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(Research Article)

Effect of temperature on growth, biomass accumulation and phytochemical contents of Panax ginseng sprouts cultivated under greenhouse conditions in Thainguyen province, Vietnam

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Abstract

This study evaluated the effects of different temperature regimes (16–26 ± 2 °C) on growth, biomass, and phytochemical composition of *Panax ginseng* sprouts cultivated in a greenhouse using peatmoss–perlite (1:1) substrate. The experiment was arranged in a randomized complete block design with three replications. Results showed that temperature significantly affected all measured parameters ($P \leq 0.05$). The optimal temperature range was identified as 18–22 °C, where plant height, root development, and biomass accumulation reached their maximum values. Ginsenosides and vitamin C contents were also highest within this range. At 24 °C, moderate reductions were observed, while 26 °C caused significant declines in growth and phytochemical accumulation. Severe stress at 28–30 °C resulted in poor survival and negligible productivity. These findings confirm that *Panax ginseng* is a cold-adapted species and highlight the importance of temperature control for optimizing both yield and quality in greenhouse cultivation systems.

Keywords: *Panax Ginseng*; Temperature Stress; Ginsenosides; Biomass; Greenhouse Cultivation; Secondary Metabolites

1. Introduction

Korean ginseng (*Panax ginseng* C.A. Meyer) is one of the most important medicinal plants worldwide and has been widely used in traditional Asian medicine for centuries. Its pharmacological properties are mainly attributed to ginsenosides, a group of triterpenoid saponins with antioxidant, anti-inflammatory, neuroprotective, and immunomodulatory activities (Attele et al., 1999; Christensen, 2009). Owing to its high medicinal and economic value, ginseng has become an important crop in countries such as Korea, China, and Japan.

Temperature is one of the most influential environmental factors governing plant growth, development, and metabolic processes. In medicinal plants, temperature not only affects biomass accumulation but also regulates the biosynthesis of bioactive compounds.

Panax ginseng C.A. Meyer is a well-known medicinal plant characterized by its adaptation to cool climates. Previous studies have shown that optimal growth occurs under relatively low temperatures, whereas elevated temperatures can reduce photosynthetic efficiency, inhibit root development, and negatively affect secondary metabolite accumulation (Li, 1995; Kim et al., 2013).

In recent years, the production of ginseng sprouts has gained attention due to their high nutritional and pharmacological value. However, optimizing environmental conditions, particularly temperature, for sprout production under greenhouse systems remains insufficiently studied. Therefore, this study aimed to determine the optimal temperature

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range for maximizing growth, biomass, and phytochemical accumulation of ginseng sprouts derived from one-year-old roots.

2. Materials and Methods

2.1. Plant materials and experimental design

One-year-old ginseng roots, pre-treated for sprouting, were used as planting materials. Plants were cultivated in a greenhouse using a peatmoss + perlite (1:1) substrate, previously identified as optimal. The experiment was arranged in a randomized complete block design (RCBD) with: 6 temperature treatments (16, 18, 20, 22, 24, and 26 ± 2 °C), 3 replications, 30 plants per replication

2.2. Measured parameters

Growth traits: Plant morphological characteristics included plant height (cm), leaf length and width (cm), root length (cm), and root diameter (mm).

Biomass: Biomass accumulation was assessed based on fresh and dry weights of roots and shoots (g).

Phytochemical analysis: (1) Vitamin C content was determined using the 2,6-dichlorophenolindophenol (DCPIP) titrimetric method following AOAC (2016) and expressed as mg ascorbic acid per 100 g fresh weight (mg/100 g FW); (2) Total flavonoid content was quantified using the aluminum chloride colorimetric method (Zhishen et al., 1999). Absorbance was measured at 415 nm, and results were expressed as mg quercetin equivalents per g dry weight (mg QE/g DW); (3) Total ginsenosides were determined using a vanillin–sulfuric acid colorimetric method (Goel et al., 2012). Absorbance was recorded at 544 nm, and results were expressed as mg Quillaja saponin equivalents per g extract (mg QS/g extract).

2.3. Statistical analysis

Data were analyzed using ANOVA. Mean comparisons were performed using Duncan's multiple range test ($P \leq 0.05$). Results were expressed as Mean ± SD.

3. Results and discussion

3.1. Effect of temperature on growth characteristics

Table 1 Effects of temperature regimes on morphological characteristics of *Panax ginseng* sprouts

Treatment	Temperature regime	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Root length (cm)	Main root diameter (mm)
1	16 ± 2 °C	7.62 c	2.63 c	2.19 d	8.88 d	7.78 c
2	18 ± 2 °C	8.08 a	2.73 ab	2.30 abc	9.48 b	8.36 a
3	20 ± 2 °C	8.24 a	2.78 a	2.35 a	9.72 a	8.54 a
4	22 ± 2 °C	8.12 a	2.74 ab	2.31 ab	9.56 ab	8.42 a
5	24 ± 2 °C	7.84 b	2.67 bc	2.24 cd	9.12 c	8.02 b
6	26 ± 2 °C	6.86 d	2.48 d	1.98 e	7.86 e	7.18 d
$LSD_{0.05}$		0.17	0.05	0.06	0.16	0.23
CV (%)		1.68	1.82	1.76	1.55	2.08

Note: Values followed by different letters within the same column are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Temperature significantly affected all morphological traits of Panax ginseng sprouts, as evidenced by clear differences among treatments ($P \leq 0.05$) (Table 1). The highest values for plant height, leaf size, and root development were observed within the temperature range of 18–22 °C, with no significant differences among these treatments. In particular, plant height ranged from 8.08 to 8.24 cm, while root length reached up to 9.72 cm at 20 °C, indicating that this temperature range provides optimal conditions for vegetative growth.

At lower temperature (16 °C), growth was significantly reduced, likely due to decreased metabolic activity and slower cell division. Conversely, increasing temperature beyond the optimal range resulted in a marked decline in all growth parameters. At 24 °C, moderate reductions were observed, whereas at 26 °C, plant height, leaf dimensions, and root development decreased significantly, reflecting the onset of heat stress.

These results confirm that P. ginseng is a cool-adapted species with optimal growth occurring under relatively low temperatures. Similar findings have been reported by Li (1995), who indicated that ginseng growth is favored under cool environmental conditions, and by Jang et al. (2024), who demonstrated that elevated temperatures significantly suppress growth and root development in ginseng sprouts. The strong reduction in root traits at higher temperatures observed in this study further supports the sensitivity of ginseng root systems to thermal stress, which may limit nutrient uptake and overall plant performance (Kim et al., 2013).

Overall, the results indicate that maintaining temperature within 18–22 °C is essential to ensure optimal growth and development of ginseng sprouts under greenhouse conditions.

3.2. Effect of temperature on biomass

Table 2 Effects of temperature regimes on root and shoot biomass of *Panax ginseng* sprouts

Treatment	**Temperature regime**	**Fresh root weight (g)**	**Dry root weight (g)**	**Fresh shoot weight (g)**	**Dry shoot weight (g)**
1	16 ± 2 °C	2.78 c	0.86 c	0.74 c	0.12 c
2	18 ± 2 °C	2.98 ab	0.94 ab	0.82 ab	0.14 ab
3	20 ± 2 °C	3.04 a	0.97 a	0.86 a	0.15 a
4	22 ± 2 °C	2.98 ab	0.95 ab	0.83 ab	0.14 ab
5	24 ± 2 °C	2.84 c	0.89 c	0.77 bc	0.13 bc
6	26 ± 2 °C	2.46 d	0.73 d	0.60 d	0.09 d
$LSD_{0.05}$		0.06	0.03	0.04	0.01
CV (%)		1.22	2.18	2.86	5.94

Note: Values followed by different letters within the same column are significantly different at P ≤ 0.05 according to Duncan's multiple range test.

Temperature significantly influenced biomass accumulation of Panax ginseng sprouts (P ≤ 0.05) (Table 2). The highest fresh and dry weights of both roots and shoots were observed within the temperature range of 18–22 °C, with no significant differences among these treatments. Root fresh weight reached 3.04 g at 20 °C, while dry root weight attained 0.97 g, indicating efficient biomass production under optimal thermal conditions.

Compared to growth traits, biomass showed a more pronounced decline at elevated temperatures. At 24 °C, reductions in both root and shoot biomass were evident, whereas at 26 °C, all biomass parameters decreased significantly, particularly in root tissues. Fresh root weight declined to 2.46 g and dry root weight to 0.73 g, suggesting that root biomass is more sensitive to temperature stress than shoot biomass.

The stronger response of root biomass to temperature may be associated with the high metabolic demand and storage function of ginseng roots. Elevated temperatures are known to increase respiration rates and reduce carbon allocation to belowground organs, leading to decreased biomass accumulation (Xu et al., 2011). Similar trends have been reported in ginseng cultivation systems, where high temperatures suppressed root development and overall productivity (Jang et al., 2024).

These results highlight that temperature not only affects morphological growth but also plays a critical role in biomass partitioning, particularly in medicinal crops where root yield is the primary economic trait.

3.3. Effect of temperature on phytochemical contents

Table 3 Effects of temperature regimes on phytochemical contents of *Panax ginseng* sprouts

Treatment	Temperature regime	Vitamin C (mg/100 g FW)	Flavonoids (mg QE/g DW)	Ginsenosides (% DW)
1	16 ± 2 °C	17.62 c	0.0142 c	4.782 c
2	18 ± 2 °C	18.28 a	0.0150 a	4.936 a
3	20 ± 2 °C	18.46 a	0.0153 a	5.012 a
4	22 ± 2 °C	18.24 a	0.0151 a	4.958 a
5	24 ± 2 °C	17.84 b	0.0146 b	4.846 b
6	26 ± 2 °C	16.48 d	0.0134 d	4.512 d

Note: Different letters within the same column indicate significant differences at $P \leq 0.05$ according to Duncan's multiple range test.

Temperature significantly affected the phytochemical composition of *Panax ginseng* sprouts ($P \leq 0.05$) (Table 3). The highest contents of vitamin C, flavonoids, and ginsenosides were recorded within the temperature range of 18–22 °C, with no significant differences among these treatments. In particular, ginsenosides reached a maximum of 5.012% DW at 20 °C, while vitamin C and flavonoids also exhibited peak values at this temperature range, indicating that moderate temperatures favor both primary and secondary metabolism.

At lower temperature (16 °C), all phytochemical contents were reduced, likely due to decreased enzymatic activity and slower metabolic processes. In contrast, increasing temperature beyond the optimal range resulted in a progressive decline in all compounds. At 24 °C, moderate reductions were observed, whereas at 26 °C, vitamin C, flavonoids, and ginsenosides decreased significantly, with ginsenosides dropping to 4.512% DW.

Among the evaluated metabolites, ginsenosides exhibited the highest sensitivity to temperature, followed by vitamin C, whereas flavonoids showed comparatively smaller variation. This pattern suggests that triterpenoid saponin biosynthesis is more vulnerable to thermal stress than phenolic metabolism. Ginsenosides are synthesized via the mevalonate (MVA) pathway, which is tightly regulated by enzyme systems such as squalene synthase and dammarenediol synthase; these enzymes are known to be sensitive to environmental stress, particularly high temperature (Kim et al., 2013; Wang et al., 2015). Elevated temperatures may downregulate the expression of genes involved in ginsenoside biosynthesis, leading to reduced accumulation.

In addition, heat stress can alter carbon allocation within the plant. Under high temperatures, increased respiration rates consume more carbohydrates, thereby limiting the availability of carbon skeletons required for secondary metabolite production (Wahid et al., 2007). This mechanism may explain the concurrent decrease in vitamin C and ginsenosides observed at 24–26 °C. Vitamin C biosynthesis, which is closely linked to photosynthetic carbon metabolism, is also known to decline under stress conditions due to reduced photosynthetic efficiency and increased oxidative degradation (Smirnoff, 2018).

Flavonoids, although also derived from carbon metabolism via the phenylpropanoid pathway, exhibited relatively smaller variation across temperature treatments. This may be attributed to their additional role as protective antioxidants, which can be induced under moderate stress conditions to mitigate oxidative damage. However, under severe heat stress (≥26 °C), even flavonoid accumulation declined, indicating that the stress level exceeded the plant's protective capacity.

Overall, the results demonstrate that temperature not only regulates plant growth but also strongly influences the balance between primary and secondary metabolism. The optimal range of 18–22 °C ensures efficient carbon assimilation and enzymatic activity, thereby maximizing the accumulation of key bioactive compounds. In contrast, elevated temperatures disrupt metabolic homeostasis, leading to reduced phytochemical quality of ginseng sprouts.

4. Conclusion

Temperature significantly influenced growth, biomass accumulation, and phytochemical composition of *Panax ginseng* sprouts. Optimal performance was consistently achieved at 18–22 °C, whereas both lower and higher temperatures reduced plant growth and bioactive compound accumulation. Ginsenosides exhibited the highest sensitivity to temperature variation. These findings highlight the importance of precise temperature control to optimize both yield and phytochemical quality in greenhouse production systems.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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