

Research article

Evaluation of Biosaka Spray for Enhancing Physiological Traits and Improving Fruit Quality in *Inodorus* Melon

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Abstract

Melon is an economically important horticultural crop, yet its productivity and fruit quality are often constrained by suboptimal cultivation practices. Biosaka, a biostimulant containing natural elicitors, has the potential to enhance physiological performance and fruit traits, but its effective concentration remains unclear. This study evaluated the optimal concentration of biosaka spray for improving physiological traits and fruit quality of *Inodorus melon*. A non-factorial completely randomized design was applied with six concentrations (0, 10, 20, 30, 40, and 50 mL L⁻¹), each with four plants and replications, totaling 96 experimental units. Biosaka application did not have significant effect on chlorophyll content, chlorophyll a/b ratio, stomatal density, biomass, net assimilation rate, or harvest index. In contrast, it significantly increased leaf area index (LAI) and fruit quality attributes. Polynomial regression predicted an optimal concentration of 26.5 mL L⁻¹ for LAI (0.845). Concentrations between 31.0 and 50.7 mL L⁻¹ produced optimal fruit traits, including fruit weight, diameter, total soluble solids, and edible portion. Correlation analysis indicated weak relationships between LAI and physiological parameters, while strong positive associations were found between biomass and NAR, and negative associations between HI and biomass. Overall, biosaka at 26.5 - 50.7 mL L⁻¹ is optimal for enhancing melon fruit quality, though further studies are required to characterize its elicitor compounds.

Keywords: biosaka; elicitor; melon; natural materials; physiological activity

1. Introduction

Biosaka is a natural biostimulant formulated by Indonesian farmers, consisting of organic compounds that act as elicitors. It is primarily applied to enhance plant productivity by stimulating physiological processes and providing protection against plant pathogens

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(Elimasni & Nasution, 2024). Several studies have reported that biosaka contributes to sustainable crop production by supporting plant nutrition and reducing reliance on chemical inputs (Umam et al., 2025). Weeds are often used as a biomass source for biosaka, since they contain both nutrients and bioactive compounds with potential elicitor activity (Indratmi et al., 2024). Notable examples include *Ageratum conyzoides* L., *Elephantopus mollis* Kunth., and *Euphorbia hirta* L., which are rich in bioactive compounds such as flavonoids and saponins that may trigger physiological responses in plants (Wang et al., 2023b). These species also contain essential macronutrients, including nitrogen (N), phosphorus (P), and potassium (K), which are important for plant growth (Gusain et al., 2018). Although biosaka is not classified as a conventional fertilizer, it has been reported to act as a natural biostimulant with potential elicitor-like activity that stimulate secondary metabolite synthesis, strengthens plant defense mechanisms, and regulates physiological activity (Verma et al., 2024).

Elicitors are known to stimulate physiological processes due to their diverse range of bioactive compounds. For instance, the application of elicitors in corn at a concentration of 3 g L⁻¹ has been shown to improve gas exchange, photosynthetic rate, stomatal conductance, and water use efficiency (Martins et al., 2021). Elicitors can also enhance antioxidant activity in plants exposed to biotic and abiotic stresses (Song et al. 2020). Salicylic acid, for example, was reported to improve tolerance to salinity (Ansari et al., 2022). In corn grown under suboptimal conditions, elicitor application increased relative water content, activated antioxidant enzymes, and reduced oxidative damage by lowering malondialdehyde (MDA) and hydrogen peroxide (H₂O₂) levels (Siddique et al., 2025). Likewise, foliar application of chitosan lactate (150 mg L⁻¹), sodium selenite (10 mg L⁻¹), and salicylic acid (100 mg L⁻¹) suppressed oxidative stress, promoted the accumulation of phenolic acids and flavonoids, and stimulated overall plant metabolism (Stasinska-Jakubas et al., 2023). While most of these studies were focused on plant responses under stress conditions, limited information is available on the role of elicitors in enhancing crop growth and fruit quality under normal cultivation practices.

Melon is one of the most important horticultural crops worldwide and is widely cultivated in Indonesia. It has high economic value in both domestic and export markets, with consumer demand strongly driven by fruit size, sweetness, and overall quality. Melon in *Inodorus* group, in particular, are highly valued for its firm texture, and extended shelf life, and consumers demonstrate preference for sweetness and aroma (Habibah et al., 2025). However, melon cultivation often faces challenges such as susceptibility to pests and diseases, inconsistent fruit weight and diameter, and relatively low sweetness levels, which reduce market competitiveness. Farmers commonly rely on chemical fertilizers and pesticides to address these problems, but excessive use of these inputs can increase production costs and harm the environment (Mejía-Guerra et al., 2025). Therefore, there is a strong need to explore eco-friendly alternatives such as biosaka to improve melon yield and fruit quality in a sustainable manner.

Based on the rationale, it is hypothesized that biosaka, with its rich content of elicitor and nutrients, could improve physiological activity and fruit quality in *Inodorus* melon. This study aimed to determine the optimal concentration of biosaka spray and to evaluate its effectiveness in improving the physiological traits and fruit quality of *Inodorus* melon.

2. Materials and Methods

2.1 Study site

The study was conducted at the Screen House of Universitas Perjuangan Tasikmalaya, Indonesia (7°21'17.6"S 108°13'17.8"E) from November 2023 to January 2024. Biosaka was prepared using biomass collected from the Agricultural Incubator area of Universitas Perjuangan Tasikmalaya (7°21'12.4"S 108°13'14.3"E). The dominant weed species used as raw materials for biosaka production included *Ageratum conyzoides* L., *Elephantopus mollis* Kunth., and *Euphorbia hirta* L., which are known to contain flavonoids, saponins, and essential macronutrients.

The experiment was arranged in completely randomized design (CRD) with six treatments of biosaka spray concentrations: 0 mL L⁻¹ (control), 10 mL L⁻¹, 20 mL L⁻¹, 30 mL L⁻¹, 40 mL L⁻¹, and 50 mL L⁻¹. Each treatment consisted of four plants per treatment, with four replications, resulting in a total of 96 experimental units. Plants in the control group were sprayed with distilled water and served as a positive control for physiological and fruit quality comparisons.

2.2 Study procedures

Biosaka was produced using a variety of disease-free plant species, including *Ageratum conyzoides* L., *Elephantopus mollis* Kunth., and *Euphorbia hirta* L. Approximately 500 g of leaves of each plant were thoroughly washed with distilled water and then subjected to a gentle squeezing process in 5 L of water. The mixture was stirred for 10 to 15 min until the liquid turned dark brown and exhibited a homogeneous consistency. To confirm the nutritional composition, the levels of organic-C and macronutrients (N, P, and K) were analyzed at the Laboratory of Soil Chemistry and Plant Nutrition of Padjadjaran University. The results (Table 1) showed that biosaka contained very low levels of organic-C and macronutrients, all of which fell below the minimum criteria established by the Soil and Fertilizer Instrument Standard Testing Center of Indonesia (2023).

Table 1. Analysis of organic-C and macronutrient content in Biosaka

Parameters	Unit	Results	Criteria
Organic-C	%	2.74	very low (min 10)
Macronutrient			
N-total	%	0.12	very low (2-6)
P ₂ O ₅ potential	%	0.03	very low (2-6)
K ₂ O potential	%	0.04	very low (2-6)

Notes: Biosaka content analyzed in Laboratory of Soil Chemical and Plant Nutrition, Padjadjaran University; criteria based on The Soil and Fertilizer Instrument Standard Testing Center Indonesia (2023).

Melon seeds of the Golden Alisha F1 variety (*Inodorus* type) were sown in seedling trays for 14 days using a 1:1 (w/w) mixture of soil and cow manure as the planting medium. The seedlings were transplanted into polybags (50 x 25 cm) filled with cocopeat, rice husks, and cow manure at a ratio of 1:1:2 (w/w/w). Transplanting was carried out in the afternoon

(16.00-17.00). Plant maintenance involved daily irrigation at a rate of 1 L plant⁻¹, removal of lateral shoots, manual pollination, and routine weeding. Pest and disease control was primarily preventive through sanitation, weeding, and removal of infected plant parts. Synthetic pesticide was applied only when pest incidence exceeded the economic threshold. Biosaka was applied as a foliar spray at a rate of 500 mL plant⁻¹ at 2, 4, and 6 weeks after planting (WAP), between 07.00-09.00 in the morning when stomata were actively open. Harvesting occurred in the morning, typically 70-85 days after planting (DAP) when the fruit exhibited a deep yellow peel color, the fruit stalks and leaves had dried, and the fruit emitted a distinct fresh aroma.

2.3 Physiological traits and fruit quality

Estimation of the LAI was determined by measuring the leaf area per plant using ImageJ version 1.54 g. Calibration was required to ensure that the captured image size accurately reflected the actual dimensions of the plant. The LAI was calculated using equation 1, following the modified method by Mendoza-Pérez et al. (2017). Chlorophyll content was estimated by extracting 1 g of leaf tissue with 20 mL of analytical-grade acetone. The mixture was filtered through Whatman No. 42 filter paper to obtain the filtrate. The absorbance of the filtrate was measured at wavelengths of 663 nm and 645 nm using a UV-VIS 752AP spectrophotometer as described by Arnon (1949). The total chlorophyll content and the chlorophyll a/b ratio were calculated using equations 2 and 3, respectively.

$$\text{LAI} = \frac{1}{\text{ground area}} \times \text{leaf area} \quad (1)$$

$$\text{Total chlorophyll content (mg g}^{-1}\text{)} = [20.2 \times A_{645}] + [8.02 \times A_{663}] \quad (2)$$

$$\text{Chlorophyll a/b ratio} = \frac{[12.7 \times D_{663}] - [2.69 \times D_{645}]}{[22.9 \times D_{645}] - [4.68 \times D_{663}]} \quad (3)$$

Stomatal density was determined using the nail polish imprint method (Zhu et al., 2018). First, the leaves were cleaned of dirt, after which the underside of the leaves was coated with clear nail polish. Once the nail polish had dried, it was gently peeled off with tape and mounted on a glass slide. Stomatal observations were performed at 40x magnification using the Euromex Novex Microscope B & B⁺ Series and OptiLab Advance Lite. LAI, total chlorophyll content, and stomatal density were measured at 7 WAP. The plant biomass, including shoots and roots, was measured using a destructive sampling method. The shoots and roots from the planting medium were cleaned and washed with water to remove any remaining soil. The plant organs were placed in envelopes and dried in a Memmert Type UN260 oven at 80°C for 48 h. After drying, the shoots and roots were weighed on a JOIL digital scale with an accuracy of 0.01 x 500 g to determine the plant biomass. The NAR was calculated using Equation 4, based on leaf area and plant biomass data collected when the plant was 4 and 7 WAP following the method by Jumin et al. (2025). Furthermore, the HI, which was the ratio of economic yield to biological yield, was calculated as specified in equation 5, according to Ren et al. (2022).

$$\text{NAR (g cm}^{-2} \text{ week}^{-1}\text{)} = \frac{W_2 - W_1}{A_2 - A_1} \times \frac{\ln A_2 - \ln A_1}{t_2 - t_1} \quad (4)$$

$$\text{HI} = \frac{\text{economical yield}}{\text{biological yield}} \quad (5)$$

Where: W2 = plant biomass at 7 WAP; W1 = plant biomass at 4 WAP; A2 = leaf area at 7 WAP; A1 = leaf area at 4 WAP; t2 = observation time at 7 WAP; and t1 = observation time at 4 WAP.

The harvested fruit was measured in diameter using a caliper at midpoint. The edible portion was estimated as the ratio of fruit flesh to peel, following the modified method of Fundo et al. (2018). Determination of TSS was performed using the R9500 MT-032 BIRX Refractometer, with liquid extracted from the fruit and placed on the refractometer's lens. The TSS value was displayed on the device's screen in °Brix units. Additionally, the weight of the harvested fruit was measured using a JOIL digital scale with an accuracy of 0.1 x 3 kg. All variables were observed using two sample plants from each treatment in every replication. All variables were observed using two sample plants from each treatment in every replication.

2.4 Data analysis

The data analysis used an F-test, followed by Duncan's Multiple Range Test (DMRT) $\alpha=5\%$ for post-hoc comparison. We conducted a polynomial regression analysis to optimize biosaka concentration. Pearson correlation analysis was used to examine relationships among physiological traits, and the results were visualized with a heatmap. In addition, principal component analysis (PCA) was performed to group the measured variables according to biosaka concentration and to identify the most influential traits contributing to treatment differences. All data are presented in Tables and graphs. Statistical analysis using Statistical Tools for Agricultural Research and Microsoft Excel Office 2019.

3. Results and Discussion

3.1 Physiological trait

Leaves play a crucial role in regulating the physiological processes that underpin photosynthesis, transpiration, and respiration (Nasrudin et al., 2025). The absorption of photons by chlorophyll in the chloroplast leads to the accumulation of assimilates, which directly influences plant growth and development (Li et al., 2024). The amount of sunlight intercepted by leaves and transmitted to the plant is often quantified using the LAI (Mendoza-Pérez et al., 2017). As illustrated in Figure 1, the application of biosaka significantly enhanced the LAI. Based on regression analysis, the predicted optimum concentration of biosaka was 26.5 mL L⁻¹, which corresponded to an LAI value of 0.845. The optimum values were not directly tested as a treatment but derived statistically from the response curve. Although the present study did not directly measure the level of elicitor compounds in biosaka, previous reports indicate that biosaka contains bioactive elicitors that may stimulate vegetative plant growth.

Elicitors in biosaka contain external compounds that stimulate plant physiological processes, resulting in an increased LAI. According to Harvey et al. (2022), several elicitors can enhance the rate of photosynthesis by activating the enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco). Furthermore, elicitors influence the hormonal balance within plants, which plays a key role in regulating plant growth (Humbal & Pathak, 2023), contributing to the observed increase in LAI. For example, salicylic acid as an elicitor has been reported to promote leaf expansion in *Achillea millefolium* L. (Gorni et al., 2021), while jasmonic acid contributes to salinity stress mitigation in wheat, thereby

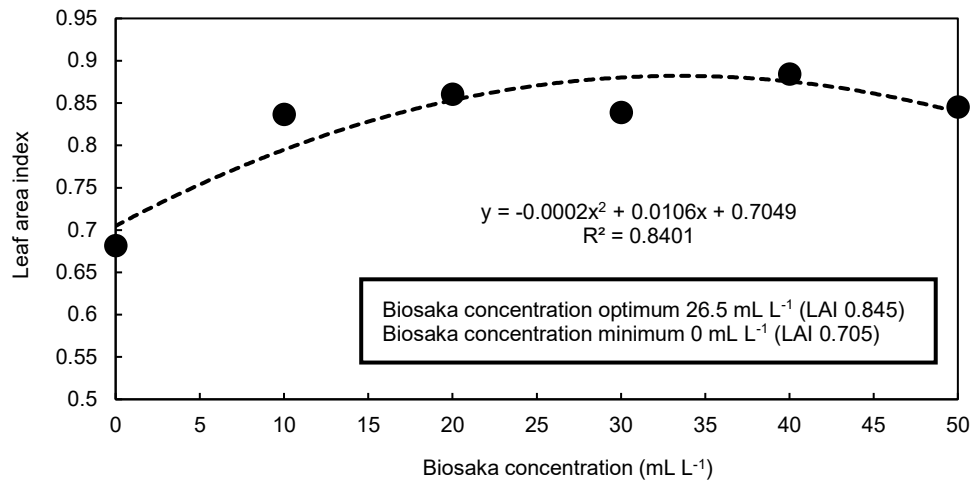


Figure 1. The correlation between leaf area index and biosaka concentrations

supporting vegetative development (Sheteiwiy et al., 2022). These findings highlight the broader role of elicitors in regulating leaf area and canopy development across plant species, which may also explain the improved LAI observed in melon treated with biosaka. An increase in total leaf area, in turn, enhances the amount of sunlight interception by the plant, further supporting its growth and development.

The increase in LAI at a concentration of 26.5 mL L⁻¹ caused optimal total chlorophyll content of 54,980 mg g⁻¹ and a chlorophyll a/b ratio of 1.766. The elevated chlorophyll content plays a significant role in intercepting sunlight to enhance the photosynthesis rate (Simkin et al., 2022). Additionally, a high chlorophyll a/b ratio suggests that chlorophyll a is indispensable in the photochemical processes of photosynthesis, serving both in light harvesting and in converting intercepted photons into chemical energy (Biswal et al., 2024). The concentration of biosaka between 20 mL L⁻¹ and 30 mL L⁻¹ can contain optimal elicitors that activate enzymes involved in chlorophyll syntheses, such as protochlorophyllide oxidoreductase (POR) for chlorophyll biosynthesis (Nguyen et al., 2021). Additionally, the light interception by chlorophyll can increase the photosynthesis rate and is also influenced by the amount of CO₂ absorbed through the stomata.

Stomata are small pore-like structures located on the leaf surface that play a critical role in gas exchange during photosynthesis, respiration, and transpiration (Wang et al., 2024). During photosynthesis, carbon dioxide (CO₂) from the atmosphere is absorbed through the stomata, serving as a key substrate for carbon fixation. In addition, stomata are involved in regulating guard cell activity and water evaporation during transpiration (Wang et al., 2020; Ding et al., 2024).

In this study, stomatal density did not differ significantly among treatments (Table 2). Although the present study did not directly analyze the elicitor compounds contained in biosaka, previous reports suggest that elicitors may regulate epidermal cell differentiation through signaling pathways involving phytohormones and reactive oxygen species. Therefore, the increase in stomatal density observed in this study is presumed to be associated with the presence of elicitor-like compounds in biosaka. Further studies are needed to directly verify the type and level of elicitors and their specific role in stomatal development.

Table 2. Effects of biosaka spray on total chlorophyll content, chlorophyll a/b ratio, and stomatal density of *Inodorus* melon

Biosaka concentration	Total Chlorophyll (mg g ⁻¹)	Chlorophyll a/b Ratio	Stomatal Density (mm ²)
0 mL L ⁻¹	54.420	1.305	1488
10 mL L ⁻¹	52.570	1.412	2150
20 mL L ⁻¹	54.980	1.078	2075
30 mL L ⁻¹	49.410	1.766	1550
40 mL L ⁻¹	49.990	1.667	1763
50 mL L ⁻¹	53.870	1.318	2012
ANOVA (P-value)	0.194	0.069	0.193

In this study, LAI primarily reflected canopy-level morphological traits such as leaf area and number of leaves. This canopy traits are not directly associated with leaf-level physiological traits. Chlorophyll content and stomatal density are strongly regulated by environmental factors and leaf anatomical characteristics rather than by canopy size. Similarly, the chlorophyll a/b ratio reflects leaf adaptation to light conditions, which may vary independently of LAI (Mibu et al., 2025). Therefore, variations in these physiological parameters do not necessarily correspond with changes in LAI.

The stomatal density was affected by biosaka at concentrations ranging from 10-20 mL L⁻¹, which increased the number of stomata (Figures 2b, 2c, 2f). Stomatal density refers to the number of stomata per unit area of the leaf surface and significantly influences the rate of gas exchange of CO₂ and O₂ in plants. A higher stomatal density indicates a higher number of stomata on the leaf surface and facilitates increased gas exchange, thereby enhancing photosynthetic activity (Vráblová et al., 2017). An increase in photosynthesis rate can produce the assimilates, supporting more efficient plant growth (Punia et al., 2020). However, the number of stomata per unit leaf area also affects the volume of water vapor lost through transpiration. Therefore, a balance between CO₂ and O₂ gas exchange and water vapor evaporation is crucial to ensure that metabolic processes within the plant remain optimal. The increase in metabolic activity, particularly the photosynthesis rate, will influence the accumulation of assimilates stored in various plant organs.

Assimilates produced through photosynthesis are stored in various plant organs, particularly shoots and roots. The results of this study showed that biosaka concentration did not significantly affect PB, SB, RB, and NAR, although concentrations between 10-30 mL L⁻¹ tended to promote higher biomass accumulation (Table 3). As shown in Table 4, PB and SB exhibited a very strong positive correlation (R²= 0.999), indicating that increases in shoot growth were consistently accompanied by increases in total plant biomass. Similarly, RB showed a positive correlation with PB and SB, suggesting that root biomass contributes to the overall growth response. Previous studies also reported that applying elicitors at specific concentrations, such as 20 mL L⁻¹, enhanced the synthesis of secondary metabolites that support biomass formation (Namin et al. 2022). These bioactive compounds can improve photosynthesis rate, water uptake, and nutrient absorption, thereby promoting shoot and root growth. Moreover, biosaka application has been associated with increased IAA hormone production, which plays a crucial role in root development, cell differentiation, and protein synthesis, further boosting plant biomass (Frick & Strader, 2018; Sun & Shahrajabian, 2025).

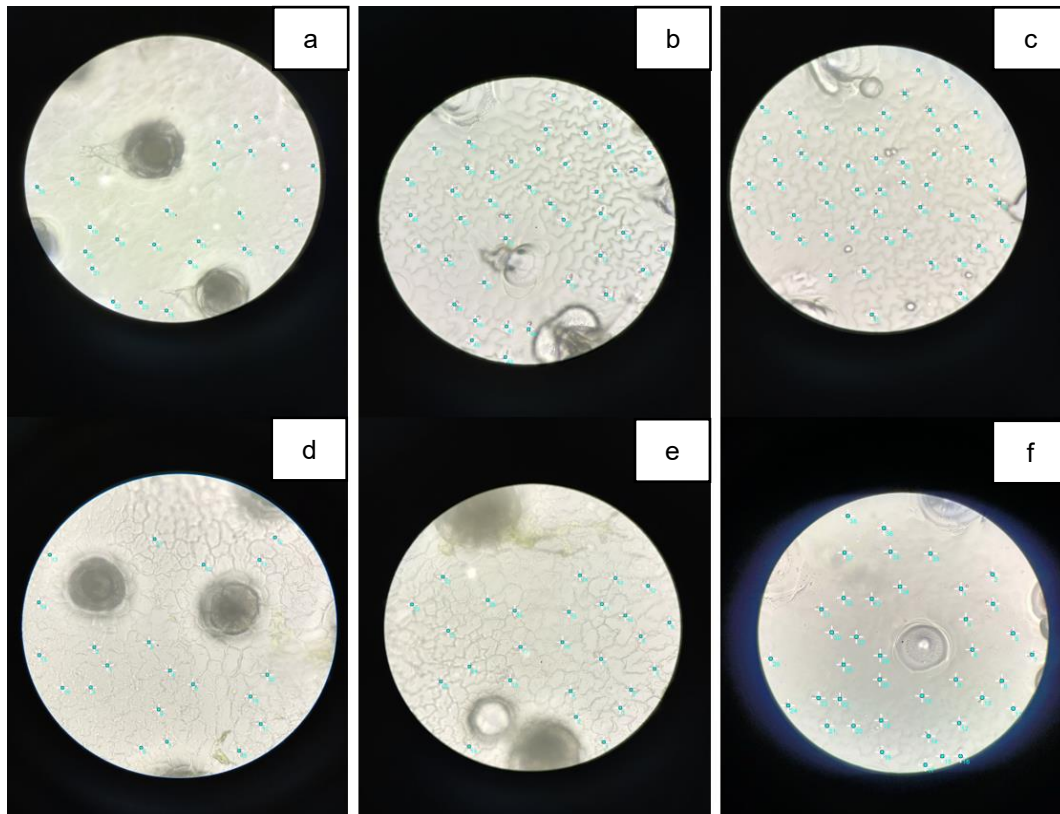


Figure 2. Stomatal density using microscope with 40x magnification with biosaka concentration of (a) 0 mL L⁻¹; (b) 10 mL L⁻¹; (c) 20 mL L⁻¹; (d) 30 mL L⁻¹; (e) 40 mL L⁻¹; (f) 50 mL L⁻¹

Table 3. Effects of biosaka spray on plant biomass, shoot biomass, root biomass, net assimilation rate, and harvest index of *Inodorus* melon

Biosaka Concentrations	PB (g)	SB (g)	RB (g)	NAR	HI
0 mL L ⁻¹	70.653	70.100	0.554	1.883	17.373
10 mL L ⁻¹	72.110	71.500	0.611	0.858	20.787
20 mL L ⁻¹	73.465	72.725	0.741	2.224	19.173
30 mL L ⁻¹	78.573	77.800	0.774	1.234	20.912
40 mL L ⁻¹	70.168	69.675	0.492	1.117	21.450
50 mL L ⁻¹	71.453	70.550	0.902	1.515	23.308
ANOVA (P-value)	0.903	0.909	0.116	0.124	0.427

Notes: PB (plant biomass); SB (shoot biomass); RB (root biomass); NAR (net assimilation rate); HI (harvest index)

Table 4. Pearson correlation analysis among all observed variables

	LAI	ChIT	Chl a/b	StoD	PB	SB	RB	HI	NAR
LAI	1	-0.221	0.059	0.117	0.137	0.132	0.200	0.068	-0.217
ChIT	-0.221	1	-0.816	0.088	0.142	0.138	0.221	-0.171	0.563
Chl a/b	0.059	-0.816	1	-0.024	-0.244	-0.238	-0.344	0.232	-0.555
StoD	0.117	0.088	-0.024	1	-0.077	-0.077	-0.001	0.096	-0.126
PB	0.137	0.142	-0.244	-0.077	1	0.999	0.299	-0.748	0.449
SB	0.132	0.138	-0.238	-0.077	0.999	1	0.278	-0.756	0.448
RB	0.260	0.221	-0.344	-0.001	0.299	0.278	1	0.109	0.156
HI	0.068	-0.171	0.232	0.096	-0.748	-0.756	0.109	1	-0.458
NAR	-0.217	0.563	-0.555	-0.126	0.449	0.448	0.156	-0.458	1

Notes: LAI (leaf area index), ChIT (total chlorophyll content), Chl a/b (chlorophyll a/b ratio), StoD (stomatal density), PB (plant biomass), SB (shoot biomass), RB (root biomass), HI (harvest index), NAR (net assimilation rate)

The increase in biomass was also reflected in the higher NAR value of 2.224 when biosaka was applied at 20 mL L⁻¹. A high NAR represents enhanced assimilate production that can be stored in plant organs as reserves (Nasrudin et al., 2022). Correlation analysis confirmed a positive relationship between NAR and biomass components (PB and SB), but a negative relationship with chlorophyll a/b ratio ($R^2 = -0.555$), indicating that physiological efficiency in biomass accumulation does not necessarily align with chlorophyll partitioning.

Regarding HI, biosaka application did not significantly affect its value (Table 3). However, the correlation matrix (Table 4) showed a strong negative correlation between HI and PB or SB ($R^2 = -0.748$ and -0.756 , respectively). This suggests that when assimilates are directed toward vegetative biomass, the proportion translocated to fruits decreases, and vice versa. A high HI value therefore reflects efficient allocation of assimilates to melon fruit, while vegetative growth is relatively limited (Yang & Zhang, 2023). In addition, HI was negatively correlated with NAR ($R^2 = -0.458$), which further supports the trade-off between vegetative growth and reproductive sink allocation. These findings highlight the complexity of assimilate partitioning, which is influenced by plant genetics, environmental factors, and cultivation practices, including biosaka application (Porker et al., 2020).

3.2 Fruit quality

The quality of melon fruit is a key factor in consumer preference and influences various on-farm and off-farm factors. Fruit quality generally encompasses several attributes, such as taste, texture, physical appearance, and nutritional content (Farcuh et al., 2020). According to the research findings, the biosaka application at 39.5 mL L⁻¹ was the optimal concentration, producing an edible portion of 73.68% (Figure 3a). The edible portion refers to the proportion of the fruit's flesh for consumption, excluding the skin. A higher value for the edible portion indicates more fruit flesh available for consumption (Fundo et al., 2018). When biosaka spray is applied at the optimal concentration, it enhances the production of assimilates and promotes the formation of fruit flesh as a storage site for food reserves (Falchi et al., 2020). Additionally, the edible portion directly influences the overall weight of the fruit produced.

Melon fruit weight becomes an important indicator of fruit quality and is influenced by the amount of assimilates translocated during plant growth and development (Liu et al., 2025). The application of biosaka at a concentration of 50.7 mL L⁻¹ resulted in a melon fruit weight of 1599 g (Figure 3b). The accumulation of assimilates from photosynthesis during on-farm growth largely determines the weight of the melon. Elicitors present in biosaka, particularly at higher concentrations, are believed to enhance the rate of photosynthesis and hormone accumulation, thereby promoting the formation of fruit tissues (Guru et al., 2022). The gibberellin hormone plays a crucial role in cell elongation and division, contributing to the increase in fruit size (Zhang et al., 2024). Furthermore, bioelicitor compounds present in biosaka are suggested to stimulate starch synthase activity, which is involved in starch and carbohydrate biosynthesis, thereby supporting the development of larger and more robust fruit tissues (Wang et al., 2023a). Additionally, the elicitors in biosaka contribute to an increase in the TSS.

TSS is a key indicator of the dissolved substances in fruit, particularly sugars such as glucose, fructose, and sucrose (Júnior et al., 2025). A higher TSS, reaching 14 °Brix, indicates a higher sugar content in the fruit, which directly influences the sweetness of the melon (Tzuri et al., 2025). In *Indorous* melon varieties, TSS increases primarily during on-farm growth, with only slight changes occurring post-harvest. This condition is due to the non-climacteric melon type, which exhibits very slow respiration activity after harvest (Perotti et al., 2023). As such, the increase in TSS in this variety is closely related to the fruit's ripeness. The optimal level of ripeness was influenced by the presence of elicitors in biosaka, with a concentration of 31 mL L⁻¹ resulting in a TSS of 9.22 °Brix (Figure 4a). A previous study reported that TSS content was affected by environmental conditions and on-farm cultivation practices, including nutrient availability, optimal climate, and the presence of hormones that facilitated fruit ripening (Li et al., 2024; Tian et al., 2024). Therefore, a high TSS value also increases its appeal to consumers. In addition to TSS, the fruit's diameter becomes another important quality indicator that can significantly impact its economic value.

Similar to other fruit quality parameters, the application of biosaka at a concentration of 38.6 mL L⁻¹ resulted in a fruit diameter of 135.97 mm (Figure 4b). The hormonal stimulation induced by the elicitors in biosaka plays a crucial role in promoting cell division and elongation within fruit tissues during plant growth (Wang et al., 2023a). Additionally, high photosynthetic rates increase carbohydrate production, which contributes to the enlargement of the fruit, thereby enhancing its diameter. Plant genetics factors also significantly influence fruit size through interact with elicitors, which may result in different fruit enlargement (Hyun et al., 2021). Generally, biosaka contains elicitors and hormones that enhance plant physiological activity and improve fruit quality. Optimal concentrations of biosaka stimulate various metabolic activities in plants, particularly photosynthesis, which directly influences the production of assimilates stored in the fruit as food reserves in a permanent sink.

3.3 Principal component analysis (PCA)

Principal component analysis provided a comprehensive overview of the relationship among physiological traits, quality parameters, and biosaka concentrations (Figure 5). The first two principal components (PC1 and PC2) explained 52.81% and 22.65% of the total variance, respectively.

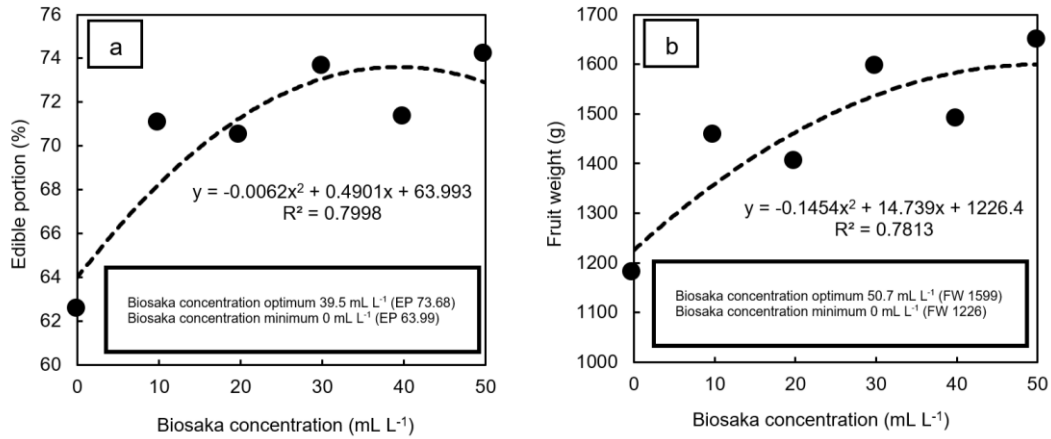


Figure 3. (a) The correlation between edible portion and biosaka concentration; and (b) The correlation between fruit weight and biosaka concentration

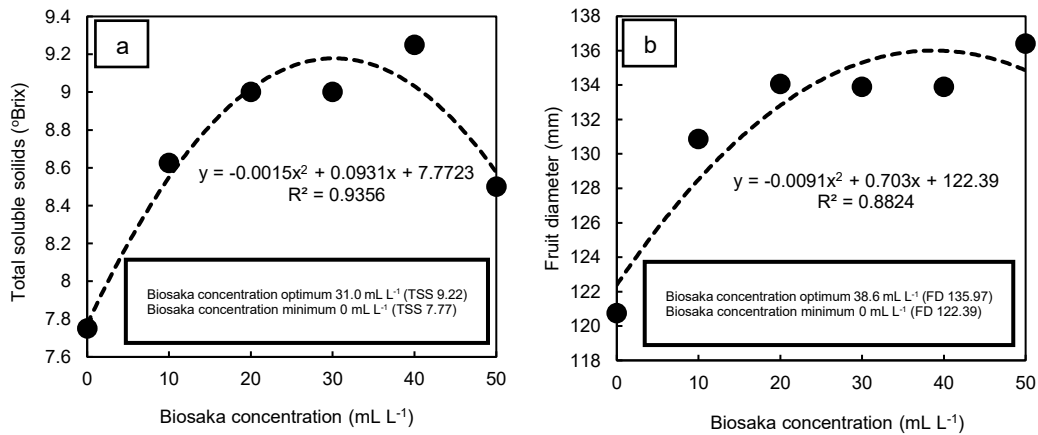


Figure 4. (a) The correlation between total soluble solids and biosaka concentration; and (b) The correlation between fruit diameter and biosaka concentration

Along with PC1, LAI, chlorophyll a/b ratio, and harvest index were positively aligned with treatments B2 (20 mL L⁻¹) and B5 (50 mL L⁻¹), indicating that these concentrations promoted vegetative growth and canopy development. Conversely, fruit quality traits such as total soluble solids, edible portion, fruit diameter, and net assimilation rate clustered in the upper positive quadrant of PC2, closely associated with treatments B1 (10 mL L⁻¹) and B4 (40 mL L⁻¹). This suggests that moderate biosaka concentrations favored assimilate allocation to reproductive sinks, improving fruit quality traits.

The B0 (control) was clearly separate in the negative PC1-PC2 quadrant, reflecting poor performance across both vegetative and reproductive parameters. Treatment B3 (30 mL L⁻¹) was positioned in the upper left quadrant, indicating a distinct response compared with other treatments. Although located on the positive side of PC2, its separation from B1

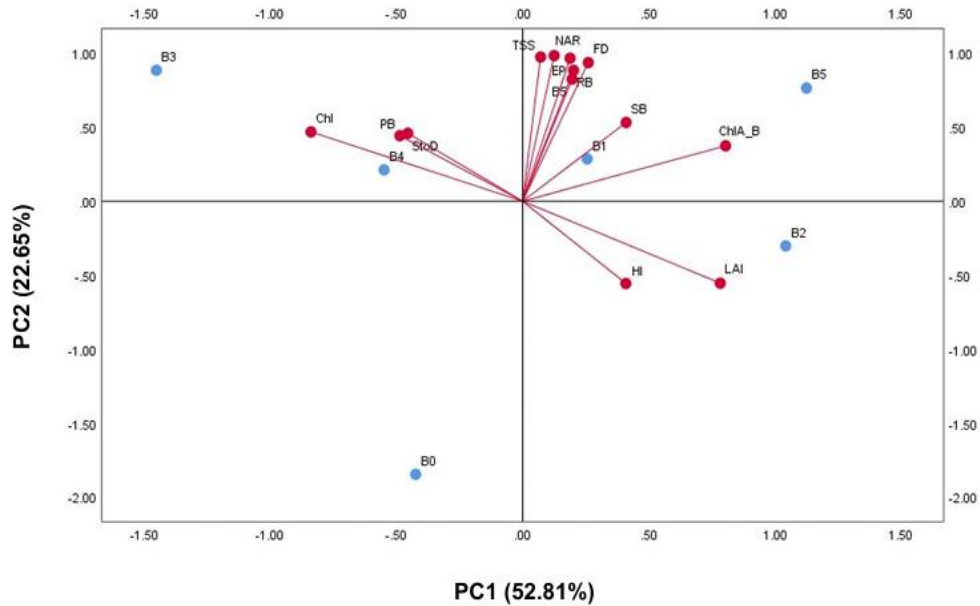


Figure 5. PCA biplot of melon traits under biosaka treatments

and B4 suggests that 30 mL L⁻¹ did not strongly associate with either vegetative development or fruit quality improvement. Overall, the PCA confirmed that biosaka concentrations exhibited differential effects, where moderate levels (10-30 mL L⁻¹) enhanced fruit quality attributes, while higher levels (30-50 mL L⁻¹) favored vegetative development. This multivariate approach complements the univariate correlation analysis (Table 4), highlighting the trade-off between vegetative and reproductive allocation under biosaka treatments.

These patterns suggest that the function of biosaka in this study was not as a liquid organic fertilizer but rather as a biostimulant acting through the action of elicitors. Elicitors are bioactive compounds capable of stimulating physiological processes, enhancing secondary metabolite production, and improving plant defense mechanisms. This mode of action could account for the improvement in fruit quality at moderate biosaka concentration. In contrast, higher concentrations tended to promote vegetative growth at the expense of reproductive performance.


4. Conclusions


Biosaka application significantly improved the physiological performance and fruit quality of *Inodorus* melon through its elicitor activity rather than its macronutrient content. The optimal concentration for vegetative growth was 26.5 mL L⁻¹, producing the highest LAI (0.845), while concentrations between 31.0 and 50.7 mL L⁻¹ enhanced fruit weight, diameter, total soluble solids, and edible portion. These findings indicate that Biosaka concentrations in the range of 26.5-50.7 mL L⁻¹ are optimal for maximizing both physiological traits and fruit quality in melon cultivation. Further studies are required to identify the specific elicitor compounds in biosaka and evaluate their synergistic role with external nutrient supplementation.


5. Authors' Contributions


Muhammad Huda contributed to the fieldwork and data collection. Nasrudin was responsible for the study design and research methodology. Arrin Rosmala handled the data analysis and interpretation. Ruhnayati Kaffah contributed to the laboratory experiments and data collection. Monita Dwiyani provided translation services for the manuscript. All authors participated in the writing, reviewing, and finalization of the manuscript.

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6. Conflicts of Interest

The authors declare that there are no conflicts of interest, real or perceived, in the research or publication of this article.

References

- Ansari, H. H., Siddiqui, A., Wajid, D., Tabassum, S., Umar, M., & Siddiqui, Z. S. (2022). Profiling of energy compartmentalization in photosystem II (PSII), light harvesting complexes and specific energy fluxes of primed maize cultivar (P1429) under salt stress environment. *Plant Physiology and Biochemistry*, *170*, 296-306. <https://doi.org/10.1016/j.plaphy.2021.12.015>
- Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidases in *Beta vulgaris*. *Plant Physiology*, *24*(1), 1-15. <https://doi.org/10.1104/pp.24.1.1>
- Biswal, A. K., Pattanayak, G. K., Ruhil, K., Kandoi, D., Mohanty, S. S., Leelavati, S., Reddy, V. S., Govindjee, G., & Tripathy, B. C. (2024). Reduced expression of chlorophyllide a oxygenase (CAO) decreases the metabolic flux for chlorophyll synthesis and downregulates photosynthesis in tobacco plants. *Physiology and Molecular Biology of Plants*, *30*(1), 1-16. <https://doi.org/10.1007/s12298-023-01395-5>
- Ding, L., Foz, A. R., & Chaumont, F. (2024). Multifaceted role and regulation of aquaporins for efficient stomatal movements. *Plant, Cell & Environment*, *49*(9), 3330-3343. <https://doi.org/10.1111/pce.14942>
- Elimasni, E., & Nasution, S. A. S. (2024). Optimizing biosaka elicitor concentration for enhanced growth and yield of cherry tomato (*Solanum lycopersicum* L. var. cerasiforme). *Pakistan Journal of Biological Sciences*, *27*(12), 577-586. <https://doi.org/10.3923/pjbs.2024.577.586>
- Falchi, R., Bonghi, C., Drincovich, M. F., Famiani, F., Lara, M. V., Walker, R. P., & Vizzotto, G. (2020). Sugar metabolism in stone fruit: source-sink relationships and environmental and agronomical effects. *Frontiers in Plant Science*, *11*, Article 573982. <https://doi.org/10.3389/fpls.2020.573982>
- Farcuh, M., Copes, B., Le-Navenec, G., Marruquin, J., Cantu, D., Bradford, K. J., Guinard, J., & Deynze, A. V. (2020). Sensory, physicochemical and volatile compound analysis of short and long shelf-life melon (*Cucumis melo* L.) genotypes at harvest

- and after postharvest storage. *Food Chemistry: X*, 8, Article 100107. <https://doi.org/10.1016/j.fochx.2020.100107>
- Frick, E. M., & Strader, L. C. (2018). Roles for IBA-derived auxin in plant development. *Journal of Experimental Botany*, 69(2), 169-177. <https://doi.org/10.1093/jxb/erx298>
- Fundo, J. F., Miller, F. A., Garcia, E., Santos, J. R., Silva, C. L. M., & Brandão, C. R. S. (2018). Physicochemical characteristics, bioactive compounds and antioxidant activity in juice, pulp, peel and seeds of *Cantaloupe* melon. *Food Measure*, 12, 292-300. <https://doi.org/10.1007/s11694-017-9640-0>
- Gorni, P. H., Pacheco, A. C., Moro, A. L., Silva, J. F. A., Moreli, R. R., de Miranda, G. R., Pelegrini, J. M., Zaniboni, C. B., Spera, K. D., Junior, J. L. B., & da Silva, R. M. G. (2021). Elicitation improves the leaf area, enzymatic activities, antioxidant activity and content of secondary metabolites in *Achillea millefolium* L. grown in the field. *Journal of Plant Growth Regulation*, 40, 1652-1666. <https://doi.org/10.1007/s00344-020-10217-x>
- Guru, A., Dwivedi, P., Kaur, P., & Pandey, D. K. (2022). Exploring the role of elicitors in enhancing medicinal values of plants under in vitro condition. *South African Journal of Botany*, 149, 1029-1043. <https://doi.org/10.1016/j.sajb.2021.10.014>
- Gusain, R., Pandey, B., & Suthar, S. (2018). Composting as a sustainable option for managing biomass of aquatic weed Pistia: A biological hazard to aquatic system. *Journal of Cleaner Production*, 177, 803-812. <https://doi.org/10.1016/j.jclepro.2017.12.261>
- Habibah, N., Sari, R.N., Nuravivah, V., Komalasari, R., & Nasrudin, N. (2025). Identification of respiratory patterns and quality assessment between melons inodorus and cantalupensis groups. *Current Applied Science and Technology*, 26(1), Article e0264092. <https://doi.org/10.55003/cast.2025.264092>.
- Harvey, C. M., Cavanagh, A. P., Kim, S. Y., Wright, D. A., Edquilang, R. G., Shreeves, K. S., Perdomo, J. A., Spalding, M. H., Ort, D. R., Bernacchi, C. J., & Huber, S. C. (2022). Removal of redox-sensitive Rubisco activase does not alter Rubisco regulation in soybean. *Photosynthesis Research*, 154(2), 169-182. <https://doi.org/10.1007/s11220-022-00962-3>
- Humbal, A., & Pathak, B. (2023). Influence of exogenous elicitors on the production of secondary metabolite in plants: A review ("VSI: secondary metabolites"). *Plant Stress*, 8, Article 100166. <https://doi.org/10.1016/j.stress.2023.100166>
- Hyun, D. Y., Sebastian, R., Lee, G., Lee, K. J., Kim, S., Yoo, E., Lee, S., Kang, M., Lee, S. B., Jang, I., Ro, N., & Cho, G. (2021). Genome-wide SNP markers for genotypic and phenotypic differentiation of melon (*Cucumis melo* L.) varieties using genotyping-by-sequencing. *International Journal of Molecular Sciences*, 22(13), Article 6722. <https://doi.org/10.3390/ijms22136722>
- Indratmi, D., Saati, E. A., Fahmi, I. Z., Purnomo, K. S., & Saputra, H. W. (2024). Use of elicitors weeds to increase the stability of the microenvironment and chili resistance to main pests and yield. *BIO Web of Conferences*, 143, Article 01011. <https://doi.org/10.1051/bioconf/202414301011>
- Jumin, H. B., Mardaleni, M., Vebionita, I., & Jekinda, J. (2025). Net assimilation rate and mean relative growth rate of horticulture plants on swamp land under control of organic compounds. *Current Applied Sciencw and Technology*, 25(4), Article e0259673. <https://doi.org/10.55003/cast.2025.259673>
- Júnior, J. L. B., Ferreira, M. V. S., de-Oliveira, V. S., Saldanha, T., Barbosa, M. I. M. J., Mancini, M. C., & Hubinger, M. D. (2025). Antioxidant capacity, quality attributes, and chemical characterization of commercial orange-fleshed honeydew melons. *Ciência Rural*, 55(2), Article e20240253. <https://doi.org/10.1590/0103-8478cr20240253>
- Li, M., Wang, H., Najm, A. A. K., Othman, B. A., & Law, D. (2024). Effects of molybdenum

- on growth and fruit quality of small fruit melon (*Cucumis melo* L.) cultivated under high-temperature stress. *Acta Scientiarum Polonorum Hortorum Cultus*, 23(4), 41-54. <https://doi.org/10.24326/asphc.2024.5345>
- Liu, Y., He, D., Wu, Y., Zhao, K., Yang, C., Zhong, Y., Yang, L., Niu, H., & Liu, S. (2025). Identification and analysis of melon (*Cucumis melo* L.) SHMT gene family members and their functional studies on tolerance to low-temperature stress. *Agronomy*, 15(1), Article 203. <https://doi.org/10.3390/agronomy15010203>
- Martins, J. V., da Silva, H. F., de Oliveira Sousa, V. F., da Silva, T. I., Dias, T. J., Ribeiro, W. S., & do Nascimento, L. C. (2021). Elicitors increase gas exchanges and induce the *Zea mays* antioxidant system. *Emirates Journal of Food and Agriculture*, 33(11), 958-964.
- Mejía-Guerra, P. A., Salas-Sanjuán, M. C., Martínez-Gallardo, M. R., Jurado, M. M., Estrella-González, M. J., López-González, J. A., Suárez-Estrella, F., & López, M. J. (2025). Microbial biofertilizers and biopesticides from vermicompost tea and rhizosphere of organic soilless melon crop: in vitro assessment. *Biocatalysis and Agricultural Biotechnology*, 63, Article 103453. <https://doi.org/10.1016/j.bcab.2024.103453>
- Mendoza-Pérez, C., Ramírez-Ayala, C., Odeja-Bustamante, W., & Flores-Magdaleno, H. (2017). Estimation of leaf area index and yield of greenhouse-grown poblano pepper. *Ingeniería Agrícola y Biosistemas*, 9(1), 37-50. <https://doi.org/10.5154/r.inagbi.2017.04.009>
- Mibu, R., Choi, Y., Ide, T., Kimura, Y., Takahashi, K., Noda, T., Takayama, K., & Sawada, K. (2025). Quantitative assessment of chl a and b in spinach chl standard solution using a filter-free wavelength sensor. *Sensors and Materials*, 37(4), 1333-1349. <https://doi.org/10.18494/SAM5455>
- Namin, P. G., Zakaria, R. A., Zare, N., & Khezri, M. (2022). Effect of nano-elicitors on the production of some secondary metabolites in hairy roots of Galega (*Galega officinalis* L.). *Agricultural Biotechnology Journal*, 14(3), 171-192. <https://doi.org/10.22103/JAB.2022.18713.1363>
- Nasrudin, N., Nurhidayah, S., & Dwiyani, M. (2025). Evaluation of organic matter enhancing the agro-physiological traits of rice cv. Banyuasin planted under saline conditions. *Current Applied Science and Technology*, 25(2), Article e0261325. <https://doi.org/10.55003/cast.2024.261325>
- Nasrudin, N., Rosmala, A., & Wijoyo, R. B. (2022). Application of silica nutrients improves plant growth and biomass production of paddy under saline conditions. *Caraka Tani: Journal of Sustainable Agriculture*, 37(1), 111-122. <https://doi.org/10.20961/carakatani.v37i1.43425>
- Nguyen, H. C., Melo, A. A., Kruk, J., Frost, A., & Gabruk, M. (2021). Photocatalytic LPOR forms helical lattices that shape membranes for chlorophyll synthesis. *Nature Plants*, 7(4), 437-444. <https://doi.org/10.1038/s41477-021-00885-2>
- Perotti, M. F., Posé, D., & Martín-Pizarro, C. (2023). Non-climacteric fruit development and ripening regulation: 'the phytohormones show.' *Journal of Experimental Botany*, 74(20), 6237-6253. <https://doi.org/10.1093/jxb/erad271>
- Porker, K., Straight, M., & Hunt, J. R. (2020). Evaluation of G x E x M interactions to increase harvest index and yield of early sown wheat. *Frontiers in Plant Science*, 11, Article 994. <https://doi.org/10.3389/fpls.2020.00994>
- Punia, H., Tokas, J., Malik, A., Satpal, S., Rani, A., Gupta, P., Kumari, A., Mor, V. S., Bhuker, A., & Kumar, S. (2020). Solar radiation and nitrogen use efficiency for sustainable agriculture. In S. Kumar, R. S. Meena, & M. K. Jhariya (Eds.). *Resources use efficiency in agriculture*. Springer. https://doi.org/10.1007/978-981-15-6953-1_6
- Ren, J., Zhang, N., Liu, X., Wu, S., & Li, D. (2022). Dynamic harvest index estimation of winter wheat based on UAV hyperspectral remote sensing considering crop aboveground biomass change and the grain filling process. *Remote Sensing*, 14(9), Article 1955. <https://doi.org/10.3390/rs14091955>

- Sheteiwiy, M. S., Ulhassan, Z., Qi, W., Lu, H., AbdElgawad, H., Minkina, T., Sushkova, S., Rajput, V. D., El-Keblawy, A., Joško, I., Sulieman, S., El-Esawi, M. A., El-Tarabily, K. A., AbuQamar, S. F., Yang, H., & Dawood, M. (2022). Association of jasmonic acid priming with multiple defense mechanisms in wheat plants under high salt stress. *Frontiers in Plant Science*, *13*, Article 886862. <https://doi.org/10.3389/fpls.2022.886862>
- Siddique, Z. S., Nida, K., Umar, M., Abideen, Z., Irshad, K., & Yong, J. W. H. (2025). Scrutinizing the role of two distinct elicitors modulating light harvesting potential, specific energy fluxes and physiological tolerance in maize plants under sub-optimal environment. *South African Journal of Botany*, *180*, 207-218. <https://doi.org/10.1016/j.sajb.2025.03.012>
- Simkin, A. J., Kapoor, L., Doss, C. G. P., Hofmann, T. A., Lawson, T., & Ramamoorthy, S. (2022). The role of photosynthesis related pigments in light harvesting, photoprotection and enhancement of photosynthetic yield in planta. *Photosynthesis Research*, *152*, 23-42. <https://doi.org/10.1007/s11120-021-00892-6>
- Song, Q., Liu, Y., Pang, J., Yong, J. W. H., Chen, Y., Bai, C., Gille, C., Shi, Q., Wu, D., Han, X., Li, T., Siddique, K. H. M., & Lambers, H. (2020). Supplementary calcium restores peanut (*Arachis hypogaea*) growth and photosynthetic capacity under low nocturnal temperature. *Frontiers in Plant Science*, *10*, Article 01637. <https://doi.org/10.3389/fpls.2019.01637>
- Stasinska-Jakubas, M., Hawrylak-Nowak, B., Dresler, S., Wojciak, M., & Rubinowska, K. (2023). Application of chitosan lactate, selenite, and salicylic acid as an approach to induce biological responses and enhance secondary metabolism in *Melissa officinalis* L. *Industrial Crops and Products*, *205*, Article 117571. <https://doi.org/10.1016/j.indcrop.2023.117571>
- Sun, W., & Shahrajabian, M. H. (2025). Biostimulant and beyond: *Bacillus* spp., the important plant growth-promoting rhizobacteria (PGPR)-based biostimulant for sustainable agriculture. *Earth Systems and Environment*, *24*, 1-34. <https://doi.org/10.1007/s41748-024-00552-4>
- Tian, M., Yu, R., Guo, S., Yang, W., Liu, S., Du, H., Liang, J., & Zhang, X. (2024). Effect of vermicompost application on the soil microbial community structure and fruit quality in melon (*Cucumis melo*). *Agronomy*, *14*(11), Article 2536. <https://doi.org/10.3390/agronomy14112536>
- The Soil and Fertilizer Instrument Standard Testing Center Indonesia. (2023). *Teknis Edisi 3 Analisis Kimia Tanah, Tanaman Air dan Pupuk* (3rd ed.). Kementerian Pertanian Republik Indonesia.
- Tzuri, G., Dafna, A., Itzhaki, B., Halperin, I., Oren, E., Isaacson, T., Faigenboim, A., Yeselson, Y., Paris, H. S., Mazourek, M., Burger, J., Schaffer, A. A., & Gur, A. (2025). Meta genetic analysis of melon sweetness. *Theoretical and Applied Genetics*, *138*, Article 68. <https://doi.org/10.1007/s00122-025-04863-6>
- Umam, S., Pandjung, R., & Jayadi, M. (2025). Toward greener harvests: unveiling the synergistic effects of biochar and biosaka on sweet corn (*Zea mays saccharata*) growth, yield, and physiology. *BIO Web of Conferences*, *158*, Article 03010. <https://doi.org/10.1051/bioconf/202515803010>
- Verma, S. K., Singh, D., & Shyam, P. (2024). Elicitation of secondary metabolites from plants. In A. Kumar, & S. Kumar (Eds.). *Secondary Metabolites and Biotherapeutics*, (pp. 127-159). Academic Press. <https://doi.org/10.1016/B978-0-443-16158-2.00009-4>
- Vráblová, M., Vrábli, D., Hronková, M., Kubásek, J., & Šantrůček, J. (2017). Stomatal function, density and pattern, and CO₂ assimilation in *Arabidopsis thaliana* tmm1 and sdd1-1 mutants. *Plant Biology*, *19*(5), 689-701. <https://doi.org/10.1111/plb.12577>
- Wang, Y., Li, P., Sun, W., & Zhang, T. (2024). Plant cell walss: emerging targets of stomata engineering to improve photosynthesis and water use efficiency. *New Crops*, *1*, Article 10021. <https://doi.org/10.1016/j.ncrops.2024.100021>

- Wang, C., Jiang, H., Gao, G., Yang, F., Guan, J., & Qi, H. (2023a). CmMYB44 might interact with CmAPS2-2 to regulate starch metabolism in oriental melon fruit. *Plant Physiology and Biochemistry*, *196*, 361-369. <https://doi.org/10.1016/j.plaphy.2023.01.047>
- Wang, X., Ma, Y., Xu, Q., Shikov, A. N., Pozharitskaya, O. N., Flisyuk, E. V, Liu, M., Li, H., Vargas-Murga, L., & Duez, P. (2023b). Flavonoids and saponins: what have we got or missed? *Photomedicine*, *109*, Article 154580. <https://doi.org/10.1016/j.phymed.2022.154580>
- Wang, Z., Liu, Q., Wu, J., Li, J., He, J., Zhang, Y., & Li, S. (2020). Downregulating VAC14 in guard cells causes drought hypersensitivity by inhibiting stomatal closure. *Frontiers in Plant Science*, *11*, Article 602702. <https://doi.org/10.3389/fpls.2020.602701>
- Yang, J., & Zhang, J. (2023). Simultaneously improving grain yield and water and nutrient use efficiencies by enhancing the harvest index in rice. *Crop and Environment*, *2*(3), 157-164. <https://doi.org/10.1016/j.crope.2023.07.001>
- Zhang, H., Dai, P., Gao, X., Li, H., Zhai, R., Yang, C., Wang, Z., & Xu, L. (2024). Gibberellin acid 4 and 7 increase indole-3-acetic acid production and induce cell division via PbCRF4-mediated activation of PbYUCCA6 expression in 'Dangshansu' pear. *Scientia Horticulturae*, *327*, Article 112858. <https://doi.org/10.1016/j.scienta.2024.112858>
- Zhu, J., Yu, Q., Xu, C., Li, J., & Qin, G. (2018). Rapid estimation of stomatal density and stomatal area of plant leaves based on object-oriented classification and its ecological trade-off strategy analysis. *Forests*, *9*(10), Article 616. <https://doi.org/10.3390/f9100616>