application of salicylic acid increased the carotenoid content by 57.38 $mg.mL^{-1}$, followed by sodium nitroprusside by 50.62 $mg.mL^{-1}$ when grown under optimum sowing. Similarly, at 90 DAS, salicylic acid and sodium nitroprusside increased the carotenoid content by 58.06 and 55.96 $mg.mL^{-1}$ in the case of optimum sowing, respectively. An increased range of carotenoids will help the plants utilize carotenoids for two primary purposes: they absorb green light energy for photosynthesis and protect chlorophyll from damage caused by sunlight. Most carotenoids are C40 terpenoids; these hydrocarbons are essential in photosynthesis, photomorphogenesis, photoprotection, and plant growth. Additionally, carotenoids are precursors to various apocarotenoids and two plant hormones. As potent antioxidants, carotenoids help plants preserve their high chlorophyll levels by protecting the chloroplasts from damage. Due to their ability to generate significant quantities of heat via photosystems I and II, carotenoids are beneficial for chloroplast membrane protection (Juan et al. 2005). Photosynthetic pigments can be protected from toxic levels of boron by being treated with SA. Because of its beneficial effects on leaf and chloroplast structure, as well as chlorophyll and carotenoid concentration, SA has been suggested as an effective regulator of photosynthesis (Uzunova et al. 2000). Alternatively, SA protects chloroplasts from ROS and boosts chlorophyll stability during synthesis (Fariduddin et al. 2003). In addition to boosting photosynthesis and anthocyanin levels, SA treatment increased phenylalanine ammonia-lyase activity. Possibly due to their free radical scavenging abilities, SNP treatment fostered the development of aerial portions but stunted the growth of roots. A similar result was reported in those sprays of sodium nitroprusside (SNP), a source of nitric oxide (NO), were administered to the leaves either before (control), during (50, 100, 150 M), or after (saline stress) application. Results may suggest that increased activity of antioxidant enzymes like ascorbate peroxidase, peroxidase, H_2O_2, and the leaf content of proline, chlorophyll content (chlorophyll a & chlorophyll b), and Carotenoid in comparison to the control indicates that exogenous application of sodium nitroprusside (SNP), a NO donor, significantly alleviated the oxidative damage of salinity in rice seedlings (Saroj et al. 2018) (Table 2).

Where DAS: Days After Sowing, Data is in form of Mean± at $p < 0.05$, Main Plot- SE- Early Sowing, S0-Optimum sowing, SL- Late sowing: Subplot- A0- Control, A1-Sodium Nitroprusside (250 $\mu M.L^{-1}$), A2-Salicylic acid (150 $mg.L^{-1}$), A3- Sodium Nitroprusside (250 $\mu M.L^{-1}$) + Salicylic acid (150 $mg.L^{-1}$)

Table 2: Effect of salicylic acid and sodium nitroprusside on Total Carotenoids content ($Mg.mL^{-1}$) of maize grown under different sowing dates at 30, 60, and 90 DAS.

Treatments	Total Carotenoids content [$mg.mL^{-1}$]		
At different Interval	30 DAS	60 DAS	90 DAS
Main Plot (Sowing Date)			
SE -Early sowing	10.943	38.905	41.548
S0 -Optimum sowing	38.372	50.200	51.749
SL -late sowing	40.474	34.213	33.753
Alpha at 0.05	6.43	0.75	2.34
Sub Plot (Agrochemicals)			
A0- Control	28.668	40.500	40.471
A1-Sodium Nitroprusside [250 $\mu M.L^{-1}$]	33.251	42.729	44.961
A2-Salicylic acid [150 $mg.L^{-1}$]	31.352	44.859	43.651
A3- Sodium Nitroprusside [250 $\mu M.L^{-1}$] + Salicylic acid [150 $mg.L^{-1}$]	26.447	36.337	40.318
Alpha at 0.05			
CV (Sowing date and agrochemical)	3.03	0.97	0.82
CD (sowing)	2.17	0.35	1.12
CD (Agrochemicals)	0.89	0.39	0.34
CD (Sowing and agrochemicals)	2.53	0.68	1.22

Total Soluble Sugar

The data presented in Table 3 show the effect of salicylic acid and sodium nitroprusside on the total soluble sugar of maize at 30, 60, and 90 DAS. The result shows that the application of salicylic acid increased the total soluble sugar of maize by 60.74 $mg.mL^{-1}$, followed by sodium nitroprusside by 59.47 $mg.mL^{-1}$ in late-sown conditions at 30 DAS, respectively. The results revealed that salicylic acid application was able to mitigate the environmental stress conditions by increasing the sugar content by 67.01 $mg.mL^{-1}$, followed by the combined application of salicylic acid and sodium nitroprusside by 66.60 $mg.mL^{-1}$ respectively at 60 DAS in early sown conditions. Similarly, at 90 DAS, the application of salicylic acid was able to increase the total soluble sugar content by 49.68 $mg.mL^{-1}$ in optimum sowing, and the combined application of salicylic acid and sodium nitroprusside also showed positive results by increasing the sugar content by 45.79 $mg.mL^{-1}$ in late sown conditions. An increased range of total soluble sugars activated the plant defense responses, acting as osmotic adjustors or nutritional and metabolic signals. To ensure osmotic adjustment, scavenging of reactive oxygen species, and regulate the cellular energy status through carbon partitioning, sugars play a crucial role in stress sensing and signaling and constitute a regulatory hub for stress-mediated gene expression. Carbohydrate partitioning and critical signal transduction processes in detecting biotic and abiotic stressors are known to be controlled by several sugar transporters. Through photosynthesis, plants can convert inorganic carbon into sugars, meeting their energy needs and those of other heterotrophs (Hennion et al. 2019). Different sugars are assimilated, including glucose and fructose monosaccharides, sucrose, starch, and polyols (Dong & Beckles 2019). Glucose and sucrose are two of the most versatile metabolites, serving as precursors for a wide range of metabolic pathways (including amino acid, sugar alcohol, nucleotide, and lipid biosynthesis), structural building blocks, short- and long-distance signaling molecules, and Osmo protectants in times of stress (Braun et al. 2014). The enzymes amylase, sucrose synthase, and sucrose phosphate synthase (SPS) were all stimulated by SA. Seedlings may develop greater tolerance to NaCl-induced salinity stressors if the extra carbohydrates they get serve as osmotic regulators and improve cellular water absorption and retention. Similarly, it was also reported that the physiological processes of growth and development, photosynthesis, root formation, and germination are regulated endogenously by salicylic acid (Miura & Tada 2014). Root growth is promoted, stomata are closed, and defense genes and secondary metabolites are expressed (Table 3).

Table 3: Effect of salicylic acid and sodium nitroprusside on Total Soluble Sugar (mg.mL^{-1}) of maize grown under different sowing dates at 30, 60, and 90 DAS.

Treatments	Total Soluble Sugar [mg.mL^{-1}]		
At different Interval	30 DAS	60 DAS	90 DAS
Main Plot (Sowing Date)			
SE -Early sowing	8.948	61.698	31.355
S0 -Optimum sowing	54.177	36.800	42.142
SL -late sowing	58.358	30.305	36.648
Alpha at 0.05	5.00	5.71	6.36
Sub Plot (Agrochemicals)			
A0- Control	38.580	36.311	28.336
A1-Sodium Nitroprusside [250 µM.L^{-1}]	43.724	43.364	36.428
A2-Salicylic acid [150mg.L^{-1}]	40.624	50.826	43.889
A3- Sodium Nitroprusside [250 µM.L^{-1}] + Salicylic acid [150mg.L^{-1}]	39.050	41.23	38.208
Alpha at 0.05			
CV (Sowing date and agrochemical)	8.19	13.36	14.17
CD (sowing)	2.29	2.78	2.64
CD (Agrochemicals)	3.28	5.68	5.15
CD (Sowing and agrochemicals)	5.41	8.94	8.14

Where DAS: Days After Sowing, Data is in form of Mean ± at $p < 0.05$, Main Plot- SE- Early Sowing, S0- Optimum sowing, SL- Late sowing: Subplot- A0- Control, A1-Sodium Nitroprusside (250 µM.L^{-1}), A2-Salicylic acid (150 mg.L^{-1}), A3- Sodium Nitroprusside (250 µM.L^{-1}) + Salicylic acid (150 mg.L^{-1})

CONCLUSION

Climate change concerns food security since it is predicted to reduce maize production. The applied agrochemicals were able to mitigate the environmental stress conditions that restrict the growth of maize when grown under different sowing dates compared to optimum sowing. The Salicylic acid and sodium nitroprusside were able to increase the chlorophyll index and carotenoid content, which is directly involved in the photosynthesis process and also protect chloroplast membranes because they can release large amounts of energy in the form of heat through photosystems I and II and also able to increase the total soluble sugar content which helps the maize plant to act as plant defense response by the activation of osmotic adjustors or nutrient and metabolic signals.

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