



임간재배환경에 따른 산마늘의 아미노산, 무기질 및 휘발성 성분 변화

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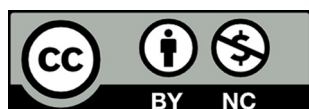
Changes in Amino acids, Minerals and Volatile Composition of Wild Garlic according to Forest Cultivation Environment

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ABSTRACT

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Background: Wild garlic (*Allium victorialis* var. *platyphyllum* Makino) is a useful wild vegetable with excellent texture and good profitability. It is produced in an environmentally friendly manner through forest cultivation. At present optimal cultivation conditions remain to be identified. We investigated the impact of inorganic nutrients available to wild garlic grown in various environments on free amino acid and volatile compounds content.

Methods and Results: While minerals available to wild garlic grown in a given cultivation environment were observed to vary with plot and cultivation year, no trend was identified. Free amino acid content varied significantly among cultivation plots, and was especially high in *Chamaecyparis obtusa* (Siebold and Zucc.) Endl. (CO) forest. Wild garlic free amino acid content increased rapidly during storage in its year after cultivation. Nineteen to twenty types of volatile compounds were detected. The main volatile compounds were sulfur compounds such as dimethyl trisulfide, disulfide, and methyl 2-propenyl. Little variation in total content by cultivation region was noted; however, differences in specific components were found.

Conclusions: These results can inform effective production of high-quality wild garlic by aiding in selection of an appropriate vegetation community for wild garlic cultivation.

Key Words: Wild Garlic, Forestry Cultivation, Amino Acids, Inorganic Ingredients, Volatile Compounds

INTRODUCTION

Wild garlic (*Allium victorialis* var. *platyphyllum* Makino) is a herbaceous perennial plant in the lily family. It grows naturally in the forests of central region in Korea, including Mt. Jiri, Mt. Seorak, Mt. Odae, and Ulleung Island. The entire plant has a strong garlic scent, spicy taste, and non-poisonous.

Wild garlic is very similar to garlic in its smell and medicinal use (Chang *et al.*, 2011). It belongs to the same genus, *Allium*,

as garlic, but its form is entirely different from that of garlic.

In Korea, when inflorescences grow among fallen leaves in March to April after winter, young leaves and shoots are collected in May and used for food (Kwon *et al.*, 2010).

Wild garlic, like garlic, has long been known as a traditional stamina food (Chang *et al.*, 2011). Additionally, in Korea, it has been used as a folk remedy for hypertension, arteriosclerosis, gastritis, constipation, abdominal pain, forgetfulness, and insomnia (Kim *et al.*, 2010). Wild garlic is edible for its tender leaves

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and the whole plant, including its stems and flowers. It has a unique taste and aroma and is rich in various minerals and vitamins, so the demand for it as a high-quality wild vegetable is increasing (Kim *et al.*, 2012).

Recently, as the mechanism for promoting vitamin B absorption in the human body and the existence of anti-thrombotic substances were discovered, it has been attracting attention as a functional food and pharmaceutical ingredient (Lee, 1985; Choi *et al.*, 2005).

The secondary metabolite content of medicinal plants is influenced by environmental factors, including climate and ecological issues (Cragg and Newman, 2013). Environmental conditions such as temperature changes, light intensity, high carbon dioxide, ultraviolet rays, ozone, drought, salinity, and flooding have a significant impact on the growth and development of medicinal plants and the synthesis of secondary metabolites (Verpoorte and Memelink, 2002; Imadi *et al.*, 2015; Gupta *et al.*, 2019; Li *et al.*, 2020).

Therefore, plants for producing biomaterials with high content of biologically active substances and high productivity must be grown under optimal environmental conditions to ensure production efficiency (Kim *et al.*, 2015).

Edible plants growing in the wild may face the risk of extinction due to excessive collection in their native habitat and continued increase in demand, and indiscriminate collection may damage the forest ecosystem and forests, resulting in ecosystem disturbance (Choi *et al.*, 1993; Kim and Um, 1997). It may cause damage to resources.

Therefore, to produce sustainable non-timber forest products while minimizing these problems, it is necessary to develop production technologies for rational and environmentally friendly forestry cultivation (Kim *et al.*, 2015).

Forest cultivation is the cultivation of useful plants in forests with an environment similar to their native habitat. It provides suitable shade and site conditions for marketable non-timber forest products and diversify income opportunities to forest farmers (Gold *et al.*, 2018). Compared to general cultivation methods, growth is slower, and yields are lower, but the texture and flavor are much better in the forest cultivation (NiFoS, 2014). Moreover, forest cultivation requires lower production cost compared to agricultural cultures.

However, wild garlic is difficult to propagate, and forestry cultivation technology needs to be established appropriately (NiFoS, 2014). Selecting optimal cultivation conditions is very important for the production of high-quality wild garlic through forest cultivation, which has potential for use in functional foods or small-scale and high-value markets. Accordingly, this study was conducted to identify the optimal site for forestry cultivation by investigating changes in amino acids, inorganic components, and volatile compounds depending on the vegetation environment of the forestry cultivation area.

MATERIALS AND METHODS

1. Overview of wild garlic samples and test strips

The wild garlic used in this experiment was from broad-leaf

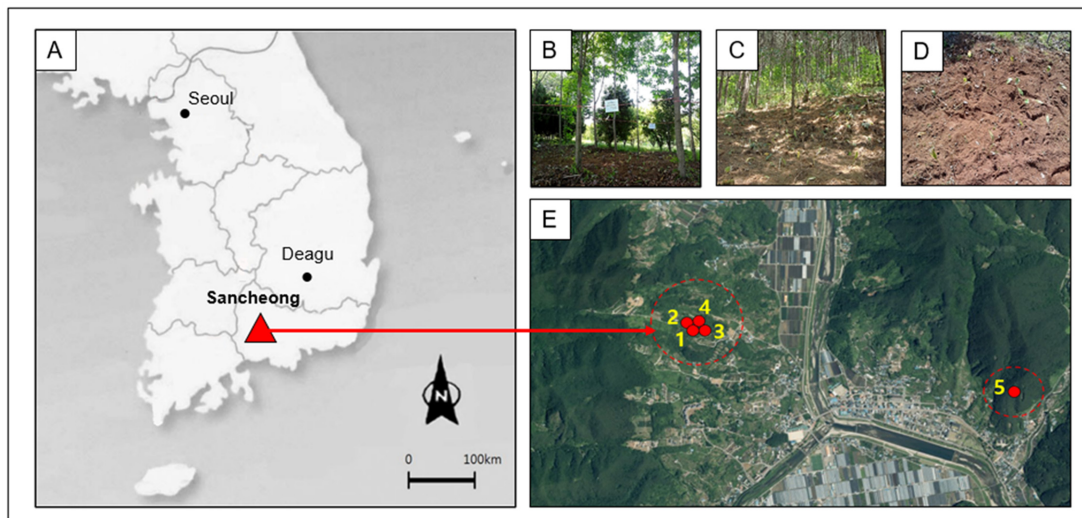


Fig 1. Five test strips of this study. A and E; experimental site locations in Korea, B; *A. turbinata* forest, C; *P. koraiensis* forest, and D; Bare ground. 1; *A. turbinata*, 2; *C. obtusa*, 3; Bare ground, 4; *A. palmatum*, 5; *P. koraiensis*.

forests (*Acer palmatum*, *Aesculus turbinata*) and coniferous forests (*Chamaecyparis obtusa*, *Pinus koraiensis*) from Gyeongsang National University Jirisan Experimental Forest (located in Sancheong-gun, Gyeongsangnam-do).

Bare ground, not a forest, was used as a negative control for forestry cultivation (Fig. 1). The test sites were set with five different sites at 10 m × 10 m each: *C. obtusa* forest (CO), *A. palmatum* forest (AP), *A. turbinata* forest (AT), and the bare ground located in one place and *P. koraiensis* forest (PK), located 2.3 km away from the main test site.

The average elevation of the wild garlic plantation was 168 m (140 - 223 m), 77% (30% - 95%) of the tree layer, 16% (5% - 30%) of the shrub layer, and 35% (10% - 90%) of the herbaceous layer (Table 1). These sites were selected to investigate the effect of dominance species and canopy cover on the composition and amount of chemical compounds produced by wild garlic.

The soil chemical properties of experimental sites were analyzed according to National Institute of Agricultural Science (NIAS, 2010). Soil pH was highest in CO and AP soil, and lowest in PK soil (Table 2).

The amount of organic matters was highest in PK soil, and lowest in CO soil. In CO soil, total N content and cation exchange capacity were lower than those of other forests. AP soil exhibited high total N and available P. BG soil had high level of available P, whereas its cation exchange capacity was lower than that of other forests.

Wild garlic seeds were collected from the Jirisan Experimental Forest of Gyeongsang National University in July 2017. They were sown in forest soil under a greenhouse and grown for two years. In May 2020, each of the 200 seedlings were planted in five test sites. Before planting, all above-ground parts of the wild garlic in each site were collected, washed, and used for

Table 1. Location and vegetation table of five sites.

Vegetation unit	CO ¹⁾	AP ²⁾	AT ³⁾	BG ⁴⁾	PK ⁵⁾
Dominance species	<i>Chamaecyparis obtusa</i>	<i>Acer palmatum</i>	<i>Aesculus turbinata</i>	Bare ground	<i>Pinus koraiensis</i>
Latitude	35°16' 55.14°N	35°16' 57.32°N	35°16' 55.14°N	35°16' 58.25°N	35°16' 41.64°N
Longitude	127°49' 32.78°E	127°49' 30.91°E	127°49' 32.78°E	127°49' 34.22°E	127°51' 02.92°E
Altitude (m)	140	149	141	147	215
The cardinal points of the compass (°)	190	208	188	205	286
Degree of slope (°)	5	3	3	2	5
Area of site (m ²)	25	25	25	25	25
Depth of organic little layer (L, cm)	2	9	3	1	2
Coverage of T1 ⁶⁾ (%)	90	30	75	-	95
Coverage of T2 ⁷⁾ (%)	-	60	-	-	-
Coverage of S ⁸⁾ (%)	20	5	5	-	20
Coverage of H ⁹⁾ (%)	70	10	20	90	10
High of T1 (m)	13	13	7	-	14
High of T2 (m)	-	6	-	-	-
High of S (m)	1	0.4	1	-	1
High of H (m)	0.3	0.2	0.2	0.2	0.2
DBH of T1 (cm)	14	24	12	-	24
DBH of T2 (cm)	-	12	-	-	-
DBH of S (cm)	-	-	-	-	1
The number of plant species	18	17	13	6	12

¹⁾CO; *C. obtusa*, ²⁾AP; *A. palmatum*, ³⁾AT; *A. turbinata*, ⁴⁾BG; bare ground, ⁵⁾PK; *P. koraiensis*, ⁶⁾T1; tree layer, ⁷⁾T2; subtree layer, ⁸⁾S; shrub layer, and ⁹⁾H; herb layer.

Table 2. Soil chemical properties of experimental sites.

Properties	CO ¹⁾	AP ²⁾	AT ³⁾	BG ⁴⁾	PK ⁵⁾
pH	5.4	5.4	5.1	5.2	5.0
Organic matter content (%)	02.75	04.74	04.43	03.78	06.10
Total N (%)	00.161	00.249	00.248	00.210	00.193
Available P (mg·kg ⁻¹)	04	47	04	52	05
Cation exchange capacity (cmol _c ·kg ⁻¹)	13.97	15.84	15.62	012.98	15.51
Exchangeable cation (cmol _c ·kg ⁻¹)	K ⁺	00.30	00.27	00.20	00.13
	Na ⁺	00.06	00.07	00.06	00.06
	Ca ²⁺	00.77	00.53	00.11	00.15
	Mg ²⁺	00.39	00.43	00.10	00.11

¹⁾CO; *C. obtusa*, ²⁾AP; *A. palmatum*, ³⁾AT; *A. turbinata*, ⁴⁾BG; bare ground, ⁵⁾PK; *P. koraiensis*

component analysis.

The analysis was also conducted in May of the following year to investigate the change in the chemical compound content of wild garlic. All parts above ground including leaves were freeze-dried at -72°C, ground, prepared into a uniform powder of 80 mesh, and then stored frozen at -20°C for use in analysis.

2. Analysis of minerals

The analysis of mineral components was performed by pretreatment using the dry decomposition method of the Korea Food and Drug Administration (MFDS, 2022).

1 g of each of the above-ground freeze-dried wild garlic was placed in a 250 mL flask, and 25 mL of wet decomposition solution (HNO₃ : H₂SO₄ : HClO₄ = 10 : 1 : 4) was added and boiled in a heating mantle for over 3 hours. The residue and liquid were separated using Whatman filter paper, and the liquid was finally adjusted to 100 mL using distilled water.

The treated samples were analyzed using an inductively coupled plasma spectrometer (ICP spectrometer, OPTIMA 4300DV, Perkin Elmer, Massachusetts, USA).

3. Free amino acid determination

Free amino acid analysis was performed by slightly modifying the method of Jeong *et al.* (2006).

To 3 g of wild garlic sample, 100 mL of 75% Et-OH was added to homogenize, extracted by shaking at 50°C for 2 hours, cooled to 4°C, and centrifuged at 6,000 rpm for 10 minutes. Then, The supernatant was concentrated using a rotary vacuum concentrator and adjusted to 25 mL with distilled water. Then, sulfosalicylic acid (50 mg per 1 mL of sample) was

added, allowed to stand for 1 hour, and centrifuged at 8,000 rpm for 10 minutes.

Then, the supernatant was filtered through a 0.22 µm membrane filter and analyzed with an amino acid analyzer (LKB 4150 Alpha, LKB Ltd., Cambridge, England).

4. Volatile compound analysis

0.5 g of wild garlic sample was mixed with 1.5 mL of tertiary distilled water and analyzed using a GC/MS (Clarus 600/Claus 600T, Perkin Elmer, Massachusetts, USA) equipped with headspace.

The initial oven temperature was 40°C and maintained for 3 minutes, raised at 5°C/min to 40°C, raised at 10°C/min to 280°C, and maintained at 300°C for 3 minutes. Helium was used as the carrier gas, the ion source temperature was 230°C, and the injector temperature was 250°C. Headspace conditions were oven temperature 120°C, transfer line temperature 125°C, and compound identification of wild garlic samples was confirmed by comparing NIST05S and Wiley7 Library.

5. Statistical analysis

Analysis of mineral, amino acid, and volatile compound was repeated at least three times and expressed as mean and standard deviation, and the results were analyzed by one-way ANOVA using the SPSS 20.0 software package (Statistical Package for Social Sciences, SPSS Inc., Chicago, IL, USA).

Means of regional ingredient compounds were compared at a 5% significance level using Duncan's Multiple Range Test (DMRT) comparisons. Means of the ingredient compounds before and after planting were compared using a *t*-test, also at a 5% significance level.

In addition, Pearson's correlation analysis was conducted to investigate the effect of soil chemical properties on the content of minerals, amino acids, and volatile compounds of wild garlic.

RESULTS

1. Changes in mineral contents in forestry cultivation sites

The mineral composition of wild garlic leaves planted in five sites showed slight differences (Table 3). The most abundant mineral was potassium, followed by calcium and phosphorus. Among the five sites, the one with the most mineral content was CO forest, followed by PK and AT forest. The mineral composition changed after planting wild garlic (Table 3).

The mineral content was compared between before planting and after planting to investigate the change in the content influenced by forestry cultivation sites (Fig. 2). After planting wild garlic, the content of minerals in the above-ground increased at five experimental sites. In the wild garlic cultivated in CO forest, K, Mn, and P content increased.

K, which showed the highest content among the mineral components, decreased in BG forest, while its content increased in CO, AP, AT, and PK forests (Fig. 2). Fe content increased in all of the cultivation areas except CO forest and BG, and Al content decreased only in CO forest cultivation areas. In particular, the P component increased in all cultivation environments.

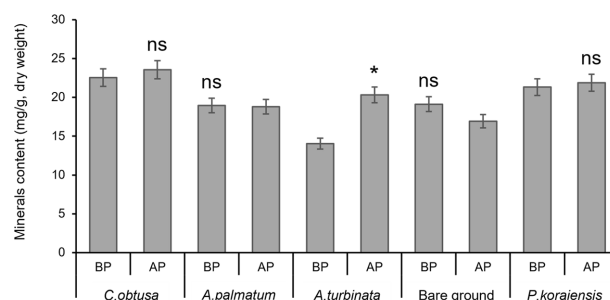


Fig. 2. Mineral content before and after planting wild garlic at five planting sites. Bars indicate means of 3 replications and error bars indicate standard deviations. BP; before planting, AP: after planting, ns: not significantly different according to t-test. Significantly different according to t-test (* $p < 0.05$).

Table 3. The mineral content of wild garlic cultivated in different experimental sites (mg/g, dry weight).

Minerals	Content after planting (mg/g)				
	CO ¹⁾	AP ²⁾	AT ³⁾	BG ⁴⁾	PK ⁵⁾
Mg	1.06±0.13 (-0.24 ^d)	1.11±0.11 (-1.15 ^e)	0.95±0.04 (+0.19 ^a)	0.58±0.05 (-0.01 ^b)	1.03±0.34 (-0.18 ^c)
Ca	4.64±0.58 (-3.21 ^d)	1.80±0.12 (-1.32 ^a)	3.12±0.58 (-1.71 ^b)	1.57±0.09 (-2.77 ^c)	1.77±0.31 (-2.58 ^c)
K	14.43±1.81 (+4.18 ^b)	11.98±1.30 (+2.07 ^c)	13.01±0.11 (+6.81 ^a)	11.60±0.50 (-0.40 ^e)	13.07±1.05 (+0.59 ^d)
Na	0.26±0.03 (-0.28 ^c)	0.29±0.00 (-0.37 ^d)	0.33±0.06 (-0.01 ^b)	0.28±0.02 (-0.01 ^b)	0.37±0.01 (+0.11 ^a)
Al	0.40±0.05 (-0.04 ^d)	0.71±0.08 (+0.41 ^b)	0.39±0.07 (+0.18 ^c)	0.38±0.02 (+0.18 ^c)	1.25±0.44 (+0.84 ^a)
Fe	0.40±0.07 (-0.07 ^c)	0.47±0.04 (+0.08 ^b)	0.24±0.03 (+0.03 ^c)	0.18±0.01 (-0.02 ^d)	0.83±0.07 (+0.45 ^a)
Mn	0.10±0.04 (+0.03 ^a)	0.11±0.02 (-0.02 ^c)	0.10±0.03 (-0.02 ^c)	0.10±0.01 (-0.01 ^b)	0.15±0.01 (-0.06 ^d)
Zn	0.02±0.00 (+0.00 ^a)	0.02±0.00 (-0.01 ^a)	0.01±0.00 (+0.00 ^a)	0.01±0.00 (+0.00 ^a)	0.02±0.00 (+0.00 ^a)
Cu	0.01±0.00 (+0.00 ^a)	0.01±0.00 (+0.00 ^a)	0.01±0.00 (+0.00 ^a)	0.00±0.00 (+0.00 ^a)	0.01±0.00 (+0.00 ^a)
P	2.23±0.31 (+0.63 ^c)	2.28±0.23 (+0.14 ^d)	2.16±0.54 (+0.81 ^b)	2.23±0.38 (+0.87 ^b)	3.38±0.22 (+1.39 ^a)

The values are expressed as means ± SD of 3 replications. The values in bracket indicate the changes in the content (mg/g) compared to the content before planting. Means following the same letter indicate no significant difference according to Duncan's multiple range test. ¹⁾CO; C. obtusa, ²⁾AP; A. palmatum, ³⁾AT; A. turbinata, ⁴⁾BG; Bare ground, and ⁵⁾PK; P. koraiensis

2. Changes in free amino acid content in forest cultivation sites

The free amino acid content of wild garlic differed depending on the cultivation environment (Table 4).

The most abundant free amino acid was urea, followed by L-asparagine, L-alanine, and L-leucine. Hydroxy-L-proline was detected in CO forest with high content, but it was not detected in the other sites. It was previously detected in AT and PK forest before planting, but not detected after planting. In AP forest, urea (5.03 mg/g), L-aspartic acid (2.10 mg/g), L-asparagine (3.84 mg/g), L-alanine (3.81 mg/g) and L-valine (3.09 mg/g) content increased, and amino acid content increased in wild garlic planted in AT forest included urea (13.14 mg/g), L-aspartic acid (6.03 mg/g), L-threonine (3.15 mg/g), and L-asparagine (2.38 mg/g). In BG, the content of urea (12.62 mg/g), L-threonine (3.65 mg/g), L-asparagine (3.12 mg/g), and L-glutamic acid (3.06 mg/g) increased. The urea, L-threonine, L-asparagine, and L-glutamic acid contents of wild garlic grown in PK forest were commonly increased.

The content of each free amino acid changed after wild garlic was planted in five different types of forest. In AP, BG, and PK forest, the content of over 24 kinds of free amino acid increased after planting: the content of 28, 24, 24 kinds of free amino acid increased in each forest. However, the content of only 14 kinds of free amino acid increased in CO forest. In AT forest, the number of free amino acid of which the content increased was less than that of CO forest. The content of urea, L-aspartic acid, L-threonine, L-asparagine, L-glutamic acid, γ -aminobutyric acid, and ethanolamine increased in AT forest and that of the other free amino acid decreased or was not detected.

3. Changes in volatile compound content in forestry cultivation sites.

20 volatile compounds were detected in wild garlic planted in five types of forest (Table 5). The most abundant volatile compound was dimethyl trisulfide, followed by disulfide, dimethyl disulfide, methyl 2-propenyl, and 2-hexenal.

The number of volatile compounds detected in wild garlic before planting remained unchanged after it was cultivated in the forests for a year (Table 6). However, in the case of single compounds, there was significant increase or decrease in the content between before and after planting of wild garlic. There was an increase in the content of some volatile compounds after cultivation in the forests. The content of 11, 8, 10, 8, and

4 volatile compounds increased in wild garlic planted in CO, AP, AT, BG, and PK, respectively.

4. Relationship between soil properties and minerals, amino acids, and volatile composition

Soil properties of each experimental site affected minerals, amino acids, and volatile composition (Table 7). pH negatively affected mineral content of wild garlic except manganese. Calcium had positive relationships with total N and cation exchange capacity, whereas sodium, aluminium, iron, and zinc had negative relationships with exchangeable cations.

Amino acid content was strongly affected by pH, exchangeable Ca^{2+} , and Mg^{2+} . In contrast, total N slightly affected amino acid content, which had significant correlations with only 6 of 41 components. Among soil properties, available P and exchangeable Na^{+} had positive correlation with the content of almost all type of amino acid. However, some amino acid such as L-citrulline, L- α -amino iso-n-butyric acid, cystathionine, L-arginine had no significant correlations with any soil properties.

The volatile compound content was strongly affected by pH, exchangeable Mg^{2+} , whereas available P and cation exchange capacity had little impact on volatile compound compositions: less than only 3 types of volatile compounds had significant correlations with these soil properties. Among volatile compound, disulfide, methyl 2-propenyl, disulfide, methyl 1-propenyl, and tetrasulfide had no significant correlations with any soil properties.

DISCUSSION

1. Effects of forest cultivation on the mineral content of wild garlic

Differences in mineral content were seen between before planting and after planting wild garlic. The most abundant minerals in wild garlic leaves are potassium, calcium, and phosphorus. Among the five regions, the region with the most mineral content was CO forest, followed by PK and AT forest.

It was confirmed that the results of this study were similar to the study by Kim *et al.* (2012), who reported that among the inorganic components of wild garlic, the potassium and calcium content was very high compared to other inorganic elements. However, the content of inorganic components in wild garlic slightly differed in each research report. Hong and Kim (2018) reported that among the inorganic components of wild garlic, the contents of potassium, calcium, magnesium, phosphorus, sulfur, iron, zinc, and sodium are 24,562.43 mg/kg, 10,538.41

Table 4. The free amino acid content of wild garlic cultivated in different experimental sites (mg/g, dry weight).

Compound	RT ^a	Content after planting (mg/g)				
		CO ¹⁾	AP ²⁾	AT ³⁾	BC ⁴⁾	PK ⁵⁾
Urea	10.63	0±0 (+0.00 ^d)	5.03±0.2 (+5.03 ^c)	13.14±1.2 (+13.14 ^b)	12.62±3.3 (+12.62 ^b)	20.05±2.8 (+20.05 ^a)
L-Aspartic acid	21.03	0±0 (+0.00 ^c)	2.10±0.1 (+2.10 ^b)	6.03±0.3 (+6.03 ^a)	0±0 (+0.00 ^c)	0±0 (+0.00 ^c)
Hydroxy-L-proline	23.53	516.51±30.3 (+450.10 ^a)	0±0 (+0.00 ^b)	0±0 (-333.84 ^c)	0±0 (+0.00 ^b)	0±0 (-451.66 ^d)
L-Threonine	26.93	0±0 (+0.00 ^c)	1.62±0.1 (+1.62 ^b)	3.15±0.5 (+3.15 ^a)	3.65±0.7 (+3.65 ^a)	3.06±0.2 (+3.06 ^a)
L-Serine	28.33	2.76±0.2 (+0.72 ^a)	1.72±0.2 (+1.32 ^a)	2.54±0.3 (-0.39 ^b)	2.64±0.1 (+0.37 ^{ab})	2.91±0.1 (+0.73 ^a)
L-Asparagine	32.70	0±0 (+0.00 ^c)	3.84±0.2 (+3.84 ^b)	2.38±0.2 (+2.38 ^d)	3.12±0.1 (+3.12 ^c)	8.97±0.4 (+8.97 ^a)
L-Glutamic acid	35.36	1.40±0.1 (-2.09 ^b)	2.45±0.2 (+1.72 ^a)	3.17±0.2 (+1.25 ^a)	3.06±0.2 (+2.13 ^a)	4.13±0.3 (+2.36 ^a)
L-Sarcosine	40.00	1.4±0.2 (+1.40 ^a)	0.49±0.1 (+0.49 ^b)	0.72±0.1 (-2.65 ^d)	1.95±0.2 (+0.89 ^b)	0.35±0.1 (-1.36 ^c)
L-?-Amino adipic acid	42.50	0±0 (+0.00 ^b)	0±0 (+0.00 ^b)	0.03±0.0 (-0.06 ^c)	0.03±0.0 (+0.01 ^b)	0.08±0.0 (+0.04 ^a)
L-Proline	44.46	4.57±0.3 (-0.44 ^{ab})	2.43±0.1 (+1.62 ^a)	4.75±0.3 (-0.87 ^b)	5.19±0.3 (+1.48 ^a)	4.74±0.2 (+1.14 ^{ab})
Glycine	46.16	0.94±0.2 (-0.01 ^b)	0.76±0.1 (+0.58 ^a)	0.96±0.2 (-0.25 ^b)	1.18±0.1 (+0.09 ^{ab})	0.99±0.1 (+0.22 ^{ab})
L-Alanine	47.70	6.41±0.4 (+1.06 ^b)	3.81±0.2 (+2.99 ^a)	5.25±0.8 (-0.87 ^c)	5.35±0.2 (+0.77 ^b)	5.85±0.8 (+1.81 ^b)
L-Citrulline	49.63	2.68±0.5 (-0.65 ^c)	0.95±0.2 (+0.66 ^a)	2.11±0.4 (-1.96 ^b)	2.03±0.1 (+0.93 ^a)	3.48±0.3 (+1.45 ^a)
L-α-Amino iso-n-butyric Acid	51.46	0.76±0.2 (-0.09 ^{ab})	0.28±0.1 (+0.19 ^a)	0.57±0.1 (-0.50 ^b)	0.49±0.1 (+0.16 ^a)	0.87±0.1 (+0.34 ^a)
L-Valine	53.73	4.73±0.1 (+0.55 ^b)	3.09±0.1 (+2.42 ^a)	4.35±0.2 (-0.83 ^c)	4.68±0.3 (+0.81 ^b)	4.66±0.1 (+1.08 ^b)
L-Cystine	57.26	3.96±0.1 (+1.93 ^a)	0.46±0.1 (+0.26 ^b)	3.17±0.2 (-2.15 ^c)	0.92±0.2 (+0.58 ^b)	1.67±0.2 (-1.31 ^c)
L-Methionine	60.70	0.77±0.2 (-0.14 ^b)	0.41±0.1 (+0.30 ^a)	0.66±0.1 (-0.24 ^b)	0.47±0.1 (-0.28 ^b)	0.78±0.1 (+0.31 ^a)
Cystathionine	62.10	0.85±0.1 (+0.29 ^a)	0.41±0.0 (+0.34 ^a)	0.70±0.0 (-0.25 ^b)	0.35±0.0 (-0.11 ^b)	1.19±0.0 (+0.58 ^a)
L-Isoleucine	65.33	2.20±0.2 (-0.07 ^c)	1.33±0.1 (+0.96 ^a)	2.23±0.3 (-0.11 ^c)	2.86±0.3 (+0.38 ^b)	2.08±0.1 (+0.57 ^b)
L-Leucine	67.16	5.24±0.4 (-0.18 ^{cd})	3.13±0.2 (+2.27 ^a)	5.01±0.4 (-0.70 ^d)	6.18±0.4 (+0.80 ^{bc})	5.25±0.2 (+1.51 ^{ab})
L-Tyrosine	70.36	2.95±0.5 (+0.03 ^b)	1.71±0.2 (+1.26 ^a)	2.87±0.4 (-0.37 ^b)	3.43±0.2 (+0.78 ^{ab})	2.77±0.2 (+0.75 ^{ab})
L-Phenyl alanine	73.53	4.74±0.7 (+0.43 ^c)	2.78±0.4 (+2.12 ^a)	4.47±0.9 (-0.97 ^d)	5.28±0.3 (+1.33 ^b)	4.64±0.2 (+1.18 ^b)

Table 4. Continued.

Compound	RT ^a	Content after planting (mg/g)				
		CO ¹⁾	AP ²⁾	AT ³⁾	BG ⁴⁾	PK ⁵⁾
D, L-β-Amino isobutyric Acid	75.30	0.26±0.2 (+0.04 ^b)	0±0 (-0.03 ^{bc})	0.20±0.0 (-0.11 ^c)	0.22±0.1 (+0.07 ^{ab})	0.33±0.1 (+0.15 ^a)
L-Homocystine	77.66	0.26±0.1 (-0.02 ^b)	0.59±0.2 (+0.55 ^a)	0.20±0.0 (-0.09 ^b)	0.20±0.1 (-0.15 ^b)	0.19±0.0 (+0.00 ^b)
γ-Amino-n-butyric Acid	79.73	2.49±0.1 (+0.81 ^b)	1.97±0.4 (+1.61 ^a)	1.89±0.1 (+0.63 ^b)	1.58±0.1 (-1.43 ^c)	2.20±0.1 (+1.09 ^{ab})
Ethanolamine	83.26	0.64±0.2 (-0.14 ^b)	0.27±0.1 (+0.16 ^a)	0.44±0.2 (+0.23 ^a)	0.37±0.0 (-0.20 ^b)	0.47±0.1 (-0.07 ^b)
Ammonium chloride	86.79	3.56±0.2 (+1.40 ^a)	1.85±0.0 (+1.49 ^a)	2.98±0.3 (-1.04 ^d)	3.16±0.0 (+0.48 ^c)	3.62±0.1 (+1.02 ^b)
δ-Hydroxylysine	90.36	0.31±0.1 (-0.15 ^{abc})	0±0 (+0.00 ^a)	0±0 (-0.26 ^c)	0±0 (-0.10 ^{ab})	0.07±0.0 (-0.22 ^{bc})
L-Ornithine	93.43	0.03±0.0 (-0.03 ^a)	0±0 (+0.00 ^a)	0±0 (-0.03 ^a)	0±0 (+0.00 ^a)	0±0 (-0.02 ^a)
L-Lysine	97.33	4.12±0.2 (+0.31 ^c)	2.58±0.1 (+1.96 ^a)	3.65±0.2 (-0.75 ^d)	4.02±0.2 (+0.07 ^c)	3.77±0.5 (+0.73 ^b)
1-Methyl-L-histidine	98.99	0.07±0.0 (+0.00 ^a)	0±0 (+0.00 ^a)	0±0 (-0.22 ^b)	0±0 (+0.00 ^a)	0±0 (-0.17 ^b)
L-Histidine	100.49	0.56±0.1 (-0.01 ^b)	0.43±0.0 (+0.35 ^a)	0.49±0.1 (-0.19 ^c)	0.58±0.2 (+0.03 ^b)	0.48±0.1 (+0.06 ^b)
3-Methyl-L-histidine	102.49	0.68±0.2 (-0.06 ^b)	0.37±0.1 (+0.28 ^a)	0.56±0.1 (-0.34 ^c)	1.00±0.2 (+0.37 ^a)	0.57±0.0 (+0.00 ^b)
L-Anserine	106.66	0±0 (+0.00 ^a)	0±0 (+0.00 ^a)	0±0 (+0.00 ^a)	0±0 (+0.00 ^a)	0±0 (-0.57 ^b)
L-Carnosine	108.86	0±0 (-0.05 ^a)	0±0 (+0.00 ^a)	0±0 (-0.07 ^a)	0±0 (+0.00 ^a)	0±0 (-0.41 ^b)
L-Arginine	114.36	3.72±0.2 (+0.41 ^{ab})	2.37±0.7 (+1.89 ^a)	3.35±0.2 (-1.34 ^b)	4.21±0.9 (+0.88 ^a)	3.70±0.2 (+0.91 ^a)

The values are expressed as means ± SD of 3 replications. The values in bracket indicate the changes in the content (mg/g) compared to the content before planting. Means following the same letter indicate no significant difference according to Duncan's multiple range test. ¹⁾CO; *C. obtusa*, ²⁾AP; *A. palmatum*, ³⁾AT; *A. turbinata*, ⁴⁾BG; Bare ground, and ⁵⁾PK; *P. koraiensis*

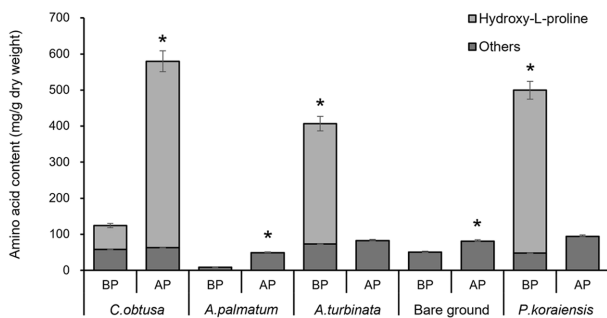


Fig. 3. Amino acid content before and after planting wild garlic at five planting sites. Bars indicate means of 3 replications and error bars indicate standard deviations. *Significantly different according to *t*-test ($p < 0.05$).

mg/kg, 2,001.38 mg/kg, and 1,656.38 mg/kg, 1,485.71 mg/kg, 203.69 mg/kg, 41.10 mg/kg, and 28.95 mg/kg respectively, which was said to have a higher content than daylily, slightly different from the content in this study.

A significant increase in mineral content was observed in the AT forest, despite its lower levels of available phosphorus and exchangeable cations (K^+ , Ca^{2+} , Mg^{2+}) compared to other sites. These results suggest that factors beyond soil mineral content, such as total nitrogen content, cation exchange capacity (CEC), and canopy coverage, may have collectively influenced nutrient uptake.

The AT forest exhibited higher CEC and total nitrogen

Table 5. Volatile compound components of wild garlic collected from planting sites.

No	RT ^a	Compound	Peak area after planting (%)				
			CO ¹⁾	AP ²⁾	AT ³⁾	BC ⁴⁾	PK ⁵⁾
1	3.24	Butanal	4.1±0.6 (+0.40 ^b)	3.6±0.5 (-1.00 ^b)	2.8±1.1 (-0.43 ^b)	7.7±2.0 (+3.20 ^a)	1.4±0.7 (-0.10 ^b)
2	3.78	Benzoic acid	11.2±3.2 (+10.60 ^a)	5.8±1.5 (+1.30 ^b)	3.6±1.7 (-0.20 ^{ab})	1.8±0.8 (-0.50 ^{ab})	4.0±1.6 (-2.90 ^b)
3	4.82	Disulfide, dimethyl	0±0 (+0.00 ^b)	0±0 (+0.00 ^b)	5.3±2.3 (+1.90 ^b)	7.8±4.1 (+4.00 ^b)	34.3±6.4 (+22.50 ^a)
4	6.21	Hexanal	11.5±2.9 (+10.00 ^a)	8.9±3.4 (+1.80 ^b)	8.4±0.6 (+0.50 ^{bc})	4.9±1.0 (+1.20 ^b)	5.0±1.4 (-3.50 ^c)
5	7.83	2-hexenal	17.0±4.2 (-7.50 ^a)	16.0±5.1 (-6.73 ^a)	14.9±2.7 (-2.20 ^a)	6.2±0.5 (-2.37 ^a)	2.6±0.8 (-3.90 ^a)
6	9.42	1,3-dithiane	0.3±0.1 (-1.20 ^b)	1.1±0.3 (+0.50 ^a)	9.6±2.1 (+1.00 ^a)	0.3±0.1 (-0.03 ^{ab})	0.2±0.1 (-0.20 ^{ab})
7	9.76	Disulfide, methyl 2-propenyl	15.1±4.9 (-2.60 ^a)	4.3±2.3 (+0.00 ^a)	4.3±0.6 (+1.10 ^a)	14.3±3.8 (+1.80 ^a)	8.4±3.6 (-2.50 ^a)
8	10.49	Disulfide, methyl 1-propenyl	2.3±1.2 (+0.80 ^b)	4.3±0.6 (-1.00 ^b)	10.7±3.7 (+7.20 ^a)	2.6±1.1 (-1.00 ^b)	4.4±1.5 (-4.90 ^c)
9	11.50	Dimethyl trisulfide	13.7±3.4 (+6.50 ^b)	28.1±5.7 (+19.00 ^a)	5.5±1.3 (+0.10 ^b)	8.7±1.8 (+1.10 ^b)	30.1±6.4 (+5.30 ^b)
10	11.91	1-octen-3-ol	5.6±3.2 (+3.50 ^a)	5.4±2.4 (+0.80 ^a)	1.1±0.3 (-0.10 ^a)	8.4±2.2 (+0.60 ^a)	0.1±0.0 (-0.07 ^a)
11	12.07	2,3-octanedione	2.0±0.6 (+1.60 ^a)	0.4±0.1 (-0.97 ^b)	4.1±1.3 (+1.60 ^a)	0.8±0.3 (-0.10 ^b)	0.4±0.0 (+0.10 ^b)
12	12.47	3-octanol	0.2±0.1 (+0.07 ^a)	0.1±0.1 (-2.93 ^b)	2.7±1.4 (+0.10 ^a)	0.8±0.5 (-0.20 ^a)	0.5±0.1 (+0.40 ^a)
13	12.66	Octanal	1.3±0.5 (+1.20 ^a)	1.9±0.6 (-1.00 ^c)	0.7±0.4 (+0.10 ^b)	0.8±0.3 (+0.17 ^{ab})	0.4±0.1 (-0.70 ^{bc})
14	13.03	Cyclopentane carboxaldehyde	1.4±0.7 (+1.00 ^{ab})	3.8±1.6 (+2.60 ^a)	4.8±3.2 (-4.90 ^c)	1.1±0.6 (+0.30 ^{ab})	0.7±0.1 (-0.50 ^b)
15	14.83	1-octanol	0.5±0.2 (+0.40 ^a)	0.7±0.1 (-0.73 ^{bc})	1.1±0.6 (-0.10 ^{ab})	0.3±0.1 (-0.03 ^{ab})	0.3±0.0 (-1.10 ^c)
16	15.09	Diallyl disulphide	3.5±1.2 (-5.90 ^c)	2.7±1.2 (-3.20 ^{ab})	3.2±0.5 (-3.30 ^{ab})	13.6±3.6 (-4.10 ^{bc})	0.2±0.0 (-1.40 ^a)
17	15.53	Tetrasulfide	0.8±0.2 (-0.80 ^a)	2.2±0.3 (-2.10 ^a)	3.3±1.2 (-1.57 ^a)	1.4±0.4 (-0.60 ^a)	0.4±0.1 (-0.80 ^a)
18	16.95	Hexane	5.9±2.1 (-14.70 ^d)	6.7±1.5 (-8.10 ^c)	10.7±3.2 (+2.10 ^a)	15.1±1.9 (-1.70 ^b)	5.9±0.3 (-4.10 ^b)
19	17.73	1-propene	0.2±0.1 (-0.13 ^b)	2.2±0.4 (+1.30 ^a)	0.4±0.2 (-0.20 ^b)	0.5±0.1 (-0.20 ^b)	0.3±0.1 (-1.10 ^c)
20	21.67	Trisulfide	3.4±1.3 (-3.10 ^a)	0.2±0.1 (-1.17 ^a)	2.7±0.4 (-2.73 ^a)	3.0±0.3 (-1.60 ^a)	0.3±0.1 (-0.70 ^a)
Total			100	100	100	100	100

The values are expressed as means ± SD of 3 replications. The values in bracket indicate the changes in peak area (%) compared to the peak area before planting. Means following the same letter indicate no significant difference according to Duncan's multiple range test. ¹⁾CO; *C. obtusa*. ²⁾AP; *A. palmatum*, ³⁾AT; *A. turbinata*, ⁴⁾BC; Bare ground, and ⁵⁾PK; *P. koraiensis*

Table 6. The number of volatile compounds, the content of total volatile compounds, and the content of dimethyl trisulfide, the main compound, before and after planting wild garlic.

Planting site	Number of VC	Number of VC increased after planting	Content of dimethyl trisulfide	
			Before planting	After planting
CO ¹⁾	19	11	7.2	13.7
AP ²⁾	19	8	9.1	28.1
AT ³⁾	20	10	5.4	5.5
BG ⁴⁾	20	8	7.6	8.7
PK ⁵⁾	20	4	24.8	30.1

Detailed results of volatile compound analysis are presented in Table 5.

¹⁾CO; *C. obtusa*, ²⁾AP; *A. palmatum*, ³⁾AT; *A. turbinata*, ⁴⁾BG; Bare ground, and ⁵⁾PK; *P. koraiensis*

Table 7. Pearson's correlation analysis between soil properties and change in amino acids, minerals and volatile composition.

	pH	OM ¹⁾ (%)	TN ²⁾ (%)	AP ³⁾ (%)	CEC ⁴⁾ (cmol _c ·kg ⁻¹)	Exchangeable cation (cmol _c ·kg ⁻¹)			
						K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺
Mg	-.631*	-.136	-.261	-.482	-.379	-.294	-.948**	-.324	-.776**
Ca	.067	.416	.921**	.298	.734**	-.136	.748**	-.407	.098
K	.055	-.301	.184	-.629*	.355	-.001	-.171	-.272	-.080
Na	-.965**	.528*	-.034	-.280	-.053	-.750**	-.686**	-.670**	-.961**
Al	-.602*	.962**	.138	-.056	.537*	-.813**	.156	-.616*	-.384
Fe	-.683**	.918**	-.036	-.283	.508	-.887**	-.045	-.655**	-.472
Mn	.792**	-.974**	-.351	.048	-.524*	.886**	-.023	.803**	.641**
Zn	-.563*	-.172	-.548*	-.554*	-.472	-.271	-.999**	-.175	-.662**
Cu	c	c	c	c	c	c	c	c	c ⁵⁾
P	-.871**	.503	-.362	-.452	-.066	-.756**	-.722**	-.538*	-.808**
Urea	-.933**	.770**	.202	-.118	.202	-.834**	-.359	-.765**	-.866**
L-Aspartic acid	-.184	.094	.743**	-.227	.552*	-.197	.101	-.577*	-.302
Hydroxy-L-proline	.874**	-.880**	-.498	.164	-.552*	.896**	.106	.938**	.799**
L-Threonine	-.762**	.536*	.461	.242	-.002	-.518*	-.247	-.592*	-.786**
L-Serine	.423	.092	-.141	.305	.084	.192	.529*	.366	.569*
L-Asparagine	-.689**	.944**	.096	-.040	.419	-.828**	.030	-.620*	-.489
L-Glutamic acid	-.555*	.721**	.562*	.410	.248	-.503	.184	-.528*	-.481
L-Sarcosine	.764**	-.605*	-.482	.499	-.632*	.798**	.239	.961**	.771**
L-α-Amino adipic acid	-.068	.328	-.532*	.193	-.213	-.159	.030	.233	.125
L-Proline	.032	.306	.109	.561*	-.063	.006	.366	.131	.141
Glycine	.286	.276	.140	.448	.203	.077	.630*	.181	.430
L-Alanine	.384	.274	-.052	.405	.195	.100	.673**	.300	.578*
L-Citrulline	-.096	.433	-.193	.457	-.141	-.149	.218	.144	.081
L-?-Amino iso-n-butyric Acid	-.002	.351	-.226	.367	-.097	-.095	.238	.182	.167
L-Valine	.426	.224	.046	.564*	.118	.195	.722**	.355	.595*
L-Cystine	.779**	-.701**	-.569*	.305	-.610*	.799**	.133	.947**	.764**
L-Methionine	-.019	.576*	.079	.019	.533*	-.349	.481	-.196	.182

Table 7. Continued.

	pH	OM ¹⁾ (%)	TN ²⁾ (%)	AP ³⁾ (%)	CEC ⁴⁾ (cmol _c ·kg ⁻¹)	Exchangeable cation (cmol _c ·kg ⁻¹)			
						K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺
Cystathionine	.067	.374	-.378	-.146	.276	-.248	.248	.047	.280
L-Isoleucine	.116	.514*	.316	.583*	.289	-.084	.703**	.017	.289
L-Leucine	.118	.500	.186	.530*	.244	-.092	.647**	.063	.307
L-Tyrosine	.156	.296	.120	.555*	.031	.054	.501	.179	.286
L-Phenyl alanine	.337	.224	-.024	.680**	-.077	.202	.607*	.405	.499
D, L-?-Amino isobutyric Acid	-.244	.249	-.606*	.001	-.312	-.234	-.271	.129	-.106
L-Homocystine	.515*	.219	.413	.378	.534*	.169	.928**	.128	.642**
γ-Amino-n-butyric Acid	.173	.350	.125	-.404	.821**	-.280	.496	-.267	.319
Ethanolamine	-.028	.299	.767**	-.117	.783**	-.231	.463	-.528*	-.040
Ammonium chloride	.549*	-.051	-.476	.255	-.107	.309	.438	.603*	.719**
δ-Hydroxylysine	.606*	-.163	.149	.673**	-.118	.528*	.648**	.538*	.650**
L-Ornithine	.240	.152	.372	.965**	-.200	.301	.590*	.316	.295
L-Lysine	.465	.285	.100	.455	.315	.138	.827**	.279	.656**
1-Methyl-L-histidine	.726**	-.508	-.243	.585*	-.500	.753**	.361	.838**	.724**
L-Histidine	.486	.223	.177	.606*	.206	.230	.837**	.336	.647**
3-Methyl-L-histidine	.345	-.024	.009	.859**	-.411	.412	.435	.542*	.411
L-Anserine	.683**	-.782**	.284	.390	-.322	.838**	.248	.544*	.486
L-Carnosine	.692**	-.709**	.294	.528*	-.349	.842**	.332	.586*	.524*
L-Arginine	.335	.141	-.084	.500	-.052	.194	.504	.375	.474
Butanal	-.074	-.337	-.281	.395	-.820**	.305	-.427	.380	-.171
Benzoic acid	.718**	-.789**	-.542*	-.228	-.315	.660**	-.037	.690**	.650**
Disulfide, dimethyl	-.741**	.754**	-.250	-.313	.216	-.818**	-.320	-.543*	-.571*
Hexanal	.735**	-.840**	-.453	-.099	-.394	.738**	-.021	.726**	.639*
2-hexenal	-.498	.205	.235	.027	-.072	-.292	-.314	-.374	-.560*
1,3-dithiane	-.252	.338	.714**	.167	.404	-.243	.244	-.480	-.286
Disulfide, methyl 2-propenyl	-.037	-.071	.447	.389	-.126	.153	.076	-.042	-.139
Disulfide, methyl 1-propenyl	.059	-.393	.392	-.249	.109	.177	-.145	-.175	-.140
Dimethyl trisulfide	.573*	.131	.214	.349	.404	.235	.852**	.263	.710**
1-octen-3-ol	.475	-.506	-.441	-.104	-.277	.443	-.035	.514*	.449
2,3-octanedione	-.110	-.423	-.332	-.708**	-.118	-.009	-.635*	-.089	-.246
3-octanol	-.518*	-.049	-.465	-.538*	-.293	-.324	-.820**	-.224	-.576*
Octanal	.242	-.726**	-.539*	-.314	-.546*	.426	-.528*	.427	.098
Cyclopentane carboxaldehyde	.595*	-.129	-.258	.491	-.195	.447	.515*	.643**	.712**
1-octanol	.363	-.762**	-.265	-.073	-.512	.567*	-.313	.463	.190
Diallyl disulphide	-.600*	.815**	.346	-.029	.507	-.716**	.108	-.666**	-.469
Tetrasulfide	-.201	-.132	-.498	-.119	-.468	-.027	-.511	.143	-.217
Hexane	-.715**	.441	.610*	.081	.157	-.496	-.234	-.694**	-.789**

Table 7. Continued.

	pH	OM ¹⁾ (%)	TN ²⁾ (%)	AP ³⁾ (%)	CEC ⁴⁾ (cmol _c ·kg ⁻¹)	Exchangeable cation (cmol _c ·kg ⁻¹)			
						K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺
1-propene	.757**	-.252	.519*	.584*	.198	.605*	.862**	.402	.741**
Trisulfide	-.234	.542*	.153	.288	.182	-.318	.255	-.193	-.099

¹⁾OM; organic matter content, ²⁾TN; total N, ³⁾AP; available P, ⁴⁾CEC; cation exchange capacity, ⁵⁾c; cannot be calculated because Cu has constant value.

*Significant at $p < 0.05$, **significant at $p < 0.01$

content than other sites, which may have facilitated increased mineral retention and absorption. In nitrogen-rich soils, root growth is enhanced, leading to an expansion of surface area for nutrient uptake, thereby improving mineral absorption efficiency. Additionally, the organic matter content in the AT forest could have played a role in increasing mineral solubility and mobility (Robinson *et al.*, 2005; Oney-Montalvo *et al.*, 2020). Organic acids released during decomposition can enhance the availability of P and other cations.

Canopy structure and shading effects may have also contributed to the increase in mineral content. Wild garlic is sensitive to high temperatures, and shading helps regulate surface temperature, reducing transpiration-induced water stress. Trees with a higher leaf area index (LAI) reduce surface temperature more effectively than those with lower values (Armson *et al.*, 2013). It seems that the trees in AT forest had the largest leaves and LAI among all sites, providing better shading and creating a more favorable microclimate for wild garlic growth.

These findings indicate that soil nitrogen content, CEC, and shading effects may have collectively led to the observed increase in mineral content. However, additional research is necessary to elucidate the precise mechanisms involved. Future studies should examine microbial activity, root structure, and long-term mineral dynamics to better understand these interactions. Additionally, experiments incorporating a broader pH range and controlled fertilizer applications would be beneficial in further investigating soil-plant interactions within forest cultivation systems.

2. Effects of forest cultivation on the free amino acid composition of wild garlic

The amino acid content of wild garlic varied depending on the cultivation environment. The most abundant amino acid in wild garlic was urea, followed by L-asparagine, L-alanine, and L-leucine. This trend was different from the previous studies.

Cho *et al.* (2011) reported that wild garlic's total free amino acid content was 535.39 mg/100 g and among the 38 free amino acids isolated, asparagine, glutamic acid, and lysine were contained in high amounts. In addition, Park *et al.* (1998) reported that the highest free amino acid content in wild garlic were arginine, followed by glutamic acid, and asparagine.

In the CO forest, hydroxy-L-proline content significantly increased, which is a major component of hydroxyproline-rich glycoproteins (HRGPs) involved in cell wall strengthening and stress responses (MacLean *et al.*, 2009; Deepak *et al.*, 2010). This increase could be linked to the allelopathic effects of *C. obtusa* (Kato-Noguchi *et al.*, 2024) and nitrogen-limited conditions. *C. obtusa* is known to release secondary metabolites that alter soil chemistry, and the low nitrogen content in the CO forest may have induced stress responses, leading to an increase in hydroxy-L-proline synthesis.

Amino acid synthesis in plants is influenced by soil mineral content. Deficiencies in iron (Fe) and zinc (Zn) have been shown to increase L-asparagine and glutamic acid synthesis, while copper (Cu) and manganese (Mn) deficiencies lead to an overall rise in amino acid levels (Possingham, 1956). Additionally, nitrogen (N) fertilization has been reported to increase arginine, serine, alanine, and γ -aminobutyric acid (Hoff *et al.*, 1974).

In this study, changes in the content of various free amino acids including urea, L-asparagine, L-aspartic acid, γ -aminobutyric acid, and L-glutamic acid were observed, and nitrogen and phosphorus enrichment in AP forest and BG likely promoted amino acid synthesis. In contrast, the D,L- β -aminoisobutyric acid in the CO and PK forest suggests that nitrogen assimilation mechanisms may have been activated under nitrogen-limited conditions.

3. Effects of environmental factors on the volatile compound composition

Change in volatile compound composition in plants occurs in response to various environmental factors, such as soil nutrients

(Chrysargyris *et al.*, 2017), foliar diseases (Ponmurugan *et al.*, 2016), and drought stress (Chandrasekaran *et al.*, 2022).

The most abundant volatile compound in wild garlic planted at five sites was dimethyl trisulfide, disulfide, dimethyl, disulfide, methyl 2-propenyl, and 2-hexenal. This result also has some differences from previous studies. The volatile compounds of wild garlic shoot grown in Ulleung Island in Korea are known as dimethyl trisulfide (5.2% - 10.3%), diallyl disulfide (0.1% - 12.1%) and dimethyl pentasulfide (0% - 0.3%), which is somewhat different from this study (Yang *et al.*, 2014). Park *et al.* (1998) reported that the main volatile compounds in wild garlic from Ulleung Island and Mt. Odae are 3-(methylthio)-I-propene and 2-vinyl-4H-1,3-dithin.

Additionally, in this study, there was no difference in the type and total content of volatile compounds between planting areas, but differences were seen in single compounds. This also is somewhat different from previous studies. Park *et al.* (1998) found that wild garlic from Mt. Odae or Mt. Jiri contained significantly higher amounts of sulfur compounds than that from Ulleung Island, which has oceanic geographical conditions. In addition, Yang *et al.* (2014) also reported differences in the types and total contents of volatile compounds between Ulleung Island regions. PCA analysis showed that the habitat of wild garlic plants significantly affected the proportion of alk(en)yl groups (methyl, m-propyl and allyl radicals) in bulb and shoot tissues.

In this study, the contents of amino acids and volatile compounds differed depending on the planting area. Since the study sites were not far apart, the metabolite differences were likely due to differences in upper vegetation. As for upper vegetation, fallen leaves, and compounds released during leaf decomposition enter the soil, affecting wild garlic's growth and metabolite biosynthesis.

Oney-Montalvo *et al.* (2020) also reported that the physical and chemical composition of the soil affects the profile and concentration of polyphenols, antioxidant activity, and maturity of habanero pepper (*Capsicum chinense* Jacq.). Additionally, three types of soil significantly affected the concentration of volatile compounds (1-hexanol, hexyl-3-methyl butanoate, 3,3-dimethyl-1-hexanol, and cis-3-hexenyl hexanoate) (Oney-Montalvo *et al.*, 2022).

This study used forestry cultivation method for the efficient production of wild garlic, a useful wild vegetable and medicinal plant. The results indicated that the content of minerals, amino acids, and volatile compounds are affected by the cultivation

environment for wild garlic. The mineral content was negatively correlated with pH, which indicates low pH could increase mineral content of wild garlic. High content of available P and exchangeable Na^+ in soil led to increase in the content of most of amino acids. The contents of exchangeable cations were related to a decrease in mineral content, whereas amino acids with long retention time were positively correlated with them.

Soil pH influences nutrient availability in soil and nutrient uptake by plants (Barrow and Hartemink, 2023). Normally, low soil pH induces adsorption of anions and cations, reducing nutrient availability. However, uptake of some nutrients, such as phosphorus and sulfur, can increase with decreasing soil pH (Vange *et al.*, 1974; Barrow and Hartemink, 2023). This could have increased the content of most minerals in wild garlic even in low soil pH in this study. However, since the difference in pH among test sites was small (5.0 - 5.4), sites with a wider pH range should be included in forestry cultivation to better determine the effect of soil pH on the mineral content of wild garlic.

Generally, plant can absorb more minerals from soil containing higher content of exchangeable cations. However, the test sites used in this study contained fewer exchangeable cations compared to its native habitat in Ulleung Island, which contained $2.1 \pm 1.4 \text{ cmol}_c \cdot \text{kg}^{-1} \text{ Ca}^{2+}$ and $1.0 \pm 0.8 \text{ cmol}_c \cdot \text{kg}^{-1} \text{ Mg}^{2+}$ (Hur *et al.*, 2012). This led to a decrease in the content of Mg, Ca, Na in leaves after transplanted in almost all test sites, which could distort the results of correlation analysis in this study.

Therefore, soil improvement, such as fertilization and amendment, should be employed to enhance mineral uptake of wild garlic to obtain more accurate and reliable correlation analysis data, which will better reflect the relationship between soil mineral content and plant mineral absorption.

This study found that the content of minerals, amino acids, and volatile compounds differed depending on the environment of forest cultivation. However, this study showed very short-term results, so long-term monitoring is likely necessary. Additionally, analysis of other secondary metabolites (e.g. flavonoid) using liquid chromatography will further support these findings. The results of this study will contribute to a better understanding of the effects of environmental factors on compounds in wild garlic. This will enable the distribution and production of quality wild garlic seeds, as well as the standardization and distribution of other valuable plants in the future.

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