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METHYL JASMONATE ENHANCES RESISTANCE OF SUGARCANE PLANTS UNDER BIOTIC AND ABIOTIC STRESS

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SÃO PAULO STATE UNIVERSITY - UNESP

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POTENTIAL IMPACT OF THIS RESEARCH

This research contributes to sustainable strategies to enhance sugarcane resilience to water deficit and sugarcane borer attack, supporting physiological crop management and more sustainable agriculture.

IMPACTO POTENCIAL DESTA PESQUISA

Esta pesquisa contribui para o desenvolvimento de estratégias sustentáveis para aumentar a resiliência da cana-de-açúcar ao déficit hídrico e à broca-da-cana, apoiando o manejo fisiológico da cultura e a agricultura sustentável.

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AUTHOR’S CURRICULUM VITAE

JÚLIA KAROLINE RODRIGUES DAS MERCÊS – Born on March 22, 1997, in Capitão Poço, Pará, Brazil. Daughter of Lúcia Maria Carlos Rodrigues and José Augusto Souza das Mercês. In 2015, she enrolled in the Agronomy program at the Federal Rural University of the Amazon (UFRA), Capitão Poço Campus, Pará, Brazil. During her undergraduate studies, she participated in the research group *Studies on Biodiversity in Higher Plants (EBPS)* and in the research group *Anthropic Action on Natural Resources in a Watershed in Northeastern Pará*. She was a voluntary undergraduate research fellow (PIVIC-UFRA) in the field of plant physiology. In February 2020, she obtained her degree in Agronomy. In March of the same year, she began her Master’s studies in the Graduate Program in Agronomy (Crop Production) at São Paulo State University (UNESP). In February 2022, she obtained her Master of Science degree in Agronomy (Crop Production) with the dissertation entitled *“Production, biofortification, and quality of kale as a function of iron concentration in the nutrient solution.”* In March of the same year, she enrolled in the Ph.D. program in Agronomy (Crop Production) at the same institution, where she published scientific articles and a book chapter, participated in undergraduate thesis defense committees, and completed an additional teaching internship in plant physiology. Since 2023, she has been a member of the *Laboratory of Stress Physiology in Plants (LASPP)*.

DADOS CURRICULARES DA AUTORA

JÚLIA KAROLINE RODRIGUES DAS MERCÊS – Nasceu em 22 de março de 1997 em Capitão Poço, Pará, Brasil. Filha de Lúcia Maria Carlos Rodrigues e José Augusto Souza das Mercês. No ano de 2015 ingressou no curso de agronomia na Universidade Federal Rural da Amazônia (UFRA), *campus* de Capitão Poço – PA. Durante a graduação participou do grupo de pesquisa Estudos da biodiversidade em plantas superiores (EBPS) e no grupo de pesquisa Ação antrópica sobre os recursos naturais em uma bacia hidrográfica no nordeste paraense. Foi bolsista voluntária de iniciação científica (PIVIC-UFRA) na área de fisiologia vegetal. Em fevereiro de 2020 obteve o título de Engenheira Agrônoma e em março do mesmo ano deu início ao curso de mestrado, junto ao Programa de Pós-Graduação em Agronomia (Produção Vegetal) na Universidade Estadual Paulista “Julio de Mesquita Filho”. Em fevereiro de 2022 obteve o título de Mestre em Agronomia (Produção Vegetal) com dissertação intitulada “Produção, biofortificação e qualidade da couve em função da concentração de ferro na solução nutritiva”. Em março do mesmo ano, ingressou programa de pós-graduação em Agronomia (Produção Vegetal) em nível de doutorado na mesma instituição, onde publicou artigos científicos, capítulos de livros, participou de eventos científicos, de bancas de defesa de trabalho de conclusão de curso de estudantes de Agronomia e realizou estágio em docência em fisiologia vegetal. Desde 2023 compõe o Laboratory of Stress Physiology in Plants (LASPP).

“Have I not commanded you? Be strong and courageous. Do not be afraid; do not be discouraged, for the Lord your God will be with you wherever you go.”

Joshua 1:9

“Não fui eu que lhe ordenei? Seja forte e corajoso! Não se apavore nem desanime,
pois o Senhor, o seu Deus, estará com você por onde você andar.”
Josué 1:9

To my parents, Lúcia Maria and José Augusto, for teaching me to fly with the reassurance of always having a home to return to.

I dedicate

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Dedico

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SUMMARY

Page

METHYL JASMONATE INCREASES THE RESISTANCE OF SUGARCANE PLANTS UNDER BIOTIC AND ABIOTIC STRESS.

ABSTRACT - The simultaneous occurrence of biotic and abiotic stresses represents one of the major challenges in agricultural production, particularly in crops of high economic importance such as sugarcane (*Saccharum* spp.). Among the most limiting factors affecting this crop are water deficit and herbivory caused by *Diatraea saccharalis* (Lepidoptera: Crambidae), which may interact synergistically, intensifying physiological, oxidative, and metabolic damage. In this context, methyl jasmonate (MeJA) has been recognized as an important regulator of plant defense responses, acting in stress signaling and modulation of antioxidant metabolism. However, information regarding the effects of MeJA in sugarcane under multiple stress conditions remains limited. Therefore, this thesis aimed to investigate the role of MeJA in modulating the antioxidant and physiological responses of sugarcane subjected to herbivory by *D. saccharalis* and water deficit, both individually and in combination. To this end, greenhouse experiments were conducted using randomized block designs in factorial arrangements involving different MeJA concentrations, presence or absence of sugarcane borer infestation, and distinct water availability conditions. Physiological parameters, oxidative stress indicators, enzymatic and non-enzymatic antioxidants, photosynthetic pigments, and variables associated with redox metabolism were evaluated. The results demonstrated that herbivory and water deficit promoted significant alterations in the antioxidant metabolism of sugarcane, intensifying the accumulation of reactive oxygen species and lipid peroxidation, particularly under combined stress conditions. Exogenous application of MeJA promoted responses dependent on both dose and physiological context, activating antioxidant defense mechanisms even under non-stress conditions. Under herbivory, MeJA enhanced the accumulation of phenolic compounds, carotenoids, glutathione, and anthocyanins, while reducing malondialdehyde levels. Under combined water deficit and herbivory conditions, MeJA stimulated antioxidant enzymes related to peroxide detoxification, such as ascorbate peroxidase (APX) and guaiacol peroxidase (GPOX), in addition to contributing to the maintenance of plant water status and partially reducing oxidative damage. Our findings indicate that MeJA acts in the reprogramming of redox metabolism and in the induction of antioxidant responses in sugarcane, contributing to greater tolerance to isolated and combined stresses. Thus, the use of MeJA shows potential as a complementary strategy to enhance the physiological resilience of sugarcane under multiple stress scenarios.

Keywords: Water deficit; Antioxidants; Herbivory; Phytohormone; Defense priming.

METIL JASMONATO NO AUMENTA A RESISTÊNCIA DE PLANTAS DE CANA-DE-AÇUCAR SOB ESTRESSE BIÓTICO E ABIÓTICO

RESUMO - A ocorrência simultânea de estresses bióticos e abióticos representa um dos principais desafios na produção agrícola, especialmente em culturas de elevada importância econômica, como a cana-de-açúcar (*Saccharum* spp.). Entre os fatores mais limitantes para a cultura destacam-se o déficit hídrico e a herbivoria causada por *Diatraea saccharalis* (Lepidoptera: Crambidae), os quais podem atuar de forma interativa, intensificando danos fisiológicos, oxidativos e metabólicos. Nesse contexto, o metil jasmonato (MeJA) tem sido considerado como um importante regulador das respostas de defesa vegetal, atuando na sinalização de estresse e na modulação do metabolismo antioxidante. No entanto, ainda são limitadas as informações sobre os efeitos do MeJA em cana-de-açúcar sob condições de estresses múltiplos. Assim, esta tese teve como objetivo investigar o papel do MeJA na modulação das respostas antioxidantes e fisiológicas da cana-de-açúcar submetida à herbivoria por *D. saccharalis* e ao déficit hídrico, de forma isolada e combinada. Para isso, foram conduzidos experimentos em casa de vegetação utilizando delineamentos em blocos ao acaso, em esquemas fatoriais envolvendo diferentes concentrações de MeJA, presença ou ausência de infestação pela broca-da-cana e condições de disponibilidade hídrica. Foram avaliados parâmetros fisiológicos, indicadores de estresse oxidativo, antioxidantes enzimáticos e não enzimáticos, pigmentos fotossintéticos e variáveis associadas ao metabolismo redox. Os resultados demonstraram que a herbivoria e o déficit hídrico promoveram alterações significativas no metabolismo antioxidante da cultura, intensificando o acúmulo de espécies reativas de oxigênio e a peroxidação lipídica, principalmente sob estresse combinado. A aplicação exógena de MeJA promoveu respostas dependentes da dose e do contexto fisiológico, ativando mecanismos de defesa antioxidante mesmo em condições sem estresse. Sob herbivoria, o MeJA favoreceu o aumento de compostos fenólicos, carotenoides, glutationa e antocianinas, além da redução dos níveis de malondialdeído. Em condições de déficit hídrico combinado com herbivoria, o MeJA estimulou enzimas antioxidantes relacionadas à detoxificação de peróxidos, como APX e GPOX, além de contribuir para a manutenção do estado hídrico e para a redução parcial dos danos oxidativos. Nossos resultados indicam que o MeJA atua na reprogramação do metabolismo redox e na indução de respostas antioxidantes em cana-de-açúcar, contribuindo para maior tolerância a estresses isolados e combinados. Dessa forma, o uso de MeJA apresenta potencial como estratégia complementar para aumentar a resiliência fisiológica da cultura em cenários de estresse múltiplo.

Palavras-chave: Deficiência hídrica; Antioxidantes; Herbivoria; Fitormônio; *Priming* de defesa.

CHAPTER 1 – General considerations

1. Introdution

Modern agriculture faces the growing challenge of maintaining crop productivity under increasingly adverse and unpredictable environmental conditions. Among the main factors limiting plant performance are abiotic stresses, such as water deficit, and biotic stresses, such as insect herbivory, which frequently occur simultaneously and interactively (Sahu and Giri, 2025). This overlap of stresses represents a complex condition in which plant responses cannot be interpreted as the simple additive effects of each stressor, but rather as the result of dynamic interactions among different physiological and metabolic pathways (Moustaka et al., 2025).

This interaction occurs because water deficit impairs the maintenance of plant water status, reduces photosynthetic activity, and promotes the accumulation of reactive oxygen species (ROS) (Nour et al., 2024), whereas herbivory induces mechanical damage, alters primary metabolism, and activates defense-related signaling pathways (Gautam et al., 2026). When these stresses occur simultaneously, plants must reallocate resources among water conservation, photosynthetic maintenance, cellular repair, and the activation of defenses against herbivores (Sahu and Giri, 2025). Thus, the combination of water deficit and herbivory may generate a physiological trade-off, since water limitation reduces carbon assimilation and energy availability, while insect defense requires metabolic investment in protective compounds, antioxidant enzymes, and defense signaling.

Sugarcane (*Saccharum* spp.), one of the most economically important crops worldwide and widely used in the sugar industry and bioethanol production, is particularly vulnerable to these conditions, as it is cultivated in regions exposed to climatic variability and constant pest pressure (Kumar et al., 2023). Water deficit compromises key processes such as photosynthesis, growth, and energy balance, whereas insect herbivory, particularly by *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae), affects plant structural integrity and metabolism (Ferreira et al., 2017; Santos-Cividanes et al., 2022). When combined, these factors may intensify physiological damage and substantially reduce crop productivity.

One of the main points of convergence between water deficit and herbivory is the modulation of redox metabolism, which is characterized by the balance between ROS production and scavenging (Rao et al., 2025; Sachdev et al., 2021). Although ROS play essential roles as signaling molecules in defense processes, their excessive accumulation can lead to oxidative stress, causing damage to lipids, proteins, and nucleic acids (Hasanuzzaman, 2020). To maintain cellular homeostasis, plants rely on a highly integrated antioxidant system composed of enzymatic and non-enzymatic mechanisms, whose efficiency is critical for stress tolerance (Irato and Santovito, 2021; Rajput et al., 2021).

In this context, plant growth regulators such as methyl jasmonate (MeJA) have emerged as important modulators of stress responses (Đurić et al., 2023). MeJA is associated with the activation of defense pathways, particularly those related to herbivory, and also plays a relevant role in regulating antioxidant metabolism and integrating signals associated with different types of stress (Wang et al., 2021). Its exogenous application can induce defense mechanisms and promote a primed state, in which plants acquire an enhanced capacity to respond rapidly and efficiently to subsequent stress events.

Despite advances in the understanding of these processes, significant gaps remain regarding how MeJA modulates redox metabolism under multiple-stress conditions, particularly in crops such as sugarcane. Most available studies address the effects of water deficit or herbivory separately, without adequately considering the complexity of the interactions that frequently occur in agricultural environments. Moreover, it remains unclear whether exogenous MeJA application can coordinate antioxidant and physiological responses in sugarcane when water deficit and herbivory by *D. saccharalis* occur simultaneously.

Given this context, this review aimed to investigate the role of MeJA in modulating antioxidant and physiological responses in sugarcane plants subjected to water deficit, *D. saccharalis* herbivory, and the combination of these stresses. We hypothesized that exogenous MeJA application attenuates oxidative damage and improves plant responsiveness by regulating the antioxidant system, maintaining redox homeostasis, and activating mechanisms associated with plant defense.

5. Conclusion

Water deficit and D. saccharalis infestation induce distinct redox responses in sugarcane, whereas their combination results in a synergistic effect, intensifying oxidative stress and compromising cellular homeostasis. Methyl jasmonate acts as a modulator of redox metabolism, reducing oxidative pressure under water deficit, enhancing signaling under SB infestation, and promoting functional reorganization of defense mechanisms under combined stress. Thus, stress tolerance is associated with the coordination and efficiency of the antioxidant system rather than its magnitude alone, highlighting MeJA as a promising strategy to enhance crop resilience under multiple stress conditions.

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Supporting Information

Fig. 1. Maximum and minimum values of temperature and relative humidity throughout the greenhouse experiment.