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Effects of Ethephon and Fertilization on Latex Physiology and Rubber Yield in GT1, BPM 24, PB260 and IRR112 Clones

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Abstract

This study was conducted to evaluate the effects of ethephon stimulation and fertilization on latex production and physiological latex in different clones. This study was conducted in the experimental field of the Indonesian Rubber Research Institute in South Sumatra. The experiment was laid out in a randomized complete block design with three replications. The main block is the rubber clones, and the subblocks are fertilization rate and ethephon stimulation. The rubber clones for this research were GT 1, BPM 24, PB 260, and IRR 112. The different fertilization rates used in the experiment were control (no fertilizer), 50% recommended rate (50 RR), 100% recommended rate (100 RR), and 150% recommended rate (150 RR). Ethephon stimulation was applied every two months during the observation period with a rate of S/2 d3 ET2.5% 6/y. The observed parameters included: latex yield, physiological latex (sucrose, inorganic phosphorus, and thiol), and tapping panel dryness. Results showed that rubber yields, such as latex production and dry rubber content, increased by 10%–16% with fertilization and ethephon stimulation. Latex characteristics, including thiol, inorganic phosphate, and sucrose, remained within their optimal ranges, with thiol levels increasing from 0.11 to 0.29 mM, inorganic phosphate from 7.29 to 1.58 mM, and sucrose from 0.42 to 7.12 mM upon fertilization.

Keywords: clones, fertilizer, latex production, stimulation

Introduction

Rubber is one of the important commodities of the Indonesian economy. Indonesia is the second largest rubber producer after Thailand with a production share of about twice of the world's total production (Statistics Indonesia, 2019). In 2016, the total rubber plantation area in Indonesia were 3,696,245 ha with a total production of 3,153,186 tons. The value of rubber export in 2016 amounted to US$ 4,741,574,00 (Statistics Indonesia, 2017). Rubber plantations in Indonesia are classified into smallholders (85%), government estates (7%), and private estates (8%). The low productivity of rubber in Indonesia is due to low-quality planting material, suboptimal land management, and poor maintenance of productive plants, including inadequate fertilization. Low maintenance of rubber plants will result in low latex production. Efforts to improve rubber production have included the use of high-quality planting material and stimulants to enhance latex metabolism. However, the physiological response to stimulants varies among clones. The application of stimulants should be referred to plant physiological properties, which are associated with latex-forming metabolism. Latex properties will serve as the basis for determining the maximum limit for each clone to reach its production capacity. For example, optimal thiol levels indicate sufficient antioxidant capacity to sustain prolonged latex flow, adequate inorganic phosphate levels reflect active energy metabolism, and balanced sucrose levels indicate efficient assimilate supply. Thiol

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compounds such as glutathione can maintain redox balance and prevent coagulation of rubber particles, thus supporting continuous latex flow (Chrestin, 1989; d'Auzac et al., 1997). Ethylene (commonly applied as ethephon) increases and prolongs latex flow by stimulating latex cell metabolism, enhancing sucrose uptake, and delaying vessel plugging (Chrestin, 2001; Jacob et al., 1989). Stimulating PB 260 with ethephon stimulation can disrupt the growth and development of latex cells. While RRIM 600 and PB 217 include moderate and low metabolic clones that are responsive to stimulation, in the long term the use of stimulants does not have a negative effect on latex cells (Lacote et al., 2010). A stimulant is a growth regulator that can increase metabolism, thereby boosting latex yield. The use of ethephon stimulants has been widely applied by large rubber plantations to increase latex production. The action is achieved by prolonging latex flow and hindering the blockage of latex vessels (Krishnakumar et al., 2011). The use of superior rubber clones requires a higher amount of fertilizer. Using high-yield clones will increase nutrient depletion from the soil, which in turn requires higher additional nutrients through fertilization. Fertilization based on nutrient analysis will yield positive results for latex production and the health of rubber plants. George and Jacob (2000) stated that soil nutrient reserves and fertilizer requirements can vary considerably across clones. This study aimed to evaluate the effects of ethephon stimulation and fertilization on latex yield and physiological latex characteristics in different rubber clones.

Materials and Methods

This study was conducted in the experimental field of the Indonesian Rubber Research Institute in South Sumatra from September 2018 to August 2019. The field is situated in 2.9275° South and 104.5386° East. The rubber clones used in research were GT 1, BPM 24, PB 260, and IRR 112. They have been planted since 2011 at a spacing of 6 m x 3 m. Routine soil analysis was carried out and served as a basis for fertilizer application. Based on the initial soil and leaves analysis, the recommended dosage of fertilizers per tree was 510 g Urea (46% N), 200 g SP (super phosphate) (36% P_2O_5), and 400 g KCl (potassium chloride) (60% K_2O). Different fertilization rates were used in the experiment: control (no fertilizer), 50% of the recommended rate (50 RR), 100% of the recommended rate (100 RR), and 150% of the recommended rate (150 RR). Ethephon stimulation was applied every two months during the observation period with a rate of S/2 d3 ET2.5% 6/y (half spiral cut, tapped downward every three days with ethephon stimulation of 2.5% active ingredient and application 1g per tree on the groove, six times per year at a monthly interval). The experiment was arranged as a randomized complete block design (RCBD) with three replications. The main plots were the rubber clones, while the subplots consisted of combinations of fertilization rates and ethephon stimulation treatments. The observed parameters included latex yield, physiological latex (sucrose, inorganic phosphorus, and thiol), and tapping panel dryness. Latex yield per tree per tapping day was measured by weighing fresh latex. Total solid content (TSC) was measured using the Chee method, as defined by formula 1:

$$TSC = \frac{DW}{FW} x\ CF\ x\ 100\% \text{ ....1)}$$

Where: DW = dry weight, FW = fresh weight, and CF = the correction factor value at 0.72.

A spectrophotometer (SpektrAA 55B, Varian) was used to measure sucrose, inorganic phosphorus, and thiol concentrations at 627, 750, and 412 nm, respectively. Every latex sample (1 ml) was taken and prepared in 9 ml TCA 2.5% (trichloroacetic acid) to separate C serum (the cytoplasmic fraction of latex obtained after centrifugation, containing soluble metabolites such as sugars, inorganic phosphorus, and thiols). The sucrose content was analyzed using the Anthrone method (Yemm & Willis, 1954). The levels of inorganic phosphorus were determined by binding ammonium molybdate, reduced by $FeSO_4$, in acid (Taussky & Shorr, 1953). Thiol levels were measured based on the reaction

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with dithiol-bis-nitrobenzoic acid (DTNB), which forms the TNB yellow. The dry cut length was estimated visually and then expressed as a percentage range (Table 1). Dry cut refers to the portion of the tapping cut where no latex exudes after tapping, indicating partial obstruction or coagulation in the latex vessels. This condition is associated with tapping panel dryness (TPD), a physiological disorder in rubber trees characterized by the reduction or complete cessation of latex flow due to metabolic or structural dysfunction in the laticifers (d'Auzac et al., 1997).

Results and Discussion

Latex Yield

The analysis of variance indicated a significant three-way interaction among rubber clones, ethephon stimulation, and fertilizer rates for latex yield in March, April, and May 2019 ($p \leq 0.05$). These months coincided with periods of active latex production, suggesting that the combined effects of clone physiology, stimulation, and nutrient availability strongly influenced yield performance. Although higher fertilizer rates (150 RR) occasionally produced the highest yields, the yield efficiency per unit of fertilizer applied often favored lower rates such as 50 RR or 100 RR, particularly when combined with a responsive clone (BPM 24) under stimulation.

Latex production is measured as the average dry rubber production per month (grams per tree tapped, g/t/t). Production in March, April, and May in 2019 showed significant differences among treatments for clones, fertilization, and stimulation (Figure 1). Assimilates from photosynthesis are used for growth and latex production, mainly as sucrose (Chantuma et al., 2006; Silpi et al., 2006). In March, the highest yield was observed in the treatment of the IRR 112 clone with 50 RR and ethephon stimulation at 57.55 g/t/t, and the lowest in the PB 260 clone with 50 RR and without ethephon stimulation. In April and May, the highest yields were observed in BPM 24 clone with 150 RR and with ethephon stimulation and IRR 112 clone with 50 RR and with ethephon stimulation at 77.72 g/t/t and 77.37 g/t/t, respectively. The lowest yield in April and May was observed in the treatment of the PB 260 clone with control fertilizer and with ethephon stimulation at 36.55 g/t/t and 29.50 g/t/t, respectively. Based on these results, fertilizer and stimulant increased latex production. BPM 24 clone is a medium starter clone that responds to added stimulants. Stimulants affect latex cell metabolism, as reflected in various physiological changes. Growth and latex production are negatively correlated; as growth increases, latex production tends to decrease (Silpi et al., 2006). However, each clone has a different ability to mobilize assimilates. The assimilates will be distributed according to sink requirements, with the source-to-sink ratios varying for each clone (Chantuma et al., 2009; Silpi et al., 2007).

Table 1

Scoring System for Tapping Panel Dryness

Score	Tapping panel condition (%)
0	Healthy cut (no dry cut)
1	1%-25% dry cut
2	26%-50% dry cut
3	51%-75% dry cut
4	76%-100% dry cut

Notes. Experimental data was analyzed using SAS programs (version 9.0) and mean comparison (effect of treatment) were performed using Tukey Significant Difference Test at a 5% level of significance.

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The application of soluble Si enhanced the accumulation of Si and the production of total phenolic compounds (Hadi et al., 2022). Silpi et al. (2006) showed that with stimulants, the total amount of assimilates used for growth and latex production was greater than that without stimulants. The response of rubber plants to fertilization results in higher production than without fertilization. These phenomena were observed in all treatments, with the absence of fertilization resulting in low latex production. The increase in rubber production due to fertilization in the experiment was 21% higher than in plants with no fertilizer application. Melti et al. (2002) reported that N and K fertilization are important for latex production. The plants with N and K fertilization had better growth, leaf nutrient status, and some degree of dry rubber contents and thicker bark.

Dry Rubber Content

The analysis of variance revealed significant interactions among rubber clones, ethephon stimulation, and fertilization rates for dry rubber content (DRC) during March–May 2019 ($p \leq 0.05$). These three-way interactions indicate that the combined effect of clone physiology, stimulation, and nutrient supply influenced latex concentration during peak production months. However, the main effects of fertilizers and stimulants alone showed negligible differences in most months, suggesting that DRC is relatively stable unless driven by strong genotype-by-treatment interactions. From October 2018 to August 2019, clone and stimulant effects were more significant than fertilizer effects. High DRC values are economically advantageous because they increase the amount of marketable dry rubber per unit of harvested latex. For example, an increase in DRC from 28% to 32% under optimal clone–stimulation combinations translate to approximately a 14% increase in dry rubber yield from the same volume of latex. This improvement directly enhances revenue potential without increasing tapping frequency or input costs.

Observation of dry rubber content was carried out using the gravimetric method every month (%). Dry rubber content in March, April, and May showed significant differences due to the interaction among the variables (rubber clones, fertilization, and ethephon stimulation) (Figure 2). One parameter closely related to latex flow is dry rubber content (Krishnakumar et al., 2011). The highest dry rubber content in March, April, and May was found in BPM 24 clone treatment with control fertilizer and with 57.86% ethephon stimulation; IRR 112 clone with 50 RR and with 56.53% ethephon stimulation; BPM 24 clone with 50 RR and with 55.57% ethephon stimulation, respectively. The lowest dry rubber content in March, April, and May was observed in PB 260 clone with 150 RR and without 47.90% ethephon stimulation; GT 1 clone with 100 RR and with 46.24% ethephon stimulation; IRR 112 clone with 50 RR and without 46.93% ethephon stimulation, respectively. However, the decreasing level of dry rubber due to stimulant use is still within normal limits (Chotiphan et al., 2019; Thanh et al., 2006). Most P fractions varied seasonally at different soil depths (Liu et al., 2018). These conditions indicate that key physiological processes supporting latex regeneration—such as sucrose supply, energy metabolism (inorganic phosphate levels), and antioxidant capacity (thiol levels)—remain within optimal ranges, suggesting that the functionality of latex vessels has not been compromised. Generally, based on observations after a 1-year experimental period, dry rubber content levels tend to be higher in the treatment with additional stimulants. An appropriate fertilizer application rate can improve soil conditions and increase yields (Geng et al., 2019). Stimulation is more effective in increasing production by influencing latex flow and regeneration. The production increase is due to increased latex flow, thereby expanding latex drainage. This condition is associated with an increase in the stability of lutoid, which delays the blockage of latex vessels. Decay rate of fine root litter was slower than that of leaf litter (Bonanomi et al., 2021; Wen et al., 2022).

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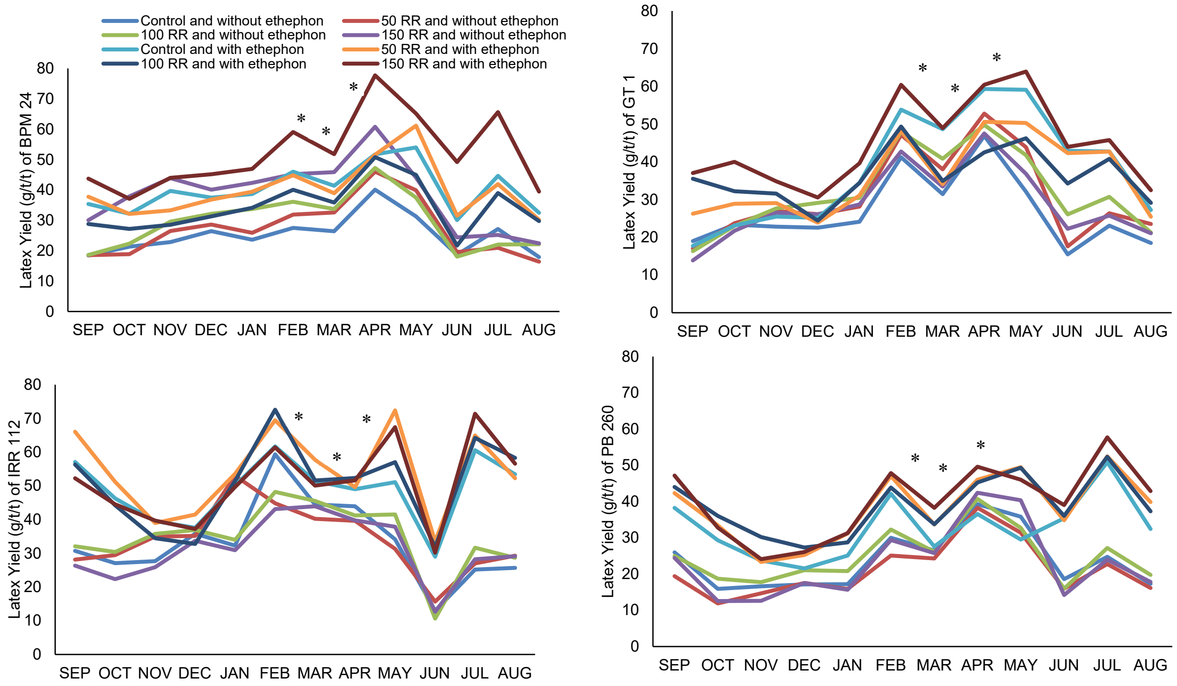
Figure 1

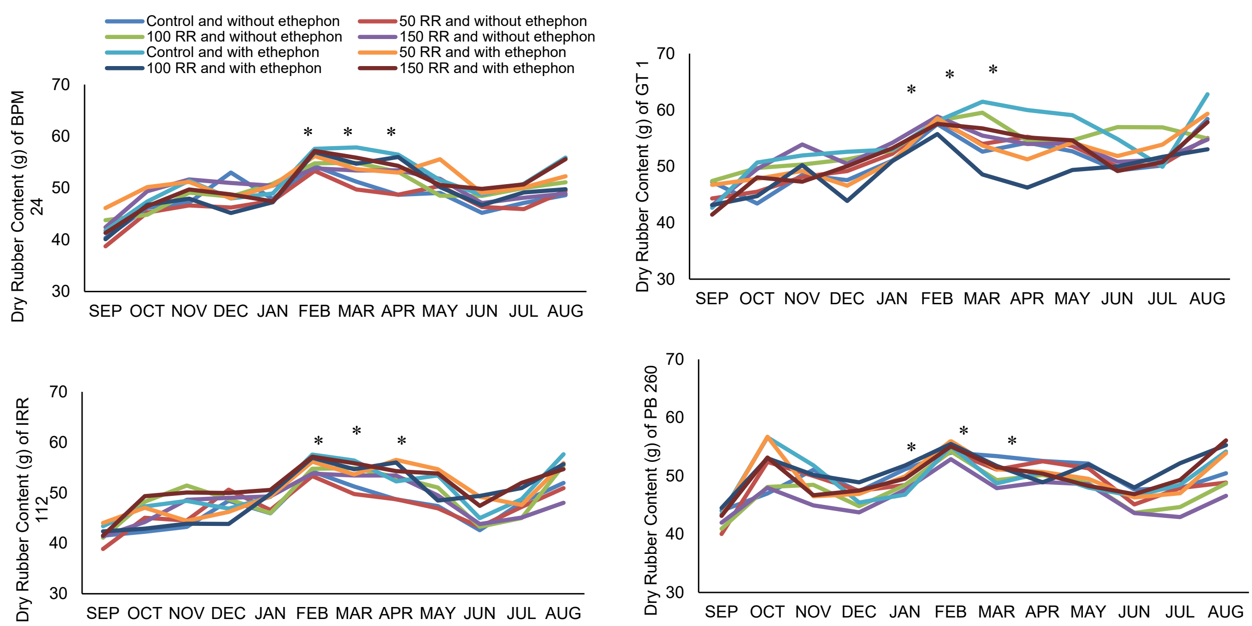
Latex Yield (grams per tree tapped) of BPM 24, GT 1, IRR 112, and PB 260 Clones as Affected by the Application of Fertilization and Stimulation



Note. * = Significant according to Tukey test at 5% level of significance.

Figure 2

Dry Rubber Content (%) of BPM 24, GT 1, IRR 112, and PB 260 Clones as Affected by Fertilization and Ethephon Stimulation



Note. * = Significant according to Tukey test at 5% level of significance.

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Latex Physiological Thiol

A significant interaction was observed among rubber clones, ethephon stimulation, and fertilization on thiol content. This three-way interaction significantly affected thiol content in September 2018. In contrast, fertilizer and stimulation treatments alone had relatively minor effects across most months. Monthly thiol content was determined from fresh latex samples collected in the field and analyzed in the laboratory. The analysis showed that clone differences were consistently significant across several months in both 2018 and 2019, indicating a strong genetic influence on thiol levels relative to the effects of fertilizers or stimulants. There were significant differences in thiol content due to treatment in a given year of application (Figure 3). The IRR 112 clone with 100 RR and without ethephon stimulation had the greatest thiol content of 0.29 mM. The lowest was in the PB 260 clone with control fertilizer and without ethephon stimulation, at 0.11 mM. Fertilization and stimulation result in a higher thiol content than control over the course of a year of observation. Thiols are indicators of the tapping panel's dryness and of plants' (active oxygen species) ability to prevent free radicals. With optimum thiol levels in BPM 24, GT 1, and IRR 112 clones, the intensity of tapping panel dryness with stimulation was categorized as moderate, while PB 260, which showed tapping panel dryness intensity with stimulation for 12 months, was categorized as quite high. Harvest residues in young trees are generally distributed more uniformly, which can improve the potential for nutrient release and subsequent uptake over time. Composite films packaging treatment reduced the decay rate and weight loss rate of blueberries during storage (Liu et al., 2024). High-frequency stimulation is feared in the long term due to its metabolic disorders in latex biosynthesis, which may lead to latex vessel fatigue (Krishnakumar et al., 2011; Lacote et al., 2010). Thus, fertilizer type was used to overcome these limitations (Wang et al., 2021; Wang et al., 2023).

Inorganic Phosphate

There was a significant interaction between rubber clones, ethephon stimulation, and fertilization on inorganic phosphate levels in latex. This effect was most noticeable in September 2018. In contrast, the individual effects of fertilizer and stimulation were generally smaller. Inorganic phosphate levels were measured monthly by collecting fresh latex samples and analyzing them in the laboratory.

There was a significant difference in inorganic phosphate content among treatments in a year of application (Figure 4). The IRR 112 clone treated with 150 RR and with ethephon stimulation gave the highest inorganic phosphate content at 7.29 mM, and the treatment of the GT 1 clone with 100 RR and without ethephon stimulation gave the lowest inorganic phosphate with a value of 1.58 mM. The inorganic phosphate content from September to April has increased and decreased on May. PB 260 clone appears to have a different pattern in treatment without fertilization and without ethephon stimulation in inorganic phosphate content, with a higher level than that of BPM 24, GT 1, and IRR 112 clones. Inorganic phosphate levels in the PB 260 clone were observed to be highest (without ethephon stimulation), and the additional stimulation was unable to increase energy for latex synthesis. Fig. 5 shows the trend in inorganic phosphate content across clones. Inorganic phosphate content in all clones showed a positive trend following fertilizer application. PB 260 provides the highest response in inorganic phosphate content in May. Figure 6 showed that ethephon stimulation resulted in a higher inorganic phosphate content than without ethephon stimulation. Inorganic phosphate levels show intensity of metabolic activity in latex vessels (Lacote et al., 2010). A high frequency of stimulants is feared in the long run, causing metabolic disorders in latex biosynthesis. Further effects result in fatigue of latex vessels (Krishnakumar et al., 2011; Lacote et al., 2010). Cuticular wax rod-like structure and delayed wax degradation (Liu et al., 2023) and increasing the SOC content in the long term (Bai et al., 2024; Cheng et al., 2023).

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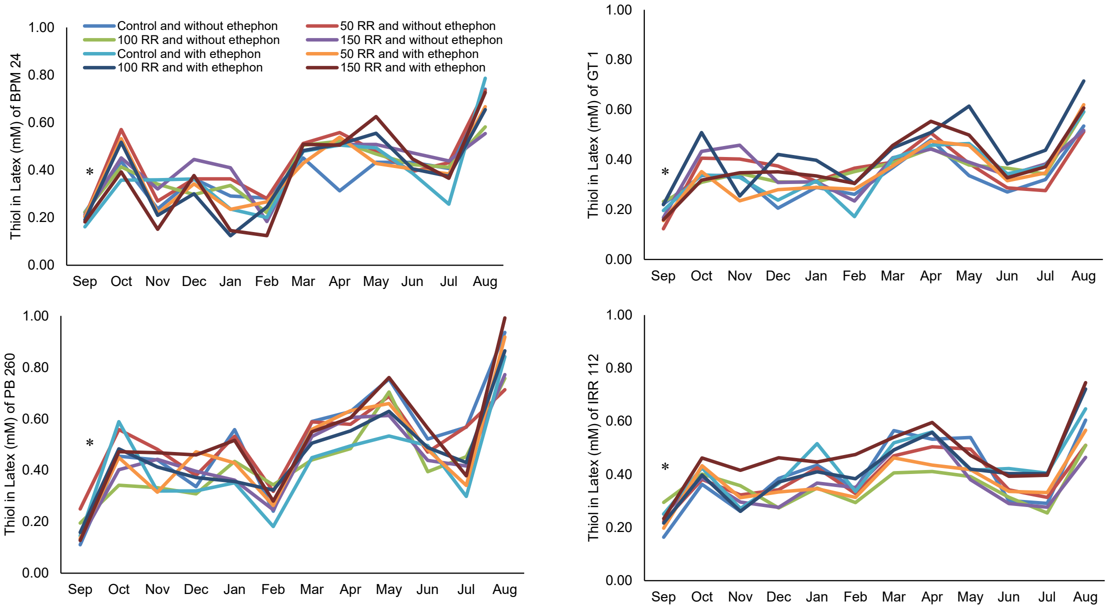
Figure 3

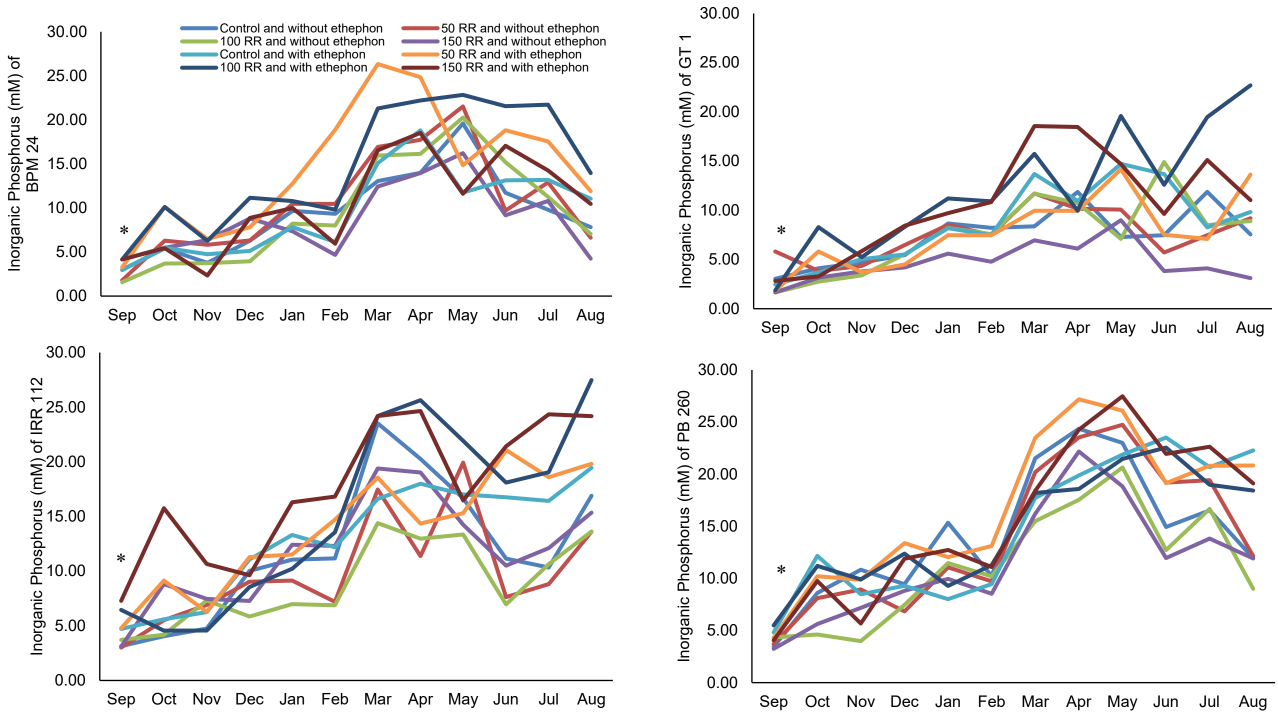
Thiol (mM) Content of BPM 24, GT 1, IRR 112 and PB 260 Clones in Latex as Affected by Fertilization and Ethephon Stimulation



Note. * = Significant at 5% level of significance.

Figure 4

Inorganic Phosphate (mM) Content of BPM 24, GT 1, IRR 112 and PB 260 Clones in Latex as Affected by Fertilization and Ethephon Stimulation



Note. * = Significant according to Tukey test at 5% level of significance.

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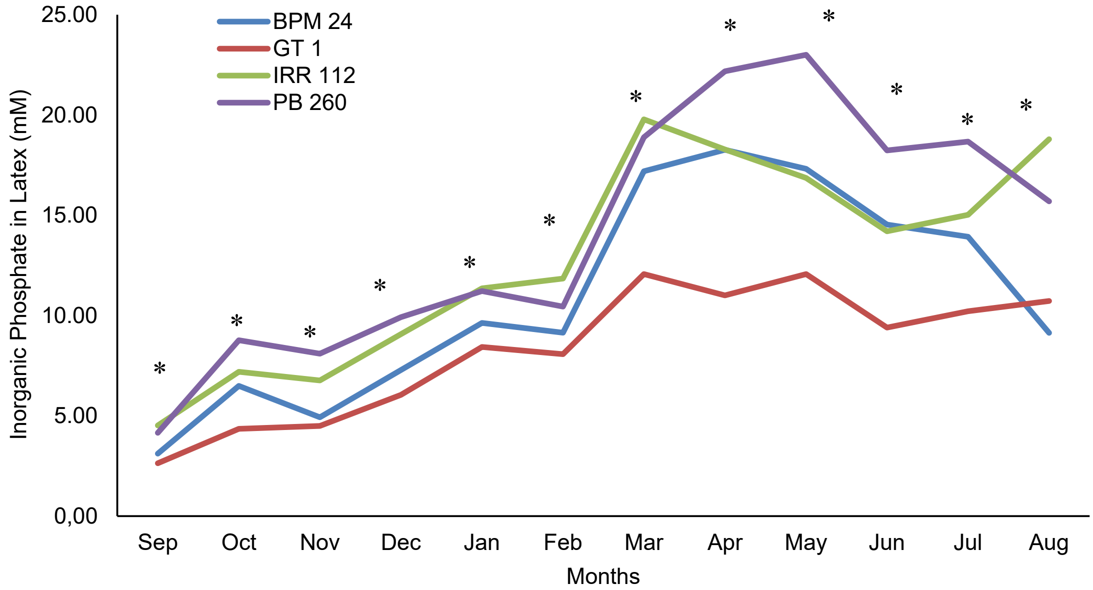
Figure 5

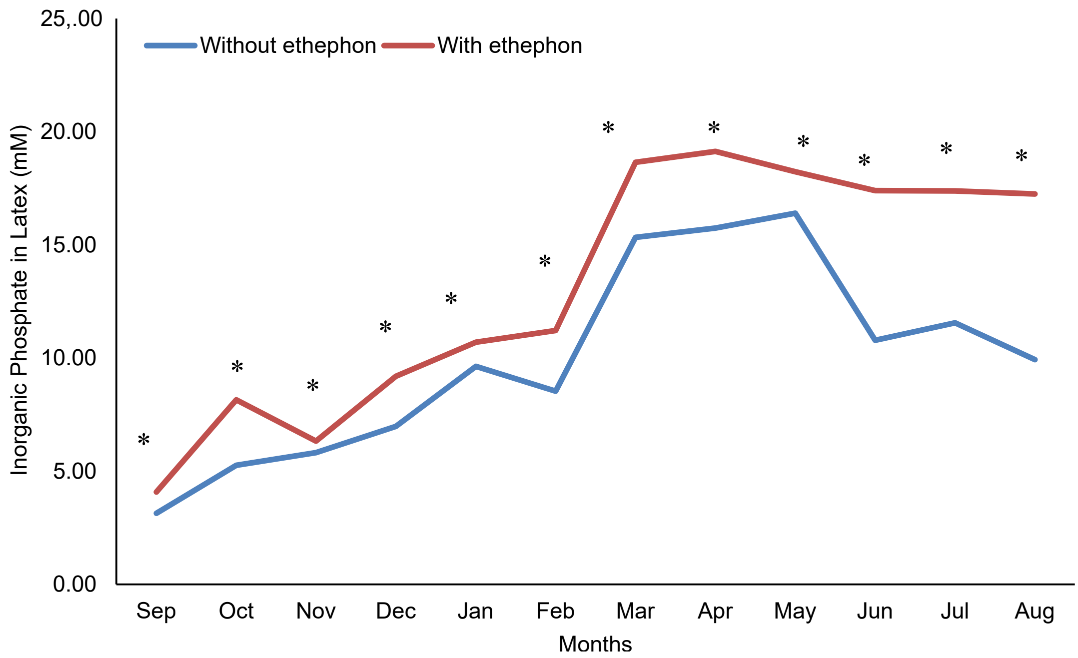
Inorganic Phosphate (mM) Content in Latex as Affected by Clone



Note. * = Significant according to Tukey Test at 5% level of significance.

Figure 6

Inorganic Phosphate (mM) Content in Latex as Affected by Stimulation



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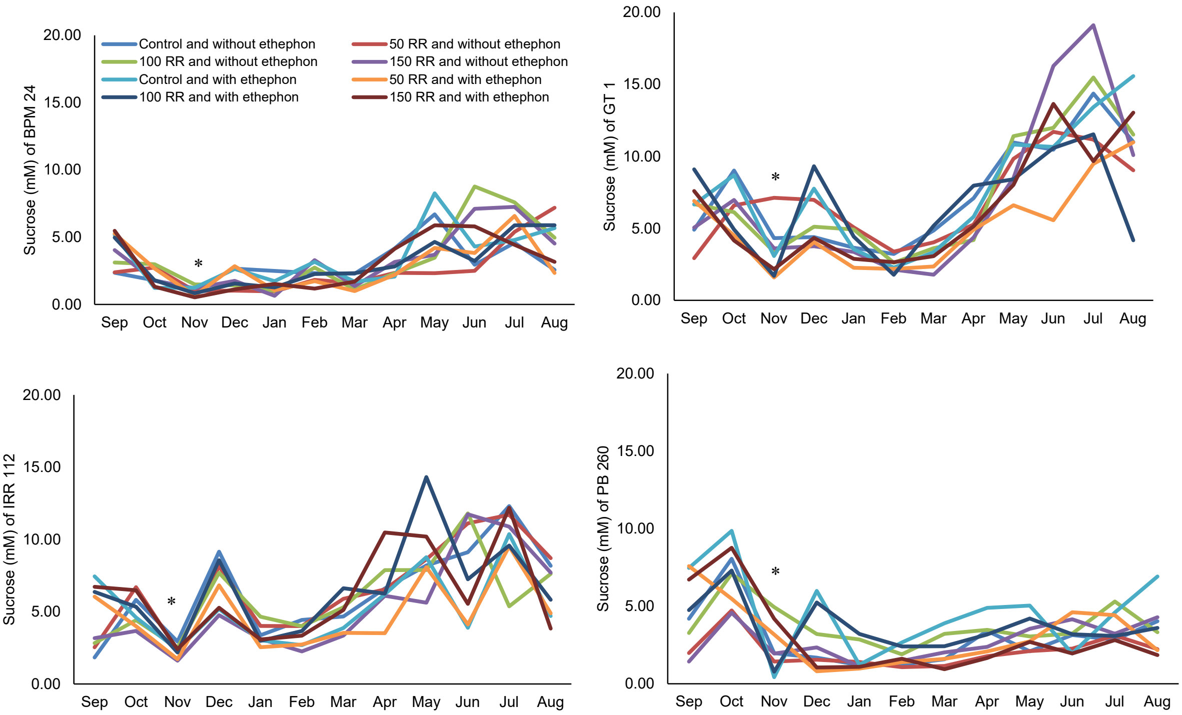
Sucrose

There is a significant interaction effect between variables (rubber clones, ethephon stimulation, and fertilization) on sucrose content. The interaction of the three treatments resulted in a significant difference in sucrose content in November 2018. Fertilizers and stimulation interacted less. Observation of sucrose content was carried out monthly by collecting fresh latex samples in the laboratory for analysis.

There was a significant difference observed between the sucrose content of treatment in a year of application (Figure 7). The treatment of GT 1 clone with 50 RR and without ethephon stimulation gave the highest sucrose content yield at 7.12 mM, and the lowest was in PB 260 clone with control fertilizer and with ethephon stimulation of 0.42 mM. N fertilizer application rate affects agronomic and environmental responses (Bronson et al., 2021). Observation of sucrose content over the year showed an increasing pattern from January to July. PB 260 clones have lower sucrose content compared to BPM 24, IRR 112, and GT 1 clones. However, based on the latex yield, the PB 260 clone exhibited high latex production even without ethephon stimulation. Without ethephon stimulation, the PB 260 clone has produced high output with high inorganic phosphate content and low sucrose content. This indicates that the PB 260 clone does not experience obstacles in latex regeneration. The low sucrose levels in the PB 260 clone do not support the use of stimulation. PB 260 clone exhibits flow resistance, indicating high dry rubber content, so stimulation at low frequency (≤6/y) can reverse these effects. Figure 8 showed an upward trend in sucrose content in all evaluated clones. GT 1 clone showed a positive trend from February to July. GT 1 clones are classified as clones that respond to stimulant applications. Sucrose is the raw material of cis-polyisoprene synthesis, which is required by latex cells for latex regeneration (Gohet et al.,

Figure 7

Latex Sucrose Content (mM) of BPM 24, GT 1, IRR 112, and PB 260 Clones as Affected by Fertilization and Ethephon Stimulation



Note. * = Significant according to Tukey test at 5% level of significance.

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2003). The excessive application of N fertilizer can increase soil mineral N contents in both first and second seasons of pineapple (Liang et al., 2022). A low sucrose concentration in the latex of PB 260 suggests limited carbohydrate supply to the laticiferous tissue. This limitation could be due to either reduced translocation from photosynthetic organs or higher metabolic consumption within the latex vessels. With stimulant application, latex cell metabolism becomes active, increasing production (Soumahin et al., 2009). Better suspension stability of modified nanochitins under alkaline conditions (Li et al., 2023). Application of organic fertilizer in combination with inorganic fertilizers can increase nutrient uptake (Feng & Zhu, 2021; Sofyan & Sara, 2018). Field management is considered very important to alleviate soil acidification, including increasing straw return and controlling fertilizer application (Dong et al., 2021). Girth size is important in determining the yield and quality of latex (Gashua et al., 2022). Accumulation of sugar components differs significantly between the two varieties, with four CsSPSs identified in citrus (Lu et al., 2024). Sugar content undergoes changes throughout its development and ripening process (Parra-Palma et al., 2024).

Tapping Panel Dryness

There is a significant interaction effect among variables (rubber clones, ethephon stimulation, and fertilization) of tapping panel dryness. The interaction of the three treatments gave significant differences in tapping Panel Dryness in December 2018. Furthermore, clones and stimulations have significant effects on the said parameter during November 2018 and August 2019.

The tapping panel dryness observations were made every month visually, using the score assessment, and the results were then transformed into percentages (Table 2). A significant difference in the tapping panel was observed after a year of treatment. Analysis of stimulants cannot only elucidate plant physiology and production aspects but also reflect the plant's health. After a year of observation, PB 260 clones exhibit greater characteristics of tapping

Figure 8

Latex Sucrose (mM) Content as Affected by Rubber Clones

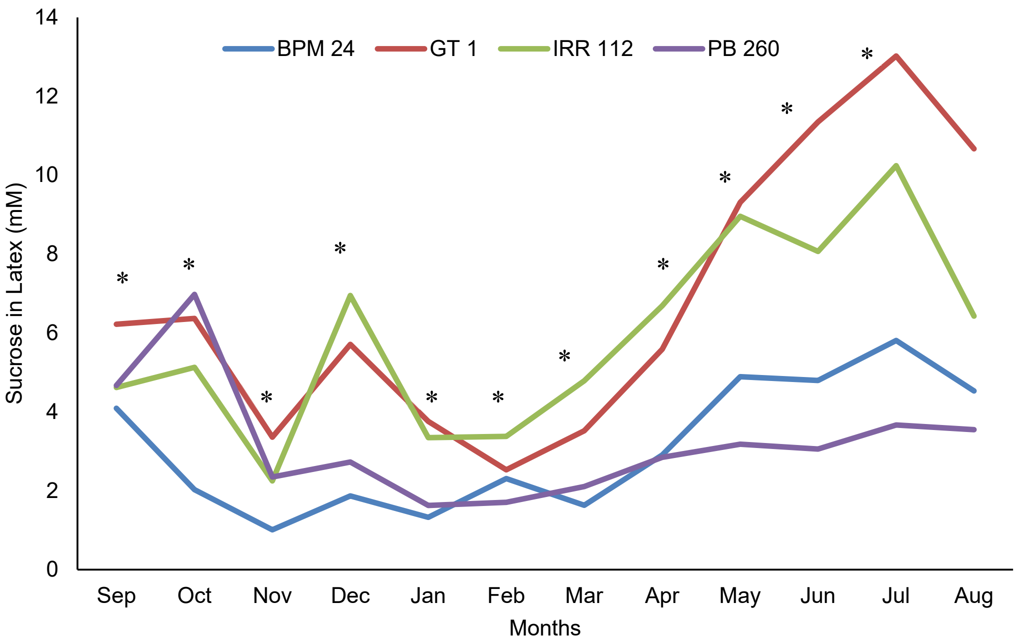

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Table 2

Tapping Panel Dryness (TPD) Measurements for Four Rubber Clones During 12 Months of Observation

Clone	Fertilizer Recom-menda-tion (%)	Stimulation	2018				2019							
			Sep	Oct	Nov	Des	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
BPM 24	0	0/y												
		6/y												
	50	0/y												
		6/y												
	100	0/y												
		6/y												
	150	0/y												
		6/y												
GT 1	0	0/y												
		6/y												
	50	0/y												
		6/y												
	100	0/y												
		6/y												
	150	0/y												
		6/y												
IRR 112	0	0/y												
		6/y												
	50	0/y												
		6/y												
	100	0/y												
		6/y												
	150	0/y												
		6/y												
PB 260	0	0/y												
		6/y												
	50	0/y												
		6/y												
	100	0/y												
		6/y												
	150	0/y												
		6/y												

Notes. light brown, medium brown, and dark brown colors representing 0%–33%, 34%-66%, and 67%–100% of Tapping Panel Dryness (TPD), respectively.

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panel dryness than BPM 24, GT 1, and IRR 112 clones. Provision of stimulation on PB 260 clone has a higher tapping panel dryness risk of 26%-50% compared to other clones. Latex cell metabolism in high metabolic clones (PB 260) is very susceptible to stimulation, which can have a negative impact on plant health (Lacote et al., 2010). Replacing chemical fertilizers with organic fertilizers can reduce soil acidification, nutrient contents, and enzyme activities (P. Liu et al., 2023; Song et al., 2022). BPM 24 and GT 1 clones are classified as moderate and low metabolic clones. Fertilization had a significant effect on tree girth (Mak et al., 2022) and enhanced productivity of winter wheat by increasing the post-anthesis dry matter translocation and accumulation (Xing et al., 2022; Yan et al., 2022). Understory N application treatments were 20%–50% higher than the corresponding canopy treatments (Jiang et al., 2023). Cellulose and hemicellulose tended to increase in the pre-maturation stage (Hu et al., 2024) and low-quality litter that requires a specialized fungal community to maximize decomposition (Pan et al., 2023; Pugnaire et al., 2023).

Conclusions

Rubber yield, such as latex production and dry rubber content, was significantly affected by fertilization and ethephon stimulation. IRR 112, PB 260, and BPM 24 clones with 50-100 RR and with ethephon stimulation have higher yield than the GT 1 clone. Latex characteristics, such as thiol, inorganic phosphate, and sucrose, were optimized within an optimal range upon fertilization. IRR 112, BPM 24, and PB 260 clones with 100-150 RR application and with ethephon stimulation have higher production. The tapping panel dryness parameter was related to the health of rubber plants. The results demonstrate that ethephon stimulants significantly influenced the BPM 24, GT 1, and IRR 112 clones due to increased nutrient availability. GT 1 stimulation can be moderately applied due to its relatively lower yield potential but higher tolerance. In contrast, PB 260 is more sensitive to stimulant application; therefore, stimulation should be applied less frequently (6–9 applications per year) and only during periods of high sucrose content and should be accompanied by a consistent potassium and magnesium supply to support carbohydrate translocation. Such clone-specific management could optimize yield while preserving long-term panel health.

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References

Bai, X., Zhai, G., Wang, B., An, S., Liu, J., Xue, Z., & Dippold, M. A. (2024). Litter quality controls the contribution of microbial carbon to the main microbial groups and soil organic carbon during its decomposition. *Biology and Fertility of Soils, 60*, 167–181. https://doi.org/10.1007/s00374-023-01792-8

Bonanomi, G., Idbella, M., Zotti, M., Santorufo, L., Motti, R., Maisto, G., & Di Marco, A. (2021). Decomposition and temperature sensitivity of fine root and leaf litter of 43 Mediterranean species. *Plant and Soil, 464*, 453–465. https://doi.org/10.1007/s11104-021-04974-1

Bronson, K. F., Hunsaker, D. J., El-Shikha, D. M., Rockholt, S. M., Williams, C. F., Rasutis, D., Soratana, K., & Venterea, R. T. (2021). Nitrous oxide emissions, N uptake, biomass, and rubber yield in N-fertilized, surface-irrigated guayule. *Industrial Crops and Products, 167*, Article 113561. https://doi.org/10.1016/j.indcrop.2021.113561

Chantuma, P., Lacointe, A., Kasemsap, P., Thanisawanyangkura, S., Gohet, E., Clément, A., Guilliot, A., Améglio, T., & Thaler, P. (2009). Carbohydrate storage in the wood and bark of rubber trees submitted to different levels of C demand induced by latex tapping. *Tree Physiology,*

Received 24/10/2024; Revised 14/08/2025; Accepted 14/01/2026
https://doi.org/10.29244/jtcs.13.01.45-60

29(8), 1021–1031. https://doi.org/10.1093/treephys/tpp043

Chantuma, P., Thanisawanyangkura, S., Kasemsap, P., Gohet, E., & Thaler, P. (2006). Distribution patterns of latex sucrose content and concurrent metabolic activity at the trunk level with different tapping systems and in latex production bark of *Hevea brasiliensis*. *Kasetsart Journal: Natural Science, 40*, 634–642.

Cheng, X., Xing, W., & Liu, J. (2023). Litter chemical traits, microbial and soil stoichiometry, regulate organic carbon accrual of particulate and mineral-associated organic matter. *Biology and Fertility of Soils, 59*, 777–790. https://doi.org/10.1007/s00374-023-01746-0

Chrestin, H. (1989). Biochemical basis of latex regeneration and latex flow. *Plant Physiology and Biochemistry, 27*(4), 431–440.

Chrestin, H. (2001). Molecular and physiological regulation of latex production. *Plant Science, 160*(5), 777–788.

Chotiphan, R., Vaysse, L., Lacote, R., Gohet, E., Thaler, P., Sajjaphan, K., Bottier, C., Char, C., Liengprayoon, S., & Gay, F. (2019). Can fertilization be a driver of rubber plantation intensification? *Industrial Crops and Products, 141*, Article 111813. https://doi.org/10.1016/j.indcrop.2019.111813

d'Auzac, J., Jacob, J. L., & Chrestin, H. (1997). *Physiology of rubber tree latex: The laticiferous cell and latex—A model of cytoplasm*. CRC Press.

Dong, Y., Yang, J. L., Zhao, X. R., Yang, S. H., & Zhang, G. L. (2021). Contribution of different proton sources to the acidification of red soil with maize cropping in subtropical China. *Geoderma, 392*, Article 114995. https://doi.org/10.1016/j.geoderma.2021.114995

Feng, J., & Zhu, B. (2021). Global patterns and associated drivers of priming effect in response to nutrient addition. *Soil Biology and Biochemistry, 153*, Article 108118. https://doi.org/10.1016/j.soilbio.2020.108118

Gashua, A. G., Sulaiman, Z., Yusoff, M. M., Samad, M. Y. A., Ramlan, M. F., Salisu, M. A., & Mokhatar, M. S. J. (2022). Potting media made with bokashi compost to improve the growth and biomass accumulation of rubber seedlings. *Journal of Rubber Research, 25*(2), 127–139. https://doi.org/10.1007/s42464-022-00163-6

Geng, Y., Cao, G., Wang, L., & Wang, S. (2019). Effects of equal chemical fertilizer substitutions with organic manure on yield, dry matter, and nitrogen uptake of spring maize and soil nitrogen distribution. *PLoS ONE, 14*(7), Article e0219512. https://doi.org/10.1371/journal.pone.0219512

George, P. J., & Jacob, C. K. (Eds.). (2000). *Natural rubber: Agro-management and crop processing*. Rubber Research Institute, Kottayam, India.

Gohet, E., Chantuma, P., Lacote, R., Obouayeba, S., Dian, K., Demange, A. C., Kurnia, D., & Eschbach, J. M. (2003). *Physiology modelling of yield potential and clonal response to ethephon stimulation*. IRRDB Workshop on Exploitation Technology.

Hadi, S. M. H. S. A., Zakaria, L., Sidique, S. N. M., Mahyudin, M. M., Berahim, Z., Idris, M. A., & Nor, N. M. I. M. (2022). Silicon mediates the changes in physiological performance, nutrient uptake, root colonization morphology and secondary metabolite activity in rubber rootstock seedlings (*Hevea brasiliensis*) inoculated with *Rigidoporus microporus*. *Plant Pathology, 71*, 1956–1968. https://doi.org/10.1111/ppa.13621

Hu, Z., Liu, J., Xu, H., Tian, L., & Liu, D. (2024). Exploring the mechanism of *Lycium barbarum* fruit cell wall polysaccharide remodeling reveals potential pectin accumulation contributors. *International Journal of Biological Macromolecules, 258*, Article 128958. https://doi.org/10.1016/j.ijbiomac.2023.128958

Jacob, J. L., Prévôt, J. C., & Lacrotte, R. (1989). The regulation of latex flow from *Hevea brasiliensis*. *Plant Science, 59*(1), 1–8.

Jiang, W., Zhang, H., Fang, Y., Chen, Y., Zhuo,

Received 24/10/2024; Revised 14/08/2025; Accepted 14/01/2026
https://doi.org/10.29244/jtcs.13.01.45-60

S., Chen, Z., Liang, C., Van, Z. L., Fu, S., Li, Y., Yu, B., Cai, Y., & Chang, S. X. (2023). Understory N application overestimates the effect of atmospheric N deposition on soil N_2O emissions. *Geoderma, 437*, Article 116611. https://doi.org/10.1016/j.geoderma.2023.116611

Krishnakumar, R., Helen, R. L., Ambily, P. K., & Jacob, J. (2011). A modified stimulation method in *Hevea brasiliensis* for reducing oxidative stress. https://tarr.arda.or.th/preview/item/2oHcKY-spUN7PdLTVJjln

Lacote, R., Gabla, O., Obouayeba, S., Eschbach, J. M., Rivano, F., Dian, K., & Gohet, E. (2010). The long-term effect of ethylene stimulation on the yield of rubber trees is linked to latex cell biochemistry. *Field Crops Research, 115*(2), 94–98. https://doi.org/10.1016/j.fcr.2009.10.015

Liang, Z., Jin, X., Zhai, P., Zhao, Y., Cai, J., Li, S., Yang, S., Li, C., & Li, C. (2022). Combination of organic fertilizer and slow-release fertilizer increases pineapple yields, agronomic efficiency and reduces greenhouse gas emissions under reduced fertilization conditions in tropical areas. *Journal of Cleaner Production, 343*, Article 131054. https://doi.org/10.1016/j.jclepro.2022.131054

Li, X., Liu, Y., Chen, F., Liu, L., & Fan, Y. (2023). Facile modification of nanochitin in aqueous media for stabilizing tea tree oil-based Pickering emulsion with prolonged antibacterial performance. *International Journal of Biological Macromolecules, 242*, Article 124873. https://doi.org/10.1016/j.ijbiomac.2023.124873

Liu, C., Jin, Y., Liu, C., Tang, J., Wang, Q., & Xu, M. (2018). Phosphorous fractions in soils of rubber-based agroforestry systems: Influence of season, management, and stand age. *Science of the Total Environment, 616–617*, 1576–1588. https://doi.org/10.1016/j.scitotenv.2017.10.156

Liu, M., Zou, X., Wu, X., Li, X., Chen, H., Pan, F., Zhang, Y., Fang, X., Tian, W., & Peng, W. (2024). Preparation of chitosan/*Tenebrio molitor* larvae protein/curcumin active packaging film and its application in blueberry preservation. *International Journal of Biological Macromolecules, 275*, Article 133675. https://doi.org/10.1016/j.ijbiomac.2024.133675

Liu, P., Guo, X., Zhou, D., Zhang, Q., Ren, X., Wang, R., Wang, X., Chen, X., & Li, J. (2023). Quantify the effect of manure fertilizer addition and optimal nitrogen input on rainfed wheat yield and nitrogen requirement using nitrogen nutrition index. *Agriculture, Ecosystems & Environment, 345*, Article 108319. https://doi.org/10.1016/j.agee.2022.108319

Liu, R., Fanzhen, S., Niu, B., Wu, W., Han, Y., Chen, H., & Gao, H. (2023). Melatonin treatment delays the softening of blueberry fruit by modulating cuticular wax metabolism and reducing cell wall degradation. *Food Research International, 173*, Article 113357. https://doi.org/10.1016/j.foodres.2023.113357

Lu, W., Hao, W., Liu, K., Liu, J., Yin, C., Su, Y., Hang, Z., Peng, B., Liu, H., Xiong, B., Liao, L., He, J., Zhang, M., Wang, X., & Wang, Z. (2024). Analysis of sugar components and identification of SPS genes in citrus fruit development. *Frontiers in Plant Science, 15*, Article 1372809. https://doi.org/10.3389/fpls.2024.1372809

Mak, S., Tiva, L. K., Phearun, P., Gohet, E., Lacote, R., & Gay, F. (2022). Impact of mineral fertilization on the growth of immature rubber trees: New insights from a field trial in Cambodia. *Journal of Rubber Research, 25*(2), 141–149. https://doi.org/10.1007/s42464-022-00164-5

Melti, S. T., Gohain, & Chaudhuri, D. (2002). Response of rubber of *Hevea* to fertilizer in northern West Bengal. *Indian Journal of Natural Rubber Research, 2*, 119–128.

Pan, W., Zhou, J., Tang, S., Wu, L., Ma, Q., Marsden, K. A., Chadwick, D. R., & Jones, D. L. (2023). Utilisation and transformation of organic and inorganic nitrogen by soil microorganisms and its regulation by excessive carbon and nitrogen

Received 24/10/2024; Revised 14/08/2025; Accepted 14/01/2026
https://doi.org/10.29244/jtcs.13.01.45-60

availability. *Biology and Fertility of Soils, 59*, 379–389. https://doi.org/10.1007/s00374-023-01712-w

Parra-Palma, C., Valdes, C., Munoz-Vera, M., Morales-Quintana, L., & Castro, R. I. (2024). Assessing the modifications and degradation of cell wall polymers during the ripening process of *Rubus ulmifolius* Schott fruit. *Journal of Horticultural Science and Biotechnology, 99*, 471–479. https://doi.org/10.1080/14620316.2024.2302515

Pugnaire, F.I., Aares, K.H., Alifriqui, M., Bråthen, K.A., Kindler, C., Schöb, C., & Manrique, E. (2023). Home-field advantage effects in litter decomposition is largely linked to litter quality. *Soil Biology & Biochemistry 184*, 109069. https://doi.org/10.1016/j.soilbio.2023.109069

Silpi, U., Thaler, P., Kasemsap, P., Lacointe, A., Chantuma, A., Adam, B., Gohet, E., Thanisawanyangkura, S., & Ameglio, T. (2006). Effect of tapping activity on the dinamics of radial growth of *Hevea brasiliensis* trees. *Tree Physiology*, *26*, 1579–1587. https://doi.org/10.1093/treephys/26.12.1579

Silpi, U., Lacointe, A., Kasempsap, P., Thanysawanyangkura, S., Chantuma, P., Gohet, E., Musigamart, N., Clément, A., Améglio, T., & Thaler, P. (2007). Carbohydrate reserves as a competing sink: evidence from tapping rubber trees. *Tree Physiology*, *27,* 881–889. https://doi.org/10.1093/treephys/27.6.881.

Song, W., Shu, A., Liu, J., Shi, W., Li, M., Zhang, W., Li, Z., Liu, G., Yuan, F., Zhang, S., Liu, Z., & Gao, Z. (2022). Effects of long-term fertilization with different substitution ratios of organic fertilizer on paddy soil. *Pedosphere*, *32*(4), 637–648. https://doi.org/10.1016/S1002-0160(21)60047-4

Soumahin, E. F., Obouayeba, S., & Anno, P. A. (2009). Low tapping frequency with hormonal stimulation on *Hevea brasiliensis* PB 217 clone to reduces tapping manpower requirement. *Journal of Animal and Plant Sciences*, 2(3), 109–117.

Statistics Indonesia. (2017). *Statistiscs of Indonesia*. https://www.bps.go.id/

Statistics Indonesia. (2019). Indonesian Rubber Statistics 2019. BPS–Statistics Indonesia

Sofyan, E. T., & Sara, D. S. (2018). The effect of organic and inorganic fertilizer applications on N, P and K uptake and yield of sweet corn (*Zea mays* saccharata Sturt). *Journal of Tropical Soils*, *23*(3), 111–116. https://doi.org/10.5400/jts.2018.v23i3.111-116

Taussky, H. H., & Shorr, E. (1953). A microcolorimetric method for the determination of inorganic phosphorus. *Journal of Biological Chemistry*, *202*(2), 675–685.

Thanh, D. K., Van, N. T. H., Nang, N., Thanh, N. T. H., & Sivakumaran, H. (2006). *Preliminary results of the application of ethylene gas stimulation (RRIMFLOW) in Vietnam*. International Natural Rubber Conference. Ho Chi Minh City, Vietnam.

Wang, J., Barański, M., Hasanaliyeva, G., Korkut, R., Kalee, H. A., Leifert, A., Winter, S., Janovska, D., Willson, A., Barkla, B., Iversen, P. O., Seal, C., Bilsborrow, P., Leifert, C., Rempelos, L., & Volakakis, N. (2021). Effect of irrigation, fertiliser type and variety on grain yield and nutritional quality of spelt wheat (*Triticum spelta*) grown under semi-arid conditions. *Food Chemistry*, *358*. https://doi.org/10.1016/j.foodchem.2021.129826

Wang, Z., Tao, T., Wang, H., Chen, J., Small, G.E., Johnson, D., Chen, J., Zhang, Y., Zhu, Q., Zhang, S., Song, Y., Kattge, J., Guo, P., & Sun, X. (2023). Forms of nitrogen inputs regulate the intensity of soil acidification. *Global Change Biol*ogy, 29(14), 4044–4055. https://doi.org/10.1111/gcb.16746

Wen, Z., Wang, R., Li, Q., Liu, J., Ma, X., Xu, W., Tang, A., Collett, J.L., Li, H., & Liu, X. (2022). Spatiotemporal variations of nitrogen and phosphorus deposition across China. *The Science of The Total Environment, 830,* 154740. https://doi.org/10.1016/j.scitotenv.2022.154740

Xing, Y., Zhang, T., Jiang, W., Li, P., Shi, P., Xu, G., Cheng, S., Cheng, Y., Fan, Z., & Wang, X. (2022). Effects of irrigation and

Received 24/10/2024; Revised 14/08/2025; Accepted 14/01/2026
https://doi.org/10.29244/jtcs.13.01.45-60

fertilization on different potato varieties growth, yield and resources use efficiency in the Northwest China. *Agricultural Water Management*, *261*. https://doi.org/10.1016/j.agwat.2021.107351

Yan, S., Wu, Y., Fan, J., Zhang, F., Guo, J., Zheng, J., & Wu, L. (2022). Optimization of drip irrigation and fertilization regimes to enhance winter wheat grain yield by improving post-anthesis dry matter accumulation and translocation in northwest China. *Agricultural Water Management*, *271*. https://doi.org/10.1016/j.agwat.2022.107782

Yemm, E. W., & Willis, A. J. (1954). The estimation of carbohydrates in plant extracts by the anthrone method. *Biochemical Journal*, *57*(3), 508–514.