



## Research Article

Phenological growth stages of Korean ginseng (*Panax ginseng*) according to the extended BBCH scaleYun-Soo Kim<sup>\*</sup>, Chol-Soo Park, Dong-Yun Lee, Joon-Soo Lee, Seung-Hwan Lee, Jun-Gyo In, Tae-Kyun Hong

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## ABSTRACT

**Background:** Phenological studies are a prerequisite for accomplishing higher productivity and better crop quality in cultivated plants. However, there are no phenological studies on *Panax ginseng* that improve its production yield. This study aims to redefine the phenological growth stages of *P. ginseng* based on the existing Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale and proposes a disease control reference.

**Methods:** This study was conducted at the Korea Ginseng Corporation Experiment Station in Gyeonggi province, South Korea. Phenological observations were performed once weekly or twice monthly, based on the developmental stages. The existing BBCH scale with a three-digit code was used to redefine and update *P. ginseng*'s phenological growth codes.

**Results:** The phenological description is divided into eight principal growth stages: three for vegetative growth (perennating bud, aerial shoot, and root development), four for reproductive growth (reproductive organ development, flowering, fruit development, and fruit maturation), and one for senescence according to the extended BBCH scale. A total of 58 secondary growth stages were described within the eight principal growth stages. Under each secondary growth stage, four mesostages are also taken into account, which contains the distinct patterns of the phenological characteristics in ginseng varieties and the process of transplanting seedlings. A practical management program for disease control was also proposed by using the BBCH code and the phenological data proposed in this work.

**Conclusion:** The study introduces an extended BBCH scale for the phenological research of *P. ginseng*.

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## 1. Introduction

Ginseng (genus *Panax*) is one of the most well-known medicinal plants and is widely used in Asia, including Korea, China, and Japan. In modern times, ginseng products have come to be highly recognized as an immune booster in Europe and the United States [1,2]. Recently, the pharmaceutical efficacy of ginseng has led to an increase in the use of ginseng products worldwide. The ginseng market value is expected to grow at a compounded annual growth rate (CAGR) of 4.8% during the 2019–2027 forecast period [3].

Currently, seventeen plants have been grouped under the genus *Panax* [4]. The most common species used for botanical preparations are *Panax ginseng* (Korean ginseng), grown in Korea and

China, and *Panax quinquefolius* (American ginseng) grown in the United States (Virginia and Wisconsin) and Canada (Ontario and Quebec) [2,5]. More than 50% of ginseng consumed in the world is produced in China, followed by South Korea (34.3%), Canada (8.1%), the United States (1.3%), and other countries (0.4%) [2]. As far as market distribution is concerned, Hong Kong has the largest trading market of both *P. ginseng* and *P. quinquefolius*. In contrast, South Korea has the largest consumption market of *P. ginseng* [2,6].

*P. ginseng* is a slow-growing, herbaceous perennial plant that is cultivated under artificial shade using a synthetic fabric for 4 to 6 yr to mimic the environments of its native forest habitat [7]. These environments are conducive for the survival and propagation of pests, particularly fungal pathogens [8]. The pathogenic microbes infect and damage both the leaves and the roots of ginseng, causing death and reducing yield. In addition to pathogens, climate change, including changes in temperature and precipitation, can threaten the stable production of ginseng [9]. Souther and McGraw [9] reported that ginseng is vulnerable to extremely early spring

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temperature fluctuations, or a spring freeze after a period of unusually warm temperatures. Therefore, establishing planned cultivation practices for stable ginseng production is required.

In cultivated plants, phenological studies are a prerequisite to accomplishing higher productivity and better crop quality because critical cultivation practices (sowing and transplanting periods, disease control, irrigation, nutrient management, and harvest time) are based on the phenological phases of plants [10]. The Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale is an official code accepted by the European and Mediterranean Plant Protection Organization (EPPO) for a wide range of crops and weeds [11,12]. The phenological scale, a system for uniform growth stage coding, is a widely used system that describes the phenological growth stages of plants [13–16]. While proposing a reference for the timing of agrochemical use for disease control, Proctor et al [15] described the phenological growth stages of North American ginseng (*P. quinquefolius*) using the extended BBCH scale. However, there are no phenological studies on *P. ginseng* for sustainable agricultural production. Therefore, this study was conducted to redefine the phenological growth stages for *P. ginseng* based on the existing BBCH scale, starting with germination/bud development and ending with senescence [15]. This study contributes to the standardization of phenological growth stages, quantitative analysis of the growth cycle, and efficient implementation of crop management practice across countries that grow *P. ginseng*.

## 2. Materials and methods

### 2.1. Location and plant material

This study was conducted at the Korea Ginseng Corporation Experiment Station, Anseong (N37°4'18" E127°21'38", altitude 220 m) located in Gyeonggi, South Korea. Temperatures in this region are warm and muggy during summer and freezing and dry during winter. The warmest month is August (21°C to 31°C), whereas January is the coldest (−9°C to 3°C) (Fig. 4). The annual precipitation ranges from 1,100 mm to 1,400 mm in the region. However, more than half of the annual precipitation falls during the summer. Meanwhile, winter precipitation is less than 10% of the total annual precipitation. Data on the phenological stages were collected from one- to six-year-old *P. ginseng* plants based on field observations and controlled environment studies from 2015–2020. Observations of vegetative and reproductive phases were performed once a week (bud, inflorescence, and flower) or twice a month (leaf, shoot, fruit, root, and dormancy) depending on the developmental stages. The weather data were obtained from the Korea Meteorological Administration from 2011–2020.

### 2.2. BBCH scale

An extended BBCH scale with a three-digit code was used to define and describe the phenological stages of *P. ginseng*. The first digit describes the principal growth stage, the second digit specifies the mesostages, and the third digit signifies secondary growth stages [12]. The existing BBCH scale for *P. quinquefolius* was used to develop an improved BBCH phenological scale for *P. ginseng* [15] (Table 1). Eight recognizable principal growth stages represented the newly proposed extended BBCH scales for *P. ginseng* compared to 10 of the general BBCH scale. Stage 0 (germination and bud development) is followed by Stages 1 (leaf development), 4 (root and perennating bud formation), 5 (peduncle elongation and inflorescence development), 6 (flowering and fruit set), 7 (development of fruit based on seed head diameter), 8 (ripening of fruit

based on fruit color), and 9 (senescence). The eight principal growth stages were further divided into ten secondary stages (0–9) corresponding to intermediate developmental phases, which represent percentage values of growth or qualitatively different phases within a given principal phenological stage. Common features in other vegetable crops, such as formation of side shoots (stage 2) and rosette growth (stage 3) were omitted from this description. Mesostages (1–n) were used to describe a more detailed vegetative difference in each developmental phase. The phenological growth stages were sequentially characterized and photographed with a digital camera (Lumix DMC-FH2, Panasonic Co. Ltd., Japan) and a stereoscopic microscope (SMZ-1000, Nikon Inc., Japan).

## 3. Results and discussion

The phenological growth stages of *P. ginseng* were described according to the extended BBCH scale according to the climate of the central regions of South Korea. There are two different cultivation methods used in South Korea to produce ginseng roots [17]. One is to sow directly on the bed of ginseng fields, and the other is to transplant one-year-old seedlings. Therefore, the phenological scales of *P. ginseng* were redefined to cover both cultivation methods based on the existing BBCH scale used for the *P. quinquefolius* growth cycle [15]. In Table 1, the description is divided into eight principal growth stages. Three describe vegetative growth (perennating bud, aerial shoot, and root development), four for reproductive growth (reproductive organ development, flowering, fruit development, and fruit maturation), and one for senescence according to the extended BBCH scale. A total of 58 secondary growth stages were described within the eight principal growth stages. Under each secondary growth stage, four mesostages are also taken into account.

### 3.1. Phenological stages of *P. ginseng*

#### 3.1.1. Principal growth stage 0: germination/bud development

This first stage describes seed germination and the budburst process of *P. ginseng*. Ripe ginseng berries (stage 809, Fig. 3) are harvested in late July and depulped to obtain creamy-white seeds (Fig. 3A). The freshly depulped ginseng seed has an immature embryo (about 0.4 mm long) and a hard seed coat, which requires a stratification period over 3 months (late July to late October) for embryo growth and maturation, seed coat splitting (dehiscence), and seed germination. During the stratification period, the seed coat changes from creamy-white to brown and cracks as the immature embryo grows to about 5.0 mm (stage 000, Fig. 1A). During the germination stage (early April to early May), a radicle emerges and elongates (stage 005, Fig. 1A) from a cracked (dehisced) seed (stage 003, Fig. 1A). The root hairs begin to appear at the tip of the radicle (stage 006, Fig. 1A) to collect water, minerals, and nutrients in the soil. The hooked epicotyl grows toward the soil surface (stage 007, Fig. 1A), and the cotyledon remains below the ground. The epicotyl only emerges above the ground (stage 009, Fig. 1A) through a hypogeous pattern, and the seedling's shoot has a trifoliate leaf (stage 109, Fig. 2) that differentiates during the elongation phase of embryo development.

Second-year ginseng stems arise from an apical bud (stage 010, Fig. 1A) on top of the root following the winter (January to February) to satisfy dormancy, regardless of direct seeding or transplantation. This second-year plant usually has 2–3 pentafo- liate leaves on their aerial shoot. In contrast, the stems and inflorescences (stage 017, Fig. 1A) of older ginseng plants (from 3rd- to 6th-year ginseng) emerge from a swollen perennating bud (stage 013, Fig. 1A) on the underground rhizome above the root following

**Table 1**

Phenological stages of Korean ginseng following the BBCH scale (modified with Proctor et al, 2003). The boldfaces in this table represent the phenological codes newly updated in this study

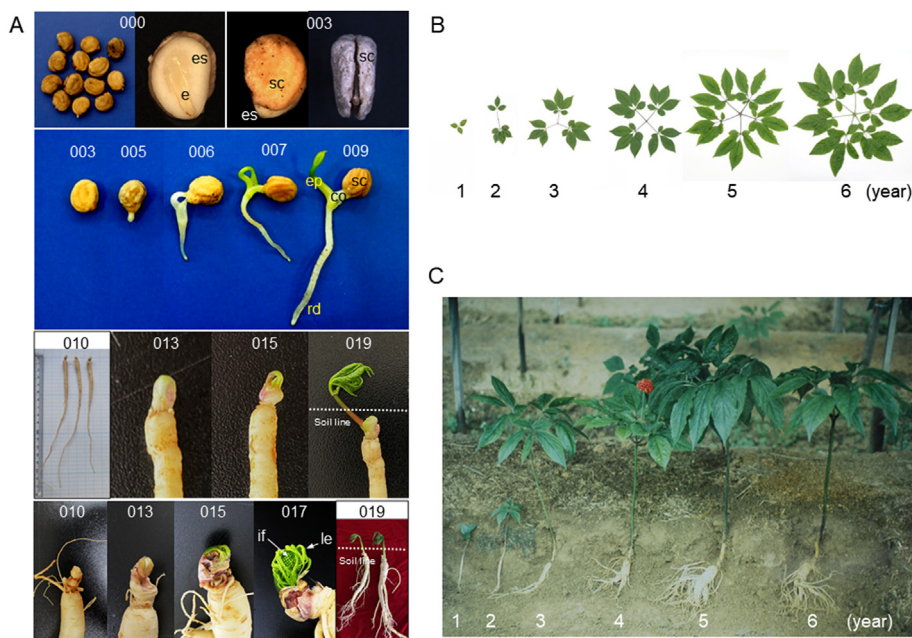
Code	Principal growth stage	Sub-code	Secondary growth stage	Figures
0	Germination/Bud development			
	<i>Development from seed</i>			
		00	Moist seed, embryo within seed fully grown.	Fig. 1
		03	Cracked seed.	Fig. 1
		05	Radicle emerged about 2 mm from seed coat.	Fig. 1
		<b>06</b>	<b>Elongation of radicle, formation of root hairs.</b>	Fig. 1
		07	Hooked epicotyl broken through seed coat and growing towards the soil surface.	Fig. 1
		09	Emergence: hooked epicotyl breaks through the soil surface.	Fig. 1
	<i>Development from rhizome (2nd and 6th year)</i>			
		10	Innate dormancy, perennating bud not enlarged.	Fig. 1
		13	Perennating bud swollen.	Fig. 1
		15	Hooked stem just visible outside bud scales.	Fig. 1
		<b>16</b>	<b>Formation of root hairs.</b>	NS
		17	Hooked stem with folded leaves enclosing the inflorescence fully emerged from the bud scales and growing towards the soil surface.	Fig. 1
		19	Emergence: hooked stem with folded leaves enclosing the inflorescence breaks through the soil surface.	Fig. 1
1	Leaf development			
	<i>Seedling growth</i>			
		01	Leaflets are folded; the petiole has reached 20% of the expected height; beginning of crop canopy.	Fig. 2
		05	Most leaves are unfolded; the petiole has reached 50% of the expected height.	Fig. 2
		09	All trifoliolate leaves are unfolded and horizontal; the petiole has reached maximum height; crop canopy is complete.	Fig. 2
	<i>Growth from bud (2nd and 6th year)</i>			
		11	Leaves are folded, enclosing the inflorescence; the aerial stem has reached 20% of the expected height; beginning of canopy.	Fig. 2
		15	Most leaves are unfolded; the aerial stem has reached 50% of the expected height.	Fig. 2
		19	All pentafoliolate leaves are unfolded and horizontal; the aerial stem has reached maximum height; inflorescence, if present, is exposed, erect and on a short peduncle; crop canopy complete.	Fig. 2
4	Root and perennating bud formation			
	<i>Seedling growth</i>			
		00	Root initiation: swelling and elongation of the radicle to form a taproot.	Fig. 2
		03	30% of expected yearly root weight reached; perennating bud 30% of the expected length.	NS
		07	70% of expected yearly root weight reached; perennating bud 70% of the expected length.	Fig. 2
		09	Maximum yearly root growth reached; perennating bud has reached the maximum length	Fig. 2
	<i>Root growth of 2nd and 6th year</i>			
		<b>10</b>	<b>Decrease of root weight to form the crop canopy.</b>	Fig. 2
		<b>13</b>	<b>30% of expected yearly root weight reached; perennating bud 30% of the expected length.</b>	Fig. 2
		<b>17</b>	<b>70% of expected yearly root weight reached; perennating bud 70% of the expected length.</b>	Fig. 2
		<b>19</b>	<b>Maximum yearly root growth reached; perennating bud has reached the maximum length.</b>	Fig. 2
5	Peduncle elongation and inflorescence development			
		01	Peduncle has reached about 10% of its expected length and inflorescence about 10% of its respected diameter.	Fig. 2
		05	Peduncle has reached about 50% of its expected length and inflorescence about 50% of its respected diameter.	Fig. 2
		09	Peduncle has reached maximum height and inflorescence its maximum diameter.	Fig. 2
6	Flowering and fruit set			
		00	First open flowers.	Fig. 3
		01	Beginning of flowering: 10% of the flowers in the inflorescence open.	Fig. 3
		05	Full flowering: 35% of the flowers in the inflorescence open, 15% of fruit set.	Fig. 3
		07	Most petals have fallen, 75% of fruit set.	Fig. 3
		09	End of flowering in the inflorescence, most fruit set.	Fig. 3
7	Development of fruit based on seed head diameter			
		00	First berries visible.	Fig. 3
		01	10% of the berries have reached full size.	NS
		05	50% of the berries have reached full size.	NS
		09	90% of the berries have reached full size, seed head of maximum diameter.	Fig. 3
8	Ripening of fruit based on fruit color			
	<i>Red-fruit landrace</i>			
		00	All fruits are green.	Fig. 3
		01	Beginning of fruit reddening.	Fig. 3
		05	50% of fruit red.	NS
		07	70% of fruit red.	Fig. 3
		09	Fully ripe fruits, beginning of fruit abscission.	Fig. 3

(continued on next page)

Table 1 (continued)

Code	Principal growth stage	Sub-code	Secondary growth stage	Figures
<b>Yellow-fruit landrace</b>				
		<b>10</b>	<b>All fruit green.</b>	Fig. 3
		<b>11</b>	<b>Beginning of fruit yellowish.</b>	NS
		<b>15</b>	<b>50% of fruit yellow.</b>	Fig. 3
		<b>17</b>	<b>70% of fruit yellow.</b>	Fig. 3
		<b>19</b>	<b>Fruit fully ripe, beginning of fruit abscission.</b>	Fig. 3
9	Senescence			
<b>Yellowing fall foliage</b>				
		02	Beginning of leaf yellowing.	Fig. 3
		03	Most of the leaves yellowish and drooping.	Fig. 3
		05	Leaves abscise, onset of stem yellowing.	Fig. 3
		07	Stems dead, erect and persisting.	Fig. 3
		09	Harvestable product: root.	Fig. 2
<b>Reddening fall foliage</b>				
		<b>12</b>	<b>Beginning of leaf reddening.</b>	Fig. 3
		<b>13</b>	<b>Most of the leaves yellowish and drooping.</b>	Fig. 3
		<b>15</b>	<b>Leaves abscise, onset of stem yellowing.</b>	Fig. 3
		<b>17</b>	<b>Stems dead, erect and persisting.</b>	Fig. 3
		<b>19</b>	<b>Harvestable product: root.</b>	Fig. 2

NS, Figure not shown.



**Fig. 1. Phenological growth stages of *P. ginseng*.** (A) Seed/bud developmental phenophases with corresponding BBCH codes. co, cotyledon; e, embryo; ep, epicotyl; es, endosperm; if, inflorescence; le, leaf; rd, radicle; sc, seed coat. (B) Leaf development from the trifoliate leaf of seedling to the pentafoliate leaves of sixth year. (C) Development of ginseng roots by years.

an extended cold period. The hooked stem emerges from the membranous bud scales enclosing the shoot primordium (stage 015, Fig. 1A) and grows towards the soil surface (stage 017, Fig. 1A). Emergences in both seeding and seedling propagation are completed when the hooked stem breaks through the soil surface, which exposes folded leaves and, if developed, a single umbellate inflorescence (stage 019, Fig. 1A). In older plants, the pentafoliate leaves increase up to the sixth year, and the number of leaves seldom exceeds six (Fig. 1B and C).

### 3.1.2. Principal growth stage 1: leaf development

This second stage begins when the leaflets are folded and completed when most leaves are fully unfolded and horizontal. In older plants, the phenological code is determined by their leaves unfolding and their petioles' heights in seedlings or aerial stems. At stage 101 (Fig. 2), the three leaflets of a single trifoliate are mostly folded, and the stems thrive to complete crop canopy. Most leaflets are unfolded, and petioles have reached 50% of their expected height when the seedling reaches about 40 mm in late-April (stage 105, Fig. 2). At the beginning of May, all trifoliate leaflets are unfolded horizontally, and the petioles are fully expended (stage



**Fig. 2.** Leaf and root developmental phenophases of *P. ginseng* with corresponding BBCH codes. (A and B) Harvested six-year-old *P. ginseng* and *P. quinquefolius*, respectively (white arrows = perennating bud, red = wrinkled marks). as, aerial shoot; if, inflorescence; pd, peduncle; pe, petiole. Bars = 30 mm.

109, Fig. 2). Like the *P. quinquefolius* seedlings, the leaflet is elliptical, serrated, and have small trichomes along the upper surface of the midrib [15]. In older (2- to 6-year-old) reproductive plants, the aerial shoot arises from a perennating bud bearing several penta-foliolate leaflets or an inflorescence (stage 111, Fig. 2). It is uncommon for second-year ginseng to develop inflorescences, but only 5%–10% of the plant have them [18]. The shoot primordium grows vertically for further development. Meanwhile, the penta-foliolate leaflet does not unfold until mid-April, and its aerial shoot reaches 20% of its expected height (stage 111, Fig. 2). After about 20 d, most leaves are unfolded, and the aerial stem is about 100–250 mm (stage 115, Fig. 2). The ginseng canopy is completed when all penta-foliolate leaves are unfolded and horizontal, the aerial stem has reached maximum height (ca. 500 mm), and the inflorescence is exposed and erect (stage 119, Fig. 2).

### 3.1.3. Principal growth stage 4: root and perennating bud formation

*P. ginseng* has a thick, spindle-shaped root, which is 150–250 mm long and 10–40 mm thick, and often irregularly branched (Fig. 2A). The taproot is simple without any lateral root during the first and second year, but after the third year, it usually becomes branched. The main root is pale yellow-white and has transverse wrinkles on the body, but the wrinkled mark is smoother than that of *P. quinquefolius* (Fig. 2A and B) [15]. The rhizome develops above

the taproot and has a single apical bud that is covered with a membranous bud scale (Fig. 2A). At this stage, the plant's age can be determined by calculating the number of scars on the rhizome [19].

The root growth initiates from the radicle or the perennating bud in seedlings and older plants over the second year, respectively. Therefore, the description in seedlings and older plants should be modified with separate phenological codes based on the existing BBCH scale reported by Proctor et al [15]. The developmental scale for seedlings was coded with mesostage (second digit) "0," whereas, for the older plants, it was coded with mesostage "1" (Table 1). The radicle of the seedling is swollen and elongated to form a taproot during April (stage 400, Fig. 2). Afterward, the taproot grows exponentially until late-September (from stage 403 to stage 407, Fig. 2) and gradually enters the stationary growth phase (stage 409, Fig. 2). In older ginseng roots, the fresh weight of the root decreases slightly from the late April emergence period to mid-late May when the crop canopy is completed (stage 410, Fig. 2). The growth starts to increase linearly from the middle of June, and it almost fully grows by mid-October (stage 413–419, Fig. 2). Next, the fresh weight of all aged ginseng increases by 10% during the winter. The seedling's perennating bud initiates from the cotyledons and, in older plants, arises from the rhizome [15,20]. Here, the development of the perennating bud could not be observed, but the increase in length parallels the weight increase at the roots [15,18].

### 3.1.4. Principal growth stage 5: peduncle elongation and inflorescence development

The peduncle is a flower stalk that arises from the top of the aerial stems in mid-April and reaches its maximum height in mid-May. In older ginseng plants (3- to 6-year-old), peduncles grow to 150–250 mm in height. Inflorescences and pedicels attached to the peduncle grow actively from April to May, which is about one month faster than American ginseng [21]. When entering stage 501 (Fig. 2), the peduncle and pedicels depart from the aerial stem, the peduncle has reached about 10% of its expected growth, and the inflorescence is about 6 mm in diameter in the 6-year-old ginseng plant. The umbel bearing both the peduncle and the inflorescence reaches 50% of expected growth by the beginning of May (stage 505, Fig. 2). Both peduncle elongation and inflorescence diameter are maximized by the middle of May (stage 509, Fig. 2). This principal growth stage lasts for 1 mo, which is similar to the first stage of leaf development.

### 3.1.5. Principal growth stage 6: flowering and fruit set

A flower is a vital reproductive structure; the flowering stage of the ginseng plant begins around mid-May and finishes by late-May [22]. The flower is comprised of a five-lobed calyx, five petals, five stamens, and one to three fused carpels (Fig. 3B and C). Flowering starts with the petals opening (stage 600, Fig. 3), which arises from the exterior to the interior of the umbellate inflorescence. When 10% of the flowers are open, it is considered to have started flowering (stage 601, Fig. 3) [15]. Full flowering is achieved when about 35% of the flowers open, and 15% of the fruits have set (stage 605, Fig. 3). Even after completely flowering, the inner flowers of the

inflorescence continue to open (about 75%) until most petals have fallen (stage 607, Fig. 3). When most of the fruits have set, this growth stage is completed (stage 609, Fig. 3). In both *P. ginseng* and *P. quinquefolius*, ginseng seeds are collected from 4-year-old plants [23]. The inflorescences of older plants (5- and 6-years old) are removed before flowering to increase the root yield of ginseng [24].

### 3.1.6. Principal growth stage 7: development of fruit based on seed head diameter

A ginseng fruit (berry) is 5–10 mm in diameter and contains two seeds (Fig. 3A). The fruits are rapidly set from the outer flowers, which are first fertilized during the flowering period. All green fruits that have set (stage 700, Fig. 3) are fully grown until the beginning of July and will be collected from 4-year-old ginseng after the ripening period. When 10 (50%) of the berries are fully grown, stage 701 or 705 is reached, respectively. The fruit diameter maximizes between the beginning and middle of July (stage 709, Fig. 3), and the fruit begins to ripen.

### 3.1.7. Principal growth stage 8: ripening of fruit based on fruit color

Several landraces of *P. ginseng* in Korea are divided into two groups based on fruit color (red and yellow) (Fig. 3) [25]. In this stage, the phenological scales are separated by fruit color. The scale for landraces with red fruits was coded with mesostage (second digit) “0”, while the scale for landraces with yellow fruits was coded with mesostage “1” (Table 1).

The green berries that matured during the previous growth stage (stage 800 and 810, Fig. 3) gradually start to change color from green to red (stage 801, Fig. 3) or yellow (stage 811). Specifically, the



**Fig. 3.** Flower/fruit developmental phenophases and senescence of *P. ginseng* with corresponding BBCH codes. (A) Fruit and isolated seeds. (B) Flower. (C) Fertilized flowers. an, anther; be, berry; cx, calyx; pl, pedicel; pt, petal; st, stigma.

berry on the seed head's periphery changes color first. When the colors intensify, and more berries become reddish or yellowish, stages 805/815 and 807/817 are reached, respectively (Fig. 3). The berries then turn dark red or yellow (stage 809/819, Fig. 3) and are ready for picking in the latter half of July.

3.1.8. Principal growth stage 9: senescence

The senescence of ginseng plants can be recognized during the process of chlorophyll breakdown in their leaves and stems. Like the fruits' colors, the leaves turn into two colors, red or yellow, during this period. Hence, this phenological code was also modified with "0" and "1" in the second digit of the BBCH scale (Table 1). The leaves remain green for about one month after picking its fruits. Entering the fall (September), *P. ginseng* leaves start to yellow (stage 902, Fig. 3). However, some varieties turn red starting from the edges of the leaves (stage 912, Fig. 3). As leaf senescence continues during October, some leaves turn brown and droop (stage 903/913), while others abscise, and their stems begin to yellow (stage 905/915) (Fig. 3). Ginseng roots are commonly harvested at stage 905. If the plant canopy is not removed from the raised soil beds, all leaves abscise, and the stems turn brown but remain erect and persist (stage 907, Fig. 3). The other part that remains is the root (stage 909), which will be harvested in spring or will sprout further.

3.2. Applications of phenological growth codes for agricultural practices

Phenological studies provide a comprehensive overview of the life cycle of plants and have an impact on the production of economic crops. Accordingly, the knowledge of the annual timing of phenophases and their variability can improve crop management strategies, such as irrigation, fertilization, and crop protection, which leads to higher and stable crop yields. The phenological data can also be used to evaluate the risks caused by abnormal climate by forecasting crop development and harvest dates [26].

Hence, the phenological growth stages for *P. ginseng* were described based on the existing BBCH scale [15] (Table 1). The phenological codes were updated with three mesostages (stages 4,

8, and 9) to reflect the special cultivation method (e.g., transplantation) and the characteristics of ginseng varieties in Korea. An example of the application of the newly proposed BBCH scale was introduced with pest control practices as follows (Fig. 4).

Pest control using pesticides is one of the most crucial cultural practices for stable ginseng production. The BBCH scale updated here would be useful when making pest control recommendations and for cultural practices. As shown in Table 2, six major pathogens are fatal to ginseng production. It is difficult to control the pathogens because the pesticides used for each pathogen and the application timings are different. However, using the BBCH scale proposed in this study allows producers to devise a program aimed at controlling pathogens by timing pesticide application. For example, Phytophthora blight, which is caused by *Phytophthora cactorum*, can develop on ginseng leaves during the spring and eventually affect the roots, especially from May to June. When summer begins, the disease cannot be found on the leaves and roots. The pathogen optimally grows at 20°C to 25°C, but cannot develop at temperatures higher than 30°C [27]. Even at temperatures above 30°C, prolonged rains will more than compensate for the lower-than-optimal temperatures, resulting in a high risk of disease [28]. Therefore, controlling the growth of pathogens should start from the beginning of May when the leaf development stage is completed, which is when the monthly mean temperature reaches above 20°C and stops at the beginning of June when the temperature rises above 30°C (Fig. 4). If the temperature is over 30°C from July to August, and if the humidity is high and the temperature decreases due to the rainy season, additional control of pathogen growth should be carried out. This approach for pathogen control will reduce pesticide use and increase ginseng production.

As mentioned above, a good understanding of phenological growth stages using the BBCH scale enables producers to perform the required management practices at optimal times. The BBCH scale will also facilitate the exchange of information, knowledge, and experiences among the scientific community by unifying the criteria that describe the growth and development stages of *P. ginseng* regardless of where they are cultivated.

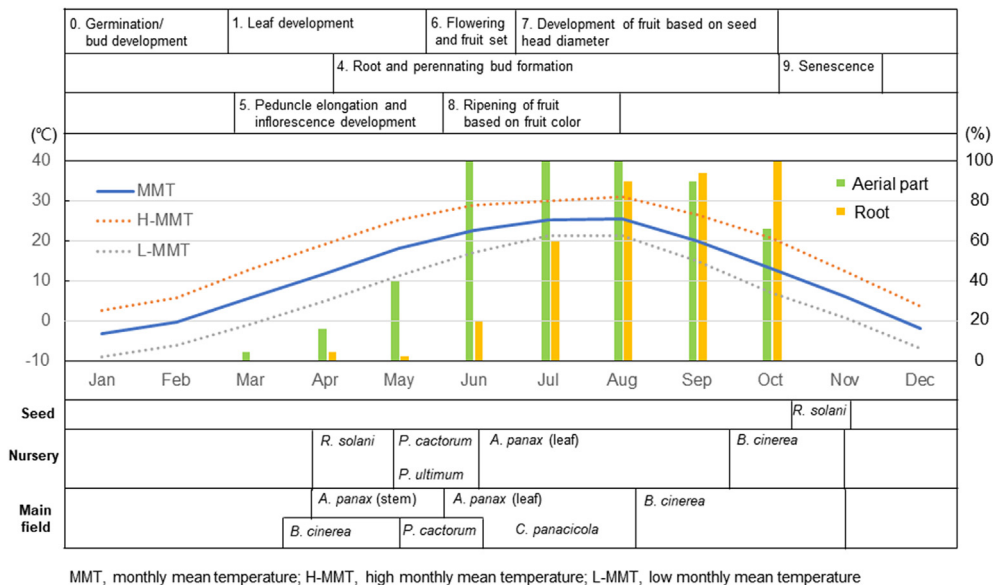


Fig. 4. Principal growth stages, annual cycle, and pathogen outbreaks of *Panax ginseng* according to the BBCH scale proposed in this study. Lines show monthly mean temperatures (°C), and bars represent the aerial parts' and roots' growth index (%).

**Table 2**  
Practical instruction for disease control of *Panax ginseng* by using the BBCH scale proposed in this study

Disease	Pathogen	Instruction on timing	BBCH scale	Figure
Alternaria stem blight	<i>Alternaria panax</i>	Apply fungicides at first full canopy	105/115	Fig. 2
Alternaria leaf blight	<i>Alternaria panax</i>	Apply fungicides when leaflets are fully unfolded and horizontal	109/119	Fig. 2
Antrachnose	<i>Colletotrichum panacicola</i>	Apply fungicides to full canopy	109/119	Fig. 2
Gray mold	<i>Botrytis cinerea</i>	Remove dead leaves and stems from raised soil bed, or apply Bordeaux mixture to yellowing leaves	907/917	Fig. 3
			902/912	Fig. 3
Damping-off	<i>Rhizoctonia solani</i> AG2-1 <i>Pythium ultimum</i>	Apply fungicides to cracked seeds before sowing, or when leaflets are fully unfolded and horizontal	003	Fig. 1
			109/119	Fig. 2
Phytophthora blight	<i>Phytophthora cactorum</i>	Apply fungicides to full canopy	109/119	Fig. 2

#### 4. Conclusion

The extended BBCH scale for *P. ginseng* was introduced with detailed descriptions and updated phenological growth scales in this study, despite the existence of a BBCH scale for American ginseng [15]. It is still applicable because it describes the distinct patterns of phenological characteristics in *P. ginseng* varieties and the process of transplanting seedlings. The phenological growth codes of *P. ginseng* can be used to understand the varieties of agricultural environments.

#### Authorship

Y.-S.K. and C.-S.P. conceived the experiments. Y.-S.K., C.-S.P., D.-Y.L., J.-S.L., S.-H.L., J.-G.I. and T.-K.H. performed the experiments. Y.-S.K. and D.-Y.L. analyzed the data. Y.-S.K. wrote the manuscript.

#### Conflicts of interest

All authors reported no conflict of interest.

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