



Management of Physiological Cherelle Wilt in *Theobroma cacao* through Foliar Boric Acid Application

Branmanda Fardhaza Saputra*, Elisabeth Nanik Kristalisasi, Herry Wirianata

Agrotechnology Study Program, Faculty of Agriculture, STIPER Agricultural Institute Yogyakarta, Indonesia

*E-mail: bfardha16@gmail.com

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Abstract

Cherelle wilt is a physiological disorder that causes fruit loss in cacao during early fruit development. It is associated with assimilate imbalance and young fruit abscission and should be distinguished from fruit wilt caused by pest injury. This study evaluated foliar boric acid application to reduce physiological cherelle wilt and improve young fruit retention in two cacao clones. The research was conducted in April - August 2025 at the Sidodadi farmer group, Gunungkidul, Yogyakarta, Indonesia. The experiment used a factorial randomized complete block design with two factors: cacao clone (MCC01, MCC02) and boric acid concentration (0, 2, 4, and 8 g L⁻¹ H₃BO₃), with five replications. Variables included flower number, physiologically wilted young fruits, *Helopeltis*-associated wilted young fruits, and healthy young fruits. The results revealed that physiological cherelle wilt was distinguished from *Helopeltis*-associated wilt by visual symptoms. Foliar boric acid application significantly affected flower number, physiological cherelle wilt, and *Helopeltis*-associated wilt through clone × concentration interactions. MCC02 treated with 4 g L⁻¹ H₃BO₃ produced the highest flower number, whereas MCC02 treated with 2 g L⁻¹ H₃BO₃ produced the lowest number of physiologically wilted young fruits. Healthy young fruit formation was independently affected by clone and boric acid concentration, with MCC02 and 4–8 g L⁻¹ H₃BO₃ showing the best responses. Foliar boron management using boric acid can serve as a supporting preventive strategy in cacao plant protection by reducing physiological fruit loss and improving young fruit retention in a clone-specific manner, while *Helopeltis*-associated wilt still requires direct pest monitoring and management.

Keywords: assimilate imbalance, fruit retention, *Helopeltis* sp., MCC02, young fruit abscission

Introduction

Theobroma cacao Linnaeus is an important plantation commodity with a strategic role in agricultural development. Cacao is the primary source of income for many farmers in major production regions. The growing processing of cacao has led to increased demand; however, several cacao-producing countries have experienced declining production despite rising

consumption. Ghana and Indonesia are among the cacao-producing countries facing production declines (Badan Pusat Statistik, 2023; Dermawan and Saputera, 2026). Cacao productivity at the farmer level remains relatively low, influenced by several factors, including the availability and balance of soil nutrients (Goudsmit et al., 2023), pest and disease disturbances (Nelly et al., 2017; Vanhove et al., 2020), and environmental

conditions that do not support optimal growth (Sri et al., 2023). Among these constraints, the failure of flowers and young fruits to develop into harvestable pods is one of the most critical problems because it directly reduces final pod number and yield potential.

One of the main factors contributing to low cacao yield is the high rate of fruit loss during early development. The limitation of assimilates causes the abscission of young fruits in cacao plants, a phenomenon known as cherelle wilt, resulting in the failure of young fruits to develop (Goudsmit et al., 2023). Cherelle wilt reduces the number of fruits that develop into harvestable pods and can reach high percentages under certain conditions (Dewi et al., 2020; Goudsmit et al., 2023). Cherelle wilt is not always associated with pest or pathogen attacks; rather, it is more frequently classified as a physiological disorder influenced by internal plant conditions (Dewi et al., 2020). Therefore, physiological cherelle wilt needs to be distinguished from young fruit wilt caused by external biotic damage, particularly feeding injury by mirid bugs such as *Helopeltis* sp., which causes puncture marks, necrotic lesions, and tissue damage on young cacao fruits (Nelly et al., 2017; Tavera et al., 2023). This distinction is important because physiological young fruit abscission and pest-induced fruit wilt may produce similar field symptoms but have different causal mechanisms and management implications.

Physiologically, cherelle wilt is associated with an imbalance between the availability of photosynthates and the demands of generative organs (Dewi et al., 2020). During the flowering and young fruit formation phases, plants require an adequate and continuous supply of assimilates (Goudsmit et al., 2023). According to Prawoto and Astuti (2015), the hormones auxin and gibberellin are also required during the generative phase and play a role in optimizing assimilate allocation toward young cacao fruits. If these requirements are not met, the plant will

naturally select by abscising some young fruits. The quantity of assimilates available as a nutrient source for young cacao fruits is influenced by the rate of photosynthesis (Vitória et al., 2026). This natural selection process aims to maintain the physiological balance of the plant, but directly impacts the reduction in the number of harvestable fruits (Dewi et al., 2020; Prawoto & Astuti, 2015). Thus, improving assimilate production, transport, and allocation to young fruits is a key physiological strategy for reducing cherelle wilt.

Nutrient availability plays an important role in maintaining plant physiological balance. Micronutrients play essential roles in horticultural crop productivity and quality because they regulate physiological and metabolic processes, including reproductive development and assimilate allocation (Ahmed et al., 2024). Research by Dewi et al. (2023) stated that boron is involved in the formation and stability of cell walls. Boron also plays a role in pollen development and the success of fertilization processes (Chen et al., 2023; Michailidis et al., 2023). Additionally, boron functions in the transport of photosynthates from leaves to sink organs, including flowers and young fruits (Prawoto & Astuti, 2015). These functions indicate that boron may contribute to reproductive success in cacao by supporting flower development, fruit set, cell wall integrity, and assimilate movement toward developing young fruits.

Boron deficiency can disrupt plant reproductive processes, manifesting as low pollen viability and inhibited fruit formation (Vanhove et al., 2020), thereby increasing the risk of young fruit abscission in cacao. The boron requirement in plants operates within a narrow range; excess boron can cause physiological disorders and reduce plant performance (Ishida et al., 2023). Therefore, boron management requires precise dosing and appropriate application methods. Boron availability in soil is

often at low levels in the field, as boron is easily leached, especially in light-textured soils with high rainfall (Sarkis et al., 2024). Soil pH and organic matter content also affect boron availability, resulting in low efficiency of soil-applied boron fertilization (Vital Biotech Publication, 2023), and plants often fail to absorb boron optimally through the root system (Alimuddin et al., 2023). Under such conditions, soil boron status may not always reflect the amount of boron effectively available for reproductive organs, making direct support through foliar application a practical alternative during the generative phase.

Foliar boron application has become an increasingly developed alternative, allowing boron to be absorbed directly by leaf tissue (Du et al., 2020). Foliar-applied boron can be immediately utilized in plant physiological processes and reduces losses due to leaching (Reyes-Díaz et al., 2024). This approach is considered more effective for supporting the generative phase of cacao plants. Several studies have reported that foliar boron application increases flowering and fruit set success in various dicotyledonous plants (Wurentuya & Chen, 2020; Michailidis et al., 2023; Reyes-Díaz et al., 2024). However, plant responses to boron application are not always consistent and are influenced by genetic factors (Bhavishya et al., 2024). Wang et al. (2024) stated that differences in clones or genotypes cause differences in boron absorption and utilization capacity, so that the boron requirements of each clone vary. This suggests that a uniform boron concentration may not be equally effective for all cacao clones.

To date, studies on the response of cacao clones to foliar boron application in relation to cherelle wilt suppression remain limited. Information on appropriate boron concentrations for specific cacao clones has not been widely reported, and a clone-based approach is essential to improve fertilization effectiveness. In addition, previous studies have

rarely separated physiological cherelle wilt from pest-induced young fruit wilt when evaluating the effect of boron application, even though both types of fruit loss may occur simultaneously in the field. Therefore, this study was conducted to evaluate the effect of foliar boron application on flower formation, physiological cherelle wilt, young fruit wilt caused by *Helopeltis* sp., and healthy young fruit formation in two cacao clones, MCC01 and MCC02. This study also aimed to determine the optimum foliar boron concentration for each clone as a basis for clone-specific boron management in cacao cultivation.

Methods

The study was conducted from April to August 2025 in a cacao plantation belonging to the Sidodadi farmer group, Putat, Patuk, Gunungkidul, Yogyakarta, Indonesia. The experimental site is located at an elevation of approximately 221 m above sea level (asl), with geographical coordinates of 7°51'30.1"S and 110°30'33.7"E. Field activities included treatment application, pre- and post-application observations, and visual assessment of young fruit conditions. Laboratory analyses were conducted to determine boron content in young cacao fruits and soil samples.

Research Design

The study was arranged in a factorial randomized complete block design (RCBD) with two factors. The first factor was cacao clone, consisting of MCC01 and MCC02. The second factor was boron concentration, consisting of 0, 2, 4, and 8 g L⁻¹ H₃BO₃. Each treatment combination was replicated five times, resulting in 40 experimental units in total. Each experimental unit consisted of one sample tree.

Sample trees were selected to represent different topographic positions, light intensities, and soil fertility conditions, with the same plant age. Blocking was used to minimize field variability caused by differences in topography, light exposure, and soil fertility. Plant

maintenance activities were carried out uniformly across all treatments throughout the study.

Boron was applied as a foliar spray using a fertilizer sprayer. The solution was applied evenly to all leaf surfaces, including the upper and lower leaf surfaces, flushes, and young cacao fruits. No wetting agent or surfactant was used. Application was performed twice per month during the cacao flowering and early fruit development phases throughout the research period. Spraying was conducted in the morning, between 06:00 and 08:00 local time, under sunny and calm weather conditions to support foliar absorption and reduce spray drift. The spray volume per plant was adjusted until all target surfaces were uniformly wet, but not to the point of excessive runoff. The foliar application procedure followed Sri et al. (2023), with modification in the tested boron concentration levels.

Observation and Data Collection

Observed variables included soil boron availability, boron content in young cacao fruits, number of flowers, number of physiologically wilted young fruits, number of young fruits wilted due to *Helopeltis* sp. infestation, and number of healthy young fruits.

Soil boron availability

Soil boron availability was determined using the Morgan–Wolf method and expressed in ppm based on laboratory analysis.

Boron content in young cacao fruits

Boron content in young cacao fruits was determined using spectrophotometry and expressed in ppm based on laboratory analysis.

Number of flowers

The number of flowers was obtained by directly counting all flowers produced on each sample tree during each observation.

$$(NF = \sum F) \dots\dots\dots (1)$$

Where: NF = number of flowers, F = total flowers counted during each observation

Number of physiologically wilted young fruits

The number of physiologically wilted young fruits was obtained by direct counting based on physiological wilt symptoms observed on each sample tree.

$$(PW = N_{[pw]}) \dots\dots\dots (2)$$

Where: PW = number of physiologically wilted young fruits, $N_{[pw]}$ = total physiologically wilted young fruits counted

Number of young fruits wilted due to *Helopeltis* sp.

The number of young fruits wilted due to *Helopeltis* sp. infestation was obtained by direct counting based on the characteristic symptoms of *Helopeltis* sp. damage.

$$(HW = N_{[hw]}) \dots\dots\dots (3)$$

Where: HW = number of young fruits wilted due to *Helopeltis* sp., $N_{[hw]}$ = total young fruits wilted due to *Helopeltis* sp. infestation.

Number of healthy young fruits

The number of healthy young fruits was obtained by direct counting of young fruits showing no symptoms of physiological wilt or *Helopeltis* sp. infestation.

$$(HF = N_{[hf]}) \dots\dots\dots (4)$$

Where: HF = number of healthy young fruits, $N_{[hf]}$ = total healthy young fruits counted

Field observations were conducted twice per month on each sample tree during the study period.

The number of flowers was recorded by counting all newly formed cacao flowers on the observed sample tree. Physiologically wilted young fruits were recorded as young fruits that showed wilting, shriveling, or abscission symptoms without visible feeding punctures, blackish-brown necrotic lesions, or other external pest injury. Young fruit wilt due to *Helopeltis* sp. infestation was recorded separately and identified based on the presence of blackish-brown necrotic spots and stylet puncture marks on the surface of young fruits, following the symptom description of Nelly et al.

(2017). Healthy young fruits were defined as young fruits that remained attached to the plant and showed no symptoms of physiological wilting, necrosis, or visible pest injury at the time of observation.

Sampling of young cacao fruits for boron content analysis was conducted twice, namely before and after foliar boron application. For each sample tree, 5–10 young fruits were collected from primary branches in four cardinal directions to represent the canopy condition of each tree. The sampled fruits were cherelles approximately 5–10 cm in length. The collected samples were used for laboratory analysis of boron content in young fruit tissue, following Sri et al. (2023).

Soil samples were collected before treatment application to determine the initial soil boron status in each clone planting block. Soil sampling was conducted using the Soil Sampling Unit (SSU) method. Soil samples were collected from the rooting zone of the sample trees at a depth of 20 cm and at a distance of 1 m from the tree trunk. Soil samples were composited according to clone block before laboratory analysis. Soil boron availability was then determined in the laboratory and used as baseline information to interpret the response of each clone to foliar boron application.

Boron content in young cacao fruits was analyzed using spectrophotometry, while soil boron availability was analyzed using the Morgan–Wolf method. For young fruit boron analysis, samples were first washed with running tap water followed by distilled water to remove surface contaminants. The samples were air-dried and then oven-dried at 70°C for 48 h until a constant weight was achieved. The dried samples were ground into a fine powder using a laboratory grinder. Approximately 0.5 g of the ground sample was subjected to wet digestion using a concentrated HNO_3 – HClO_4 acid mixture until a clear solution was obtained. The digest was filtered, diluted to a known volume with

distilled water, and the boron concentration was determined using a spectrophotometer. Soil boron availability was analyzed using the Morgan–Wolf method. The boron concentration was determined using a spectrophotometer at 420 nm using Azomethine-H reagent. A calibration curve was prepared using boron standard solutions prepared from boric acid (H_3BO_3). The results were expressed in ppm. The results were expressed in ppm. Boron content in young fruit tissue was used to determine the boron nutritional status before and after foliar application, whereas soil boron availability was used to describe the initial boron status of the experimental field.

Data Analysis

The observational data were analyzed using analysis of variance (ANOVA) at the 5% significance level. The statistical model included cacao clone, boron concentration, and their interaction as treatment sources of variation. When significant treatment effects or interactions were detected, mean comparisons were performed using the Least Significant Difference (LSD) test at the 5% significance level.

For variables showing a significant clone × boron concentration interaction, treatment combinations were interpreted directly. For variables without a significant interaction, the main effects of clone and boron concentration were interpreted separately.

Laboratory data on boron content in young cacao fruits and soil were tabulated, and mean values were calculated for each clone to determine boron status in young fruit tissue and soil. All statistical analyses were performed using IBM SPSS Statistics version 30.0 (IBM Corp., Armonk, NY, USA).

Results

Boron Content in Young Cacao Fruits

Young cacao fruits in both clones initially had boron deficiency, and that foliar boron application increased boron content in the

reproductive tissues. Based on the research, both cacao clones before foliar boron application, showed low boron content in young fruit tissues. The mean boron content was 6.78 ppm in MCC01 and 6.07 ppm in MCC02. Based on the FAO threshold, plant tissue boron content

below 15–16 ppm is classified as deficient. After the foliar application period, boron content in young fruit tissues increased in both clones, reaching 89.67 ppm in MCC01 and 106.00 ppm in MCC02. These values were categorized as high based on the FAO threshold of >83 ppm (Table 1).

Table 1. Boron content in young cacao fruits before and after foliar boron application.

Application	Clone	Boron Content (ppm)			Mean
		1	2	3	
Before application	MCC01	6.19	7.01	7.13	6.78
	MCC02	7.63	4.95	5.62	6.07
After application	MCC01	88.00	89.00	92.00	89.67
	MCC02	110.00	110.00	98.00	106.00

Soil Boron Availability

The two clone blocks differed slightly in initial soil boron availability, which is important for interpreting clone responses to foliar boron application. The mean soil boron availability was 0.58 ppm in the MCC01 block and 0.48 ppm in the MCC02 block. Based on the USDA

classification, soil boron availability of 0.5–1.0 ppm is classified as medium, whereas 0.1–0.5 ppm is classified as low. Therefore, the MCC01 block had a medium soil boron status, while the MCC02 block had a low soil boron status (Table 2).

Table 2. Soil boron availability in each cacao clone block

Clone	Boron Availability (ppm)			Mean
	1	2	3	
MCC01	0.47	0.43	0.84	0.58
MCC02	0.42	0.51	0.50	0.48

Number of Flowers

both clones responded positively to 4 g L⁻¹ H₃BO₃ for flower formation, but MCC02 produced a consistently higher number of flowers than MCC01 across all boron concentrations. The highest number of flowers was observed in the combination of MCC02 and 4 g L⁻¹ H₃BO₃, with 467.00 flowers. This value was significantly higher than those of the other

treatment combinations. In MCC02, flower number increased from 280.87 flowers in the control to 467.00 flowers at 4 g L⁻¹ H₃BO₃, but decreased to 361.50 flowers at 8 g L⁻¹ H₃BO₃. In MCC01, the highest flower number was also observed at 4 g L⁻¹ H₃BO₃, with 201.12 flowers, while the lowest value was recorded at 2 g L⁻¹ H₃BO₃, with 122.62 flowers (Table 3).

Table 3. Number of flowers in two cacao clones under several boron concentration applications.

Boron Concentration (g/l)	
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Clone	0	2	4	8	Interaction
MCC01	133.50 ef	122.62 f	201.12 d	160.87 e	
MCC02	280.87 c	271.75 c	467.00 a	361.50 b	(+)

Note: Means followed by the same letter in the same row and column are not significantly different based on LSD test at 5% significance level. (+) = significant interaction

Physiologically Wilted Young Fruits

The optimum boron concentration for reducing physiological cherelle wilt differed between clones: MCC01 responded most favorably to 4 g L⁻¹ H₃BO₃, whereas MCC02 responded most favorably to 2 g L⁻¹ H₃BO₃. The lowest number of physiologically wilted young fruits was recorded in MCC02 treated with 2 g L⁻¹

H₃BO₃, with 25.37 wilted young fruits. This treatment was significantly different from the MCC02 control, which showed the highest number of physiologically wilted young fruits, with 65.37. In MCC01, the lowest number of physiologically wilted young fruits was recorded at 4 g L⁻¹ H₃BO₃, with 28.75, while the control treatment produced 50.25 physiologically wilted young fruits (Table 4).

Table 4. Number of physiological young fruit wilt in two cacao clones under several boron concentration applications.

Clone	Boron Concentration (g/l)				Interaction
	0 (Control)	2	4	8	
MCC01	50.25 c	55.87 c	28.75 ab	35.50 b	
MCC02	65.37 d	25.37 a	36.12 b	32.12 ab	(+)

Note: Means followed by the same letter in the same row and column are not significantly different based on LSD test at 5% significance level. (+) = significant interaction

Young Fruits Wilted

The response of pest-associated young fruit wilt to foliar boron application was clone-dependent and did not follow the same pattern as physiological cherelle wilt. The lowest number of young fruits wilted due to *Helopeltis* sp. infestation was observed in MCC02 treated with 8 g L⁻¹ H₃BO₃, with 1.50 affected young fruits. The highest values were recorded in MCC02 without

boron application and in MCC01 treated with 8 g L⁻¹ H₃BO₃, each with 13.50 affected young fruits. In MCC02, the number of *Helopeltis*-associated wilted young fruits decreased from 13.50 in the control to 4.87, 7.25, and 1.50 at 2, 4, and 8 g L⁻¹ H₃BO₃, respectively. In contrast, MCC01 showed a less consistent response, with the lowest value recorded at 2 g L⁻¹ H₃BO₃ and the highest value at 8 g L⁻¹ H₃BO₃ (Table 5).

Table 5. Number of young fruit wilt due to pest infestation in two cacao clones under several boron concentration applications.

Clone	Boron Concentration (g/l)				Interaction
	0 (Control)	2	4	8	
MCC01	11.00 cd	5.12 ab	9.12 bcd	13.50 d	
MCC02	13.50 d	4.87 ab	7.25 bc	1.50 a	(+)

Note: Means followed by the same letter in the same row and column are not significantly different based on LSD test at 5% significance level. (+) = significant interaction

Healthy Young Fruits

MCC02 had a better overall capacity to retain healthy young fruits, while foliar boron application at 4–8 g L⁻¹ improved healthy young fruit formation regardless of clone. Based on the clone factor, MCC02 produced a significantly higher mean number of healthy young fruits than MCC01, with 61.06 and 47.71 healthy young fruits, respectively. Based on the boron concentration factor, the number of healthy

young fruits increased with increasing boron concentration. The control treatment produced the lowest mean number of healthy young fruits, with 33.37, while 4 and 8 g L⁻¹ H₃BO₃ produced higher values, with 64.81 and 71.93 healthy young fruits, respectively. These two concentrations were not significantly different from each other but were significantly higher than the control and 2 g L⁻¹ H₃BO₃ (Table 6).

Table 6. Number of healthy young fruits in two cacao clones under several boron concentration applications.

Clone	Boron Concentration (g/l)				Mean
	0 (Control)	2	4	8	
MCC01	25.75	38.12	63.87	63.12	47.71 b
MCC02	41.00	56.75	65.75	80.75	61.06 a
Mean	33.37 r	47.43 q	64.81 p	71.93 p	(-)

Note: Means followed by the same letter in the same row and column are not significantly different based on LSD test at 5% significance level. (-) = no significant interaction

Discussion

Foliar boron application affected early reproductive performance and young fruit protection in cacao. The response was not uniform across clones or observed variables. This pattern shows that young fruit loss in cacao is a complex problem involving physiological limitations and pest-associated damage. In this study, physiological cherelle wilt and young fruit wilt associated with *Helopeltis* sp. were recorded separately, allowing a clearer distinction between internal fruit loss and externally induced damage. Such separation is important because the two problems require different management approaches in cacao plantations.

Both cacao clones had low boron content in young fruit tissues before foliar application, with mean values of 6.78 ppm in MCC01 and 6.07 ppm in MCC02. After foliar application, boron

content increased in both clones, showing that boron supplied through leaves was able to reach young fruit tissues (Table 1). This increase is relevant for cacao protection because young fruits with insufficient nutrient support are more likely to fail during early development. Foliar application may therefore help reduce physiological vulnerability during the generative phase, particularly when soil boron availability is not sufficient to support reproductive tissues. Du et al. (2020) reported that foliar-applied boron can be transported through the phloem as a boron–sucrose complex, allowing boron movement from leaves to sink organs. Reyes-Díaz et al. (2024) also reported that foliar boron application can improve plant physiological responses by supplying boron directly to plant tissues and reducing nutrient loss through leaching.

The initial soil boron status differed between clone blocks, with MCC01 classified as having medium boron availability and MCC02 as having low boron availability. However, the young fruit tissues of both clones were still boron-deficient before treatment (Table 2). This shows that soil boron availability alone did not fully reflect boron status in reproductive tissues. In cacao, the protection of young fruits depends not only on nutrient availability in the soil, but also on nutrient uptake, translocation, and allocation to developing fruits. Sarkis et al. (2024) reported that soil boron availability is affected by soil properties, including organic matter and texture. Goudsmit et al. (2023) also showed that nutrient availability is closely associated with cacao pod development, pod nutrient content, and yield formation.

Flower number was influenced by the interaction between clone and boron concentration. The highest flower number was recorded in MCC02 treated with $4 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$, while the same concentration also gave the highest value in MCC01, although at a lower level (Table 3). This result suggests that $4 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$ was the most favorable concentration for supporting flower formation under the conditions of this study. The decline in flower number at $8 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$, especially in MCC02, also shows that increasing the boron concentration does not necessarily improve reproductive performance. Boron is involved in pollen development, fertilization, cell wall stability, and reproductive metabolism (Chen et al., 2023; Michailidis et al., 2023). Wurentuya and Chen (2020) also reported that foliar boron application improved flowering and seed production in dicotyledonous crops. In cacao plantations, better flower formation provides a stronger initial basis for fruit formation, although further fruit retention still depends on the plant's physiological condition and protection from pests.

Physiological cherelle wilt was also affected by the interaction between clone and boron concentration, but the best concentration differed between clones. MCC01 showed the lowest physiological cherelle wilt at $4 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$, with 28.75 wilted young fruits, whereas MCC02 showed the lowest value at $2 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$, with 25.37 wilted young fruits (Table 4). This clone-dependent response is important for cacao protection because it shows that the same boron concentration may not provide the same level of protection against physiological fruit loss in different clones. MCC02 appeared to respond more efficiently to a lower boron concentration, while MCC01 required a higher concentration to reduce physiological cherelle wilt. Cherelle wilt is closely related to assimilate imbalance and insufficient physiological support for young fruit development (Dewi et al., 2020; Goudsmit et al., 2023). Genotypic variation in flowering, fruit set, and cherelle wilt has also been reported in cacao, indicating that cacao genotypes may differ in nutrient use, reproductive sink strength, and fruit retention capacity (Bhat et al., 2024). These results support the need for clone-specific boron management as part of preventive protection against physiological young fruit loss.

Young fruit wilt associated with *Helopeltis* sp. showed a different pattern from physiological cherelle wilt. The lowest number of *Helopeltis*-associated wilted young fruits was recorded in MCC02 treated with $8 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$, whereas MCC01 had the lowest value at $2 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$ and the highest value at $8 \text{ g L}^{-1} \text{ H}_3\text{BO}_3$ (Table 5). This finding suggests that pest-associated fruit wilt was not controlled by the same mechanism as physiological cherelle wilt. Boron may improve young fruit condition and tissue integrity, but the present data do not show that boron directly suppresses *Helopeltis* sp. infestation. Pest population density, feeding activity, and insect preference were not measured in this study. Therefore, the lower number of *Helopeltis*-associated wilted fruits in some treatments

should be interpreted as a field association between boron treatment and fruit condition, not as evidence of insecticidal activity. *Helopeltis* sp. damages cacao fruits by inserting its stylet into young tissues and causing necrotic lesions that may lead to fruit wilting (Nelly et al., 2017). Tavera et al. (2023) also reported that cacao mirid bugs interact with host plant tissues through feeding and host-location behavior. For this reason, foliar boron application should be combined with direct monitoring and management of *Helopeltis* sp. rather than used as a substitute for pest control.

Healthy young fruit formation was affected by both clone and boron concentration, with no significant interaction between the two. MCC02 produced more healthy young fruits than MCC01, while 4 and 8 g L⁻¹ H₃BO₃ produced higher numbers of healthy young fruits than the control and 2 g L⁻¹ H₃BO₃ (Table 6). Since 4 and 8 g L⁻¹ H₃BO₃ were not significantly different, 4 g L⁻¹ H₃BO₃ may be a more efficient concentration for improving young fruit retention, particularly to avoid unnecessary increases in boron input. The increase in healthy young fruits reflects improved early fruit protection, especially against losses related to physiological weakness. Boron supports cell wall formation, membrane function, pollen tube growth, and assimilate transport, which are important for early fruit development and fruit retention (Du et al., 2020; Chen et al., 2023; Michailidis et al., 2023). Genotype-dependent responses in cacao growth, physiology, nutrient uptake, and reproductive traits have also been reported by Arévalo-Gardini et al. (2021) and Bhat et al. (2024).

The results of this study place foliar boron application as a supportive component in cacao plant protection, particularly for reducing physiological young fruit loss and improving early fruit retention. The separate evaluation of physiological cherelle wilt and *Helopeltis*-associated wilt provides a more precise

interpretation of young fruit loss under field conditions. Physiological cherelle wilt can be reduced by improving plant nutritional and physiological status, whereas *Helopeltis*-associated wilt requires pest monitoring and appropriate pest management. Foliar boron application should therefore be positioned as part of integrated cacao management, not as a stand-alone solution for all causes of young fruit loss. Further studies involving more cacao clones, different environments, multiple seasons, and direct measurements of pest pressure and physiological traits are needed to strengthen clone-specific recommendations for foliar boron use in cacao protection systems.

Conclusions

The results revealed that physiological cherelle wilt was distinguished from *Helopeltis*-associated wilt by visual symptoms. Foliar boric acid application significantly affected flower number, physiological cherelle wilt, and *Helopeltis*-associated wilt through clone × concentration interactions. MCC02 treated with 4 g L⁻¹ H₃BO₃ produced the highest flower number, whereas MCC02 treated with 2 g L⁻¹ H₃BO₃ produced the lowest number of physiologically wilted young fruits. Healthy young fruit formation was independently affected by clone and boric acid concentration, with MCC02 and 4–8 g L⁻¹ H₃BO₃ showing the best responses. Foliar boron management using boric acid can serve as a supporting preventive strategy in cacao plant protection by reducing physiological fruit loss and improving young fruit retention in a clone-specific manner, while *Helopeltis*-associated wilt still requires direct pest monitoring and management.

Declaration

Author contributions

Branmanda Fardhaza Saputra was the primary contributor to this article and served as the corresponding author. Elisabeth Nanik

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References

- Ahmed N, B Zhang, Z Chachar, J Li, G Xiao, Q Wang, F Hayat, L Deng, MN Narejo, B Bozdar, P Tu. 2024. Micronutrients and their effects on horticultural crop quality, productivity and sustainability. *Scientia Horticulturae* 323: 112512. DOI. 10.1016/j.scienta.2023.112512.
- Alimuddin S, A Ralle, Saida, N Syam. 2023. Metode aplikasi boron untuk meningkatkan produksi tanaman jagung (*Zea mays* L.) hibrida. *AGROTEK: Jurnal Ilmiah Ilmu Pertanian* 7(1): 74–83. DOI. 10.33096/agrotek.v7i1.303.
- Arévalo-Gardini E, A Farfan, F Barraza, CO Arévalo-Hernández, LB Zúñiga-Cernades, J Alegre, VC Baligar. 2021. Growth, physiological, nutrient-uptake-efficiency and shade-tolerance responses of cacao genotypes under different shades. *Agronomy* 11(8): 1536. DOI. 10.3390/agronomy11081536.
- Badan Pusat Statistik. 2023. Statistik Kakao Indonesia 2022. Badan Pusat Statistik, Jakarta. Indonesia.
- Bhat RB, SE Apshara, TN Pushpa, DS Prasad, H Nayana, SH Thube, RTP Pandian, SV Ramesh. 2024. Genotypic variation in flowering, fruit set, and cherelle wilt, and their relationship with leaf nutrient status in cocoa (*Theobroma cacao* L.) grown in humid tropics of India. *Innovations in Agriculture* 7: 1–5. DOI. 10.3897/ia.2024.124253.
- Brdar-Jokanović M. 2020. Boron toxicity and deficiency in agricultural plants. *International Journal of Molecular Sciences* 21(4): 1424. DOI. 10.3390/ijms21041424.
- Chen X, SM Smith, S Shabala, M Yu. 2023. Phytohormones in plant responses to boron deficiency and toxicity. *Journal of Experimental Botany* 74(3): 743–754. DOI. 10.1093/jxb/erac443.
- da Vitória J, V de Souza Oliveira, AT Guasti, MAC Dias, C da Silva Dias, EN de Santana, K Tesch Kuhlcamp, L de Oliveira Arantes, JA Machado Filho, RB Queiroz, CA Spaggiari Souza, ER Schmildt, S Dousseau-Arantes. 2026. Photochemical efficiency and leaf carbohydrates of *Theobroma cacao* L. genotypes under different light regimes and cultivation systems. *Plants* 15(2): 297. DOI. 10.3390/plants15020297.
- Dermawan DD, D Saputera. 2026. A comparative study of cocoa beans in Indonesia, Ghana, Côte d'Ivoire, Ecuador, and Cameroon using the RCA, RSCA, and MSI approaches. *Golden Ratio of Mapping Idea and Literature Format* 6(1): 300–315. DOI. 10.52970/grmilf.v6i1.1671.
- Dewi HS ES, P Yudono, ETS Putra, BH Purwanto. 2020. Physiological and biochemical activities of cherelle wilt on three cocoa clones (*Theobroma cacao*) under two levels of soil fertilities. *Biodiversitas* 21(1): 187–194. DOI. 10.13057/biodiv/d210124.
- Du W, ZY Pan, SB Hussain, ZX Han, SA Peng, YZ Liu. 2020. Foliar-supplied boron can be transported to roots as a boron-sucrose complex via phloem in citrus trees. *Frontiers in Plant Science* 11: 250. DOI. 10.3389/fpls.2020.00250.
- FAO. 1983. Micronutrients. *FAO Fertilizer and Plant Nutrition Bulletin*. Food and Agriculture Organization of the United Nations, Rome.
- Goudsmit E, DMA Rozendaal, A Tosto, M Slingerland. 2023. Effects of fertilizer application on cacao pod development, pod nutrient content and yield. *Scientia Horticulturae* 313: 111869. DOI. 10.1016/j.scienta.2023.111869.
- Michailidis M, C Bazakos, M Kollaros, IDS Adamakis, I Ganopoulos, A Molassiotis, G Tanou. 2023. Boron stimulates fruit formation and reprograms developmental metabolism in sweet cherry. *Physiologia Plantarum* 175(3): e13946. DOI. 10.1111/ppl.13946.

- Nelly N, U Khairul, P Januasari. 2017. Biologi penghisap buah *Helopeltis* sp. (Hemiptera: Miridae) pada buah kakao dan mentimun. JPT: Jurnal Proteksi Tanaman 1(2): 62–67. DOI. 10.25077/jpt.1.2.62-67.2017.
- Prawoto AA, MT Astuti. 2015. Fisiologi layu pential kakao. In: T Wahyudi, Pujiyanto, Misnawi, editors. Kakao. Gadjah Mada University Press, Yogyakarta: 478–494.
- Reyes-Díaz M, P Cárcamo-Fincheira, R Tighe-Neira, A Nunes-Nesi, A Savouré, C Inostroza-Blancheteau. 2024. Effects of foliar boron application on physiological and antioxidant responses in highbush blueberry (*Vaccinium corymbosum* L.) cultivars. Plants 13(11): 1553. DOI. 10.3390/plants13111553.
- Sarkis LF, FHS Rabêlo, FWR Hippler, D Guelfi. 2024. Soil organic matter influences the agronomic efficiency of boron fertilizers in sandy Oxisol cultivated with soybean. Scientia Agricola 81: e20230231. DOI. 10.1590/1678-992X-2023-0231.
- Sri Dewi HS E, P Yudono, ETS Putra, BH Purwanto, T Toyip. 2023. Pengaruh dosis dan jenis aplikasi boron terhadap tingkat layu pential (cherelle wilt) tanaman kakao. Agroscrip: Journal of Applied Agricultural Sciences 5(1): 1–13. DOI. 10.36423/agroscrip.v5i1.1219.
- Tavera MAA, MCV Dela Cruz, KLT Santos, DM Amalin, JIB Janairo. 2023. β -caryophyllene as an attractant for the cacao mirid bug, *Helopeltis bakeri* Poppius (Hemiptera: Miridae), and chemodiversity of its host plant volatiles. Frontiers in Agronomy 5: 1178558. DOI. 10.3389/fagro.2023.1178558.
- Vanhove W, RK Yao, JC N'Zi, LAN Toussaint, A Kaminski, G Smagghe, P Van Damme. 2020. Impact of insecticide and pollinator-enhancing substrate applications on cocoa (*Theobroma cacao*) cherelle and pod production in Côte d'Ivoire. Agriculture, Ecosystems & Environment 293: 106855. DOI. 10.1016/j.agee.2020.106855.
- Wang J, J Wei, D Guo, X Lv, B Wang, Y Wang, J Li. 2024. Boron homeostasis affects longan yield: a study of NIP and BOR boron transporter of two cultivars. BMC Plant Biology 24: 9. DOI. 10.1186/s12870-023-04689-8.
- Wurentuya, L Chen. 2020. The effect of foliar boron application on seed production of alfalfa (*Medicago sativa* L.). Biosis: Biological Systems 1(2): 60–64. DOI. 10.37819/biosis.001.02.0056.

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