

# Effects of Fertilizers and Biological Products on Growth and Yield of Laichau Ginseng (*Panax vietnamensis* var. *fuscidiscus* K. Komatsu, S. Zhu & S.Q. Cai)

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## Abstract

Laichau ginseng (*Panax vietnamensis* var. *fuscidiscus* K. Komatsu, S. Zhu & S.Q. Cai) is an endemic medicinal plant with high economic value in northern Vietnam. Understanding optimal cultivation practices is essential for sustainable production. This study evaluated the effects of different fertilizers and biological products on the growth and rhizome weight of three-year-old Laichau ginseng. Five fertilizer treatments (control, Song Gianh bio-fertilizer, arbuscular mycorrhizal fungi, NPK combination, and micronutrients) and six biological control treatments (control, *Trichoderma bacillus*, Emunic, arbuscular mycorrhizal fungi, *Trichoderma* + MF1, and indigenous microorganisms) were tested using a randomized complete block design. Results showed that all fertilizer treatments significantly increased rhizome diameter and weight compared to the control, with Song Gianh bio-fertilizer producing the highest rhizome weight ( $15.8 \pm 1.5$  g). However, no significant differences in vegetative growth parameters were observed among fertilizer treatments. Biological product applications showed minimal effects on growth parameters, though survival rates improved slightly with *Trichoderma* + MF1 treatment (92.2%). These findings provide practical guidance for developing cultivation protocols that balance productivity with sustainability for this valuable medicinal species.

**Keywords:** Arbuscular Mycorrhizal Fungi, Biological Control, Fertilization, Laichau Ginseng, Medicinal Plants, *Panax vietnamensis* var. *fuscidiscus*

## 1. INTRODUCTION

The genus *Panax* L. (Araliaceae) comprises approximately 19 species distributed primarily across eastern Asia and North America, with most species recognized for their exceptional medicinal properties (Yang et al., 2021). These perennial forest herbs have been utilized in traditional medicine systems for centuries, particularly in China, Korea and Vietnam, where they are valued for their adaptogenic, immunomodulatory, and health-promoting effects (Kim, 2018; Li et al., 2022). The pharmacological activities of *Panax* species are primarily attributed to ginsenosides, a diverse group of triterpene saponins, with over 150 different compounds identified to date (Hou et al., 2021; Liu et al., 2020). In Vietnam, the genus *Panax* is represented by three species (*P. vietnamensis*, *P. stipuleanatus*, and *P. bipinnatifidus*) and two varieties (*P. vietnamensis* var. *fuscidiscus* and *P. vietnamensis* var. *langbianensis*). Among these, *Panax vietnamensis* var. *fuscidiscus* K. Komatsu, S. Zhu & S.Q. Cai, commonly known as Laichau ginseng, represents a particularly valuable genetic resource. This variety was first described in 2003 from specimens collected in southern Yunnan Province, China, and Laichau Province, northern Vietnam (Zhu et al., 2003b). Laichau ginseng is distinguished from the typical variety by morphological characteristics, including distinctive dark-spotted fruits when ripe and specific habitat preferences (Phan, 2014). Laichau ginseng naturally occurs in evergreen broadleaved forests at elevations between 1,400 and 2,200 m above sea level, where it grows under dense canopy cover (>70%) on humus-rich, well-drained soils (Pham et al., 2019a). The plant exhibits remarkable medicinal properties, with total saponin content reaching 23.85% in wild specimens, notably higher than cultivated

material (18.48%) and substantially exceeding that of *P. stipuleanatus* (3.00%) (Pham et al., 2019b). Among the bioactive compounds identified in Laichau ginseng, majonoside R2 (MR2) represents a major constituent, with concentrations ranging from 7.04% to 7.78% in roots of different ages. The presence of ginsenosides Rb1, Rc, Rd, Re, and Rg1 has also been confirmed through HPLC analysis (Zhu et al., 2004; 2003a). The exceptional market value of Laichau ginseng rhizomes, ranging from 1,000 to 5,000 USD per kilogram depending on age and size, has generated significant interest in cultivation among local communities in mountainous regions of northern Vietnam (Pham et al., 2019a). However, intensive harvesting of wild populations has resulted in severe depletion of natural resources. Consequently, developing sustainable cultivation practices has become essential both for species conservation and for supporting the livelihoods of ethnic minority communities in remote areas. Despite growing interest in Laichau ginseng cultivation, scientific understanding of optimal agronomic practices remains limited. While studies on other *Panax* species have demonstrated the importance of appropriate fertilization regimes and biological soil amendments for maximizing yield and quality (Woo et al., 2004), comparable research on Laichau ginseng cultivation is scarce. Previous work by our research group established basic propagation protocols and identified suitable growing environments, but critical knowledge gaps persist regarding fertilizer requirements and disease management strategies for this endemic variety. The cultivation of medicinal plants under intensive management often faces challenges in balancing productivity with the maintenance of bioactive compound levels (Dizikisa, 2025). Excessive fertilization may promote rapid vegetative growth but potentially reduce the concentration of valuable secondary metabolites (Tran, 2011). Conversely, the application of beneficial soil microorganisms, particularly arbuscular mycorrhizal fungi, has shown promise in other ginseng species for enhancing both growth and ginsenoside accumulation while reducing chemical fertilizer requirements (Zhou et al., 2007). Similarly, biological control agents offer potential for managing soil borne pathogens that commonly afflict ginseng cultivation, thereby reducing reliance on synthetic pesticides. The objectives of this study were to evaluate the effects of different fertilizer types and application rates on the growth and rhizome yield of Laichau ginseng, and to assess the efficacy of various biological products for disease management and growth promotion. By addressing these fundamental agronomic questions, the results will provide critical evidence to contribute to the development of science-based cultivation protocols that can support sustainable production of this valuable medicinal plant while conserving wild populations.

## **2. MATERIAL AND METHOD**

### **2.1. Study Site**

The experiments were conducted at Sin Chai village, Ta Leng commune, Laichau Province, northern Vietnam, located within the natural distribution range of Laichau ginseng (Fig. 1). The site represents typical growing conditions for Laichau ginseng in the region. The experimental area is located at approximately 1,600 m above sea level, with a subtropical climate influenced by monsoons. Mean annual temperature ranges from 13 to 20°C, with 5-7 months experiencing maximum temperatures below 15°C. Annual precipitation averages 2,600-3,100 mm, with the rainy season extending from May to September. Relative humidity remains consistently high throughout the year (80-86%), and morning fog is common, creating favourable conditions for ginseng cultivation. Soil samples were collected from two representative locations at 0-20 cm depth prior to experiment establishment. Soil analysis revealed characteristics typical of high-elevation forest soils in the region, with properties suitable for Laichau ginseng cultivation (Table 1). The soils are classified as humic Alisols on high mountains, characterized by acidic pH (5.72-5.90 in KCl), high organic matter content (7.12-8.48%), and adequate levels of exchangeable cations.



**Figure 1.** Laichai ginseng, *Panax vietnamensis* var. *fuscidiscus*, leaves, ripe fruits, and rhizomes

## 2.2. Experiment

### 2.2.1. Fertilizer Effects

Five fertilizer treatments were established in a randomized complete block design with three replications. Each plot measured 5 m<sup>2</sup> and contained 30 plants. Treatments were applied to two-year-old plants established from seeds. The fertilizer treatments included: **1**) P1 (Control): No fertilizer application; **2**) P2: Song Gianh bio-fertilizer at 0.1 kg per plant after transplanting, with maintenance applications twice annually (February-March and May-June); **3**) P3: Arbuscular mycorrhizal fungi (AMF) inoculum at 200 g/m<sup>2</sup> (equivalent to 20 g/plant), with maintenance applications twice annually (February-March and May-June); **4**) P4: Inorganic NPK combination (10 g N + 20 g P<sub>2</sub>O<sub>5</sub> + 40 g K<sub>2</sub>O per m<sup>2</sup>), with maintenance applications twice annually (February-March and May-June); **5**) P5: Micronutrient combination (1.5 g Zn + 1.5 g Mg + 34 g Ca per m<sup>2</sup>), with maintenance applications twice annually (February-March and May-June).

Fertilizers were applied by broadcasting around the base of plants and lightly incorporating into the surface litter layer. Song Gianh bio-fertilizer is a commercially available product containing beneficial microorganisms. The AMF inoculum was produced in vitro and contained a mixture of indigenous arbuscular mycorrhizal fungal species. Inorganic fertilizers were applied as urea (46% N), superphosphate (16% P<sub>2</sub>O<sub>5</sub>), and potassium chloride (60% K<sub>2</sub>O). Micronutrients were supplied as chelated forms to ensure availability in acidic soil conditions.

### 2.2.2. Biological Products

Six biological treatments were established in a randomized complete block design with three replications. Each plot contained 30 plants. Treatments were also applied to two-year-old established plants. The biological control treatments included: **1**) CT1 (Control): No biological product application; **2**) CT2: *Trichoderma bacillus* biological product at 10 g/plant; **3**) CT3: Emunic antimicrobial product at 10 g/plant; **4**) CT4: Arbuscular mycorrhizal fungi (AMF) at 20 g/plant at planting, with annual maintenance applications in January-February at 20 g/plant; **5**) CT5: *Trichoderma* + MF1 combination at 10 g/plant; **6**) CT6: Indigenous microorganisms (IMO) local preparation.

Biological products were applied by mixing with the soil around plant bases. *Trichoderma bacillus* is a commercial biocontrol agent containing *Trichoderma* spp. and *Bacillus* spp. Emunic is a microbial consortium with antifungal properties. The MF1 product was developed by the Forest Protection Research Center and contains beneficial forest soil microorganisms. Indigenous microorganisms were prepared locally following traditional fermentation methods using rice bran and forest soil.

## 2.3. Cultivation Management

Both experiments received standardized cultural management throughout the study period. Artificial shading was provided using 80% shade cloth supported on frames approximately 1.5 m above ground level, simulating the natural forest canopy conditions preferred by Laichau ginseng. During the dry season (January-April), plots were irrigated using a mist sprinkler system, applying water once daily except on rainy days to maintain consistent soil moisture. Weed control was performed manually three times annually (May, July, and September) to minimize competition while avoiding soil disturbance that might damage shallow ginseng roots.

## 2.4. Data Collection

After one growing season (when plants reached three years of age), all surviving plants in each replicate were measured for the following parameters: Stump diameter (D<sub>0</sub>): Measured in millimetres using digital callipers at the soil surface; Total height (H): Measured in centimetres from soil surface to the highest point of foliage; Crown diameter (D<sub>c</sub>): Calculated as the average of two perpendicular measurements across the widest point of the canopy (cm); Leaf dimensions: Length and width of the terminal leaflet of mature leaves (cm); Leaf number: Total number of leaves per plant; Rhizome characteristics: Length (cm), diameter (mm), and fresh weight (g).

At harvest, rhizomes were carefully excavated, washed, and immediately measured for fresh weight. Rhizome length was measured from the crown to the distal end, and diameter was measured at the widest point using digital callipers. Survival rates were calculated as the percentage of initially planted individuals remaining alive at the time of assessment.

## 2.5. Data Analysis

All measured parameters were summarized as means with standard errors ( $\pm$ SE). Analysis of variance (ANOVA) was conducted to evaluate treatment effects on growth parameters, followed by post-hoc mean separation tests where significant differences were detected. Statistical significance was determined at  $p = 0.05$ . All analyses were performed using SAS 9.2 software (SAS Institute Inc., Cary, NC, USA).

## 3. RESULTS

### 3.1. Soil Characteristics of the Experimental Site

Analysis of soil samples collected from the experimental site revealed properties characteristic of high-elevation forest soils in northern Vietnam (Table 1). Both samples exhibited moderately acidic pH values (5.72-5.90 in KCl), which fall within the optimal range for Laichau ginseng cultivation. Electrical conductivity (EC) values were relatively low (0.22-0.45 mS/cm), indicating minimal salt accumulation. The soils contained substantial organic matter (OM; 7.12-8.48%), with humic acid comprising 1.52-1.79% and fulvic acid 0.32-0.37%, reflecting the accumulation of organic materials typical of forest ecosystems.

**Table 1.** Physical and chemical properties of soil at the experimental site

Parameter	Sample 1	Sample 2	Parameter	Sample 1	Sample 2
pH <sub>KCl</sub>	5.90	5.72	Ca (meq/100g)	25.00	17.00
EC (mS/cm)	0.45	0.22	Mg (meq/100g)	9.60	5.00
OM (%)	8.48	7.12	H <sup>+</sup> (meq/100g)	0.11	0.05
Humic (%)	1.79	1.52	Al <sup>3+</sup> (meq/100g)	0.01	0.02
Fulvic (%)	0.37	0.32	Coarse sand (2-0.2; %)	26.96	19.68
CEC (meq/100g)	36.20	22.80	Fine sand (0.2-0.05; %)	35.84	37.33
P <sub>2</sub> O <sub>5</sub> (mg/100g)	130.90	17.65	Silt (0.05-0.002; %)	27.20	29.40
K <sub>2</sub> O (mg/100g)	118.49	43.92	Clay (<0.002; %)	10.00	13.59
K (meq/100g)	1.19	0.46	As (mg/kg)	5.13	6.25
Na (meq/100g)	0.25	0.15			

Cation exchange capacity (CEC) ranged from 22.80 to 36.20 meq/100g, indicating good nutrient retention potential. Available phosphorus (P<sub>2</sub>O<sub>5</sub>) showed considerable variation between samples (17.65-130.90 mg/100g), as did exchangeable potassium (43.92-118.49 mg/100g K<sub>2</sub>O). Calcium levels were high (17.00-25.00 meq/100g), while magnesium concentrations were moderate (5.00-9.60 meq/100g). Exchangeable acidity (H<sup>+</sup>) and aluminium (Al<sup>3+</sup>) levels were low, suggesting that soil acidity poses no toxicity concerns for plant growth. Soil texture analysis revealed a sandy loam composition, with coarse sand (2-0.2 mm) comprising 19.68-26.96%, fine sand (0.2-0.05 mm) 35.84-37.33%, silt (0.05-0.002 mm) 27.20-29.40%, and clay (<0.002 mm) 10.00-13.59%. This texture provides favourable drainage characteristics while maintaining adequate moisture retention capacity. Arsenic levels (5.13-6.25 mg/kg) were within normal ranges for the region and below levels of environmental concern. Overall, these soil properties indicate suitable conditions for Laichau ginseng cultivation, particularly regarding organic matter content, pH, and physical structure.

### 3.2. Effects of Fertilizers on Growths and Rhizome Weight

After one growing season of fertilizer application to two-year-old plants, significant effects were observed on plant survival and rhizome development (Table 2). Survival rates remained relatively consistent across treatments, ranging from 71.1% to 76.7%, with no statistically significant differences detected among treatments. This suggests that fertilizer application at the tested rates did not adversely affect plant establishment or survival. Stump diameter showed modest variation among treatments (2.6-3.0 mm), though differences were not statistically significant. Similarly, total plant height ranged from 20.6 cm in the control to 26.1 cm in the bio-fertilizer treatment, without reaching statistical significance. Crown diameter measurements (20.8-25.8 cm) and leaf dimensions also showed no significant treatment effects, indicating that fertilizer applications did not substantially alter vegetative growth characteristics during the study period. Leaf length varied from 12.0 to 13.6 cm, while leaf width remained relatively uniform across treatments (3.8-4.2 cm). Leaf number per plant was low and similar across all treatments (1.5-1.7), reflecting the slow establishment phase typical of young ginseng plants.

In contrast to vegetative parameters, fertilizer treatments significantly influenced rhizome development. Rhizome length showed minimal variation (4.6-5.1 cm) and no significant differences among treatments. However, rhizome diameter and weight exhibited clear treatment responses. All fertilizer treatments significantly increased rhizome diameter compared to the unfertilized control (1.5 mm). Plants receiving bio-fertilizer (P2), arbuscular mycorrhizal fungi (P3), inorganic NPK (P4), or micronutrients (P5) all achieved statistically similar rhizome diameters (1.7-1.9 mm), representing an approximate 27% increase over the control.

The most pronounced treatment effect was observed for rhizome fresh weight. The control plants produced rhizomes averaging  $8.9 \pm 0.1$  g, while all fertilized treatments yielded significantly heavier rhizomes. The Song Gianh bio-fertilizer treatment (P2) produced the heaviest rhizomes ( $15.8 \pm 1.5$  g), representing a 78% increase over the control. The arbuscular mycorrhizal fungi (P3), inorganic NPK (P4), and micronutrient (P5) treatments all produced statistically similar rhizome weights (13.8-13.9 g), approximately 56% greater than the control. These results demonstrate that appropriate fertilization can substantially enhance rhizome production without requiring excessive vegetative growth.

### **3.3. Effects of Biological Products on Growths**

Application of various biological control products to established Laichau ginseng plantings resulted in subtle effects on growth parameters (Table 3). Survival rates varied considerably among treatments, ranging from 73.3% in the arbuscular mycorrhizal fungi treatment (CT3) to 92.2% in the *Trichoderma* + MF1 combination treatment (CT5). However, these differences should be interpreted cautiously given the inherent variability in field survival assessments. The elevated survival rate in the CT5 treatment suggests potential benefits from the combined action of *Trichoderma* biocontrol agents and forest soil microorganisms in suppressing root pathogens.

Stump diameter measurements were remarkably uniform across all treatments (2.4-2.5 mm), indicating no significant influence of biological products on stem diameter growth. Total plant height showed somewhat greater variation, ranging from 18.1 cm in both the control (CT1) and indigenous microorganism treatment (CT6) to 21.9 cm in the arbuscular mycorrhizal fungi treatment (CT3). Despite this numerical variation, differences were not statistically significant, suggesting that biological product applications did not substantially alter above-ground vegetative development during the study period.

Crown diameter measurements exhibited minimal variation (22.8-23.8 cm) across treatments, further indicating limited effects on canopy architecture. Leaf morphology, as assessed through terminal leaflet dimensions, showed similarly consistent patterns. Leaf length ranged narrowly from 9.7 to 10.1 cm, while leaf width remained essentially constant (3.2 cm) across all treatments. These measurements suggest that biological products, when applied at the tested rates and frequencies, do not fundamentally alter leaf morphology or size.

Leaf number per plant averaged 2.5-2.8 across treatments, reflecting the slow establishment characteristic of young ginseng plants in their third year of growth. The consistency of this parameter across treatments indicates that biological product applications neither accelerated nor inhibited the gradual increase in leaf production typical of developing ginseng plants.

Overall, the results indicate that while certain biological products (particularly the *Trichoderma* + MF1 combination) may enhance plant survival, their effects on vegetative growth parameters are minimal under the conditions tested. The lack of significant growth responses to biological products may reflect several factors, including the relatively short evaluation period (one growing season), the already favourable soil microbial conditions in the forest site, or the need for longer-term colonization and establishment of introduced beneficial microorganisms

**Table 2.** Effects of fertilizer treatments on growths and rhizome weight ( $\pm$ SE) of Laichau ginseng

Treatment	Survival rate (%)	D <sub>0</sub> (mm)	H (cm)	D <sub>c</sub> (cm)	Leaf length (cm)	Leaf width (cm)	Leaf number	Rhizome length (cm)	Rhizome diameter (cm)	Rhizome weight (g)
P1	75.6 $\pm$ 2.9	2.6 $\pm$ 0.2	20.6 $\pm$ 4.0	20.8 $\pm$ 2.3	12.0 $\pm$ 1.5	3.8 $\pm$ 0.3	1.6 $\pm$ 0.2	4.7 $\pm$ 0.2	1.5 $\pm$ 0.1 <sup>a</sup>	8.9 $\pm$ 0.1 <sup>a</sup>
P2	71.1 $\pm$ 2.9	2.8 $\pm$ 0.3	26.1 $\pm$ 3.5	25.8 $\pm$ 2.9	13.5 $\pm$ 1.4	4.2 $\pm$ 0.3	1.7 $\pm$ 0.3	4.7 $\pm$ 0.2	1.9 $\pm$ 0.1 <sup>b</sup>	15.8 $\pm$ 1.5 <sup>b</sup>
P3	76.7 $\pm$ 1.9	2.8 $\pm$ 0.1	22.0 $\pm$ 0.5	22.8 $\pm$ 1.0	13.6 $\pm$ 1.3	4.0 $\pm$ 0.2	1.5 $\pm$ 0.1	4.6 $\pm$ 0.6	1.7 $\pm$ 0.1 <sup>b</sup>	13.9 $\pm$ 3.0 <sup>b</sup>
P4	72.2 $\pm$ 2.2	2.9 $\pm$ 0.1	24.0 $\pm$ 2.4	23.2 $\pm$ 1.7	12.7 $\pm$ 1.1	4.0 $\pm$ 0.2	1.5 $\pm$ 0.1	5.1 $\pm$ 0.4	1.9 $\pm$ 0.1 <sup>b</sup>	13.9 $\pm$ 2.4 <sup>b</sup>
P5	73.3 $\pm$ 0.0	3.0 $\pm$ 0.1	23.2 $\pm$ 2.1	22.6 $\pm$ 2.1	13.2 $\pm$ 1.5	4.0 $\pm$ 0.3	1.5 $\pm$ 0.0	4.7 $\pm$ 0.1	1.9 $\pm$ 0.2 <sup>b</sup>	13.8 $\pm$ 2.6 <sup>b</sup>

Note: <sup>a,b</sup> different letters in a column indicates statistically significant difference of means between treatments. SE is standard error. D<sub>0</sub> is stump diameter. H is total height. D<sub>c</sub> is crown diameter.

**Table 3.** Effects of biological products on growths ( $\pm$ SE) of Laichau ginseng

Treatment	Survival rate (%)	D <sub>0</sub> (mm)	H (cm)	D <sub>c</sub> (cm)	Leaf length (cm)	Leaf width (cm)	Leaf number
CT1	82.2 $\pm$ 2.2	2.5 $\pm$ 0.2	18.1 $\pm$ 3.4	22.9 $\pm$ 2.0	9.7 $\pm$ 0.2	3.2 $\pm$ 0.1	2.6 $\pm$ 0.6
CT2	86.7 $\pm$ 3.3	2.5 $\pm$ 0.1	19.1 $\pm$ 2.2	22.8 $\pm$ 1.8	9.9 $\pm$ 0.3	3.2 $\pm$ 0.1	2.8 $\pm$ 0.3
CT3	73.3 $\pm$ 13.5	2.5 $\pm$ 0.1	21.9 $\pm$ 3.2	23.8 $\pm$ 2.0	10.0 $\pm$ 0.4	3.2 $\pm$ 0.1	2.8 $\pm$ 0.2
CT4	88.9 $\pm$ 5.9	2.4 $\pm$ 0.1	19.4 $\pm$ 3.4	23.1 $\pm$ 2.0	10.0 $\pm$ 0.2	3.2 $\pm$ 0.1	2.8 $\pm$ 0.5
CT5	92.2 $\pm$ 4.4	2.5 $\pm$ 0.2	20.0 $\pm$ 3.9	23.8 $\pm$ 2.5	10.1 $\pm$ 0.5	3.2 $\pm$ 0.1	2.6 $\pm$ 0.5
CT6	83.3 $\pm$ 1.9	2.5 $\pm$ 0.1	18.1 $\pm$ 2.7	23 $\pm$ 2.2	9.8 $\pm$ 0.5	3.2 $\pm$ 0.1	2.5 $\pm$ 0.2

Note: SE is standard error. D<sub>0</sub> is stump diameter. H is total height. D<sub>c</sub> is crown diameter.

#### 4. DISCUSSION

##### 4.1. Fertilizer Effects on Growths and Rhizome Production

The results of this study demonstrate that appropriate fertilization significantly enhances rhizome production in Laichau ginseng (Fig. 2), with rhizome weight increasing by 56-78% compared to unfertilized controls. These findings are consistent with research on other *Panax* species, where balanced fertilization has been shown to promote underground storage organ development (Tran, 2011; Nguyen, 2014). The superior performance of the Song Gianh bio-fertilizer treatment (15.8 g rhizome weight) suggests that organic fertilizers containing beneficial microorganisms may provide advantages beyond simple nutrient supply, potentially including enhanced nutrient availability, improved soil structure, and stimulation of beneficial rhizosphere interactions.



**Figure 2.** Size of rhizomes before and 1 year after experiment

The comparable rhizome weights achieved with arbuscular mycorrhizal fungi, inorganic NPK, and micronutrient treatments (13.8-13.9 g) indicate that multiple fertilization strategies can effectively support rhizome production in Laichau ginseng. This flexibility is important for farmers, as it allows selection of fertilizer types based on local availability, cost considerations, and philosophical preferences regarding organic versus inorganic inputs. The effectiveness of mycorrhizal inoculation is particularly noteworthy, as arbuscular mycorrhizal fungi are well-documented to enhance phosphorus uptake in many plant species and have shown benefits in other ginseng systems (Zhou et al., 2007). Interestingly, while all fertilizer treatments significantly increased rhizome diameter and weight, no significant effects were observed on vegetative growth parameters (height, crown diameter, leaf dimensions). This pattern suggests that added nutrients are preferentially allocated to underground storage organs rather than above-ground biomass. Such allocation patterns are consistent with the biology of *Panax* species as perennial herbs adapted to forest understory environments, where establishing substantial underground reserves is critical for long-term survival and reproduction. From a practical standpoint, this preferential allocation to rhizomes is advantageous, as rhizome weight directly determines economic yield in ginseng cultivation.

The absence of negative effects from fertilization on vegetative growth is also noteworthy. Excessive fertilization, particularly with nitrogen, can sometimes promote excessive vegetative growth at the expense of secondary metabolite production in medicinal plants (Dizikisa, 2025). While the current study did not assess ginsenoside content, the fact that fertilized plants maintained normal vegetative characteristics while increasing rhizome production suggests that the application rates tested are within appropriate ranges for Laichau ginseng. Future research should investigate the effects of these fertilization regimes on bioactive compound profiles to ensure that enhanced yields are not achieved at the cost of reduced medicinal quality. The fertilizer application schedule employed in this study (initial application followed by twice-annual maintenance applications) was designed to match the phenology of Laichau ginseng. The timing of applications in February-March and May-June corresponds to periods of active growth following winter dormancy and during the main growing season, respectively. This schedule appears appropriate based on the positive results obtained, though optimization studies might further refine timing and application frequencies for maximum efficiency.

#### 4.2. Limited Effects of Biological Products on Growths

In contrast to the clear benefits of fertilizer applications, biological control products showed minimal effects on growth parameters in this study, with only subtle indications of enhanced survival in the *Trichoderma* + MF1 treatment (92.2% survival vs. 73.3-88.9% in other treatments). Several factors may explain these limited responses.

First, the evaluation period of one growing season may have been insufficient to detect the full effects of biological inoculants, particularly those requiring extended colonization periods to establish effective symbioses or antagonistic relationships with pathogens. Arbuscular mycorrhizal fungi, for example, typically require several months to establish functional mycorrhizal networks capable of significantly enhancing nutrient uptake. Similarly, biocontrol agents like *Trichoderma* spp. need time to colonize the rhizosphere and build up populations sufficient to suppress pathogens effectively (Dizikisa, 2025). Second, the experimental site's location within a natural forest ecosystem may have provided inherently favourable microbial conditions. Forest soils typically harbour diverse and abundant populations of beneficial microorganisms, including mycorrhizal fungi and antagonists of plant pathogens (Tran, 2011). Under such conditions, the addition of external inoculants may provide little marginal benefit, particularly if indigenous microbial communities are already fulfilling similar ecological functions. This interpretation is supported by the high organic matter content (7.12-8.48%) observed in the study site soils, which typically correlates with robust microbial communities.

Third, disease pressure appeared to be relatively low during the study period, which may have limited opportunities to detect beneficial effects of biocontrol agents. The biological products tested, particularly *Trichoderma bacillus*, Emunic, and indigenous microorganisms, are primarily valued for their ability to suppress soil borne pathogens that cause root diseases in ginseng (Lou and Li, 2025). In the absence of substantial disease pressure, the benefits of these products would naturally be less apparent. Long-term studies examining plant performance over multiple seasons, including years with higher disease incidence, would provide more comprehensive assessments of biocontrol efficacy.

The slightly elevated survival rate observed with the *Trichoderma* + MF1 combination treatment hints at potential benefits that might become more pronounced under challenging growing conditions or extended evaluation periods. *Trichoderma* species are well-established as effective biocontrol agents against fungal pathogens affecting ginseng, including *Fusarium*, *Pythium*, and *Cylindrocarpon* species (Feng et al., 2024). The addition of MF1, containing forest soil microorganisms, may provide complementary benefits through mechanisms such as competition for resources, production of antibiotics, or induced resistance. Further research with longer observation periods and deliberate disease challenges would help clarify the practical utility of these products for Laichau ginseng cultivation.

### **4.3. Implications for Sustainable Cultivation**

These findings provide practical guidance for developing cultivation protocols that balance productivity with sustainability for Laichau ginseng. The demonstration that various fertilizer types can enhance rhizome production offers flexibility for farmers to select inputs based on local availability and preferences. For operations emphasizing organic production or agro ecological principles, the excellent performance of Song Gianh bio-fertilizer and arbuscular mycorrhizal fungi indicates that sustainable intensification is achievable without reliance on synthetic fertilizers.

The fertilization rates tested in this study (0.1 kg bio-fertilizer per plant, 20 g AMF inoculum per plant, or 70 g NPK per m<sup>2</sup>) are relatively modest compared to those used in intensive ginseng production systems in others (Tran, 2011). This suggests potential for further optimization through rate titration studies. However, caution is warranted, as excessive fertilization might shift allocation patterns toward vegetative growth, potentially reducing ginsenoside concentrations as observed in other medicinal plants (Dizikisa, 2025). Future research should examine the relationship between fertilization intensity and both yield and medicinal quality parameters. The cultivation system employed in this study, featuring natural forest regeneration with supplemental shade cloth, represents an intermediate intensity approach between wild collection and intensive monoculture under artificial structures. This system may offer advantages in terms of maintaining more natural growing conditions that could favour secondary metabolite production while still providing sufficient control over the environment to enable consistent production. The forest setting also provides multiple ecosystem services, including habitat for biodiversity, carbon sequestration, and watershed protection, making it compatible with broader landscape sustainability goals. From a conservation perspective, the development of effective cultivation protocols is critical for reducing pressure on wild populations of Laichau ginseng, which are currently classified as critically endangered due to overharvesting (Phan, 2014). By demonstrating that cultivation can produce respectable rhizome yields, this research contributes to making cultivation a viable alternative to wild collection. However, longer-term studies following plants to harvest maturity (typically 5-7 years for medicinal ginsengs) are essential for complete assessment of economic viability.

## **5. CONCLUSION**

This study demonstrates that fertilization practices significantly enhance rhizome production in Laichau ginseng, with all tested treatments, including Song Gianh bio-fertilizer, arbuscular mycorrhizal fungi, NPK combinations, and micronutrients, increasing rhizome weight by 56-78% compared to controls, while bio-fertilizer achieved the highest yields (15.8 g per plant). These improvements occurred without compromising vegetative growth or survival, indicating preferential nutrient allocation to economically valuable underground organs. The effectiveness of multiple fertilization strategies provides cultivation enterprises flexibility in selecting inputs based on availability, cost, and production philosophy, with bio-fertilizers and mycorrhizal inoculants demonstrating that sustainable intensification is achievable for operations emphasizing agroecological approaches. These findings contribute to developing science-based protocols that support sustainable production of this medicinal species while reducing pressure on endangered wild populations, though future research should examine long-term effects, ginsenoside content, economic viability, and performance across diverse cultivation sites to refine management recommendations.

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