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Phenological growth stages of North American ginseng (*Panax quinquefolius*)

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Summary

The BBCH (Biologische Bundesanstalt, Bundessortenamt, Chemische Industrie) scale is used to describe the phenological growth stages of North American ginseng (*Panax quinquefolius*). Eight principal growth stages for germination and bud development, leaf development (crop canopy), root and perennating bud formation, peduncle elongation and inflorescence development, flowering and fruit set, development of fruit, ripening of fruit and senescence, and 42 secondary growth stages are described. A practical use of the scale is proposed with reference to the timing of application of agrochemicals for disease control.

Key words: BBCH scale, ginseng, medicinal herb, phenology, rhizome

Introduction

The ginseng family, Araliaceae (Order Umbelliferales), includes the genus *Panax* L., which consists of 11 recognised species, nine of which are from Asia and two from eastern North America (Wen, 2001). North American ginseng (*Panax quinquefolius* L.) is a slow growing herbaceous plant that is native to the under-story of eastern North American hardwood forests (Proctor & Bailey, 1987). Because of its highly valued root, ginseng has been harvested from its native habitat since the 1700s and cultivated in Ontario, Canada and Wisconsin, USA for over 100 years (Evans, 1985; Proctor, 1996). Ginseng has been used since ancient times as a health tonic in Southeast Asia and Pacific Rim countries but is now gaining more extensive usage worldwide due to its reputed medicinal and herbal qualities (But *et al.*, 1995; Li, 1995). Lee (1992) and Fulder (1996) reported that ginseng has adaptogenic, stimulating, anabolic, antibiotic and anticancer activities. The expanding use of ginseng in Western medicine has stimulated production in the two traditional North American areas, Ontario and Wisconsin, and a new area, British Columbia (Bailey, 1990; Proctor, 1996). In addition, cultivation of North American ginseng in non-traditional areas, e.g. Australia (Hosemans, 1995), New Zealand (Follett *et al.*, 1995), Europe (France and Belgium), South Africa, South America and China is being evaluated.

Although North American ginseng has been cultivated for over 100 years, there are no registered cultivars or selections of known genetic or phenotypic features. The cultivated plant was taken from native woodland habitats and is genetically diverse (Boehm *et al.*, 1999). Ginseng in natural habitats is assigned a threatened status under the Convention on International Trade in Endangered Species. Work is underway to evaluate and conserve such germplasm (Nantel *et al.*, 1996) and to conserve, evaluate and use germplasm found in cultivation. A first step in this work will be to identify highly heritable phenotypic markers such as phenological events (e.g. shoot emergence and flowering periods).

A major constraint to ginseng production is the prevalence of pests, particularly fungal diseases (Parke & Shotwell, 1989; Proctor, 1996). Application of agrochemicals is necessary for disease control with an estimated average of nine fungicide applications per growing season (Oliver, 1998; Anon, 2001). A description of the developmental stages of ginseng would be useful in making pest control recommendations and for the timing of cultural practices. Descriptions of developmental stages for some horticultural crops have been published, e.g. for peas (Knott, 1987), potatoes (Jefferies & Lawson, 1991), head cabbage (Everaarts, 1994), loquat (Martínez-Calvo *et al.*,

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1999) and olive (Sanz-Cortés *et al.*, 2002). The BBCH phenological scale is now the system officially accepted by the European and Mediterranean Plant Protection Organisation (EPPO) for a wide range of crops and weeds (Lancashire *et al.*, 1991; Bleiholder *et al.*, 1997; Sanz-Cortés *et al.*, 2002). The BBCH-scale is primarily a decimal two-digit scale divided into principal (0 to 9) and secondary (0 to 9) growth stages. For some crops, e.g. vegetables, a three-digit scale is used.

The developmental stages of North American ginseng have not been described. This is a first attempt to develop a simple, illustrated description and code, using the BBCH-scale, for the growth stages of North American ginseng based on field observations and controlled environment studies (Table 1).

Phenological Stages of Ginseng

Principal growth stage 0: Germination/Bud Development

The principal method of propagating ginseng is by seed. After the seed is harvested (picking of red berries at stage 807, Fig. 2) it is processed (pulp is removed). The seed is creamy white and has a moisture content of 10-12 %. Freshly harvested ginseng seeds have immature embryos (about 0.5 mm long) and a hard endocarp (seed coat) which require a cool-warm temperature regime over a 18 to 22 months stratification period for embryo growth and maturation, endocarp splitting and seed germination (Proctor & Louttit, 1995). At the end of the stratification period (stage 000), the endocarp has changed from creamy white to brown in colour and the immature embryo has grown to about 5 mm. Endocarp splitting parallels embryo growth and is not complete (stage 005, Fig. 1) until the radicle has emerged during germination. As the radicle

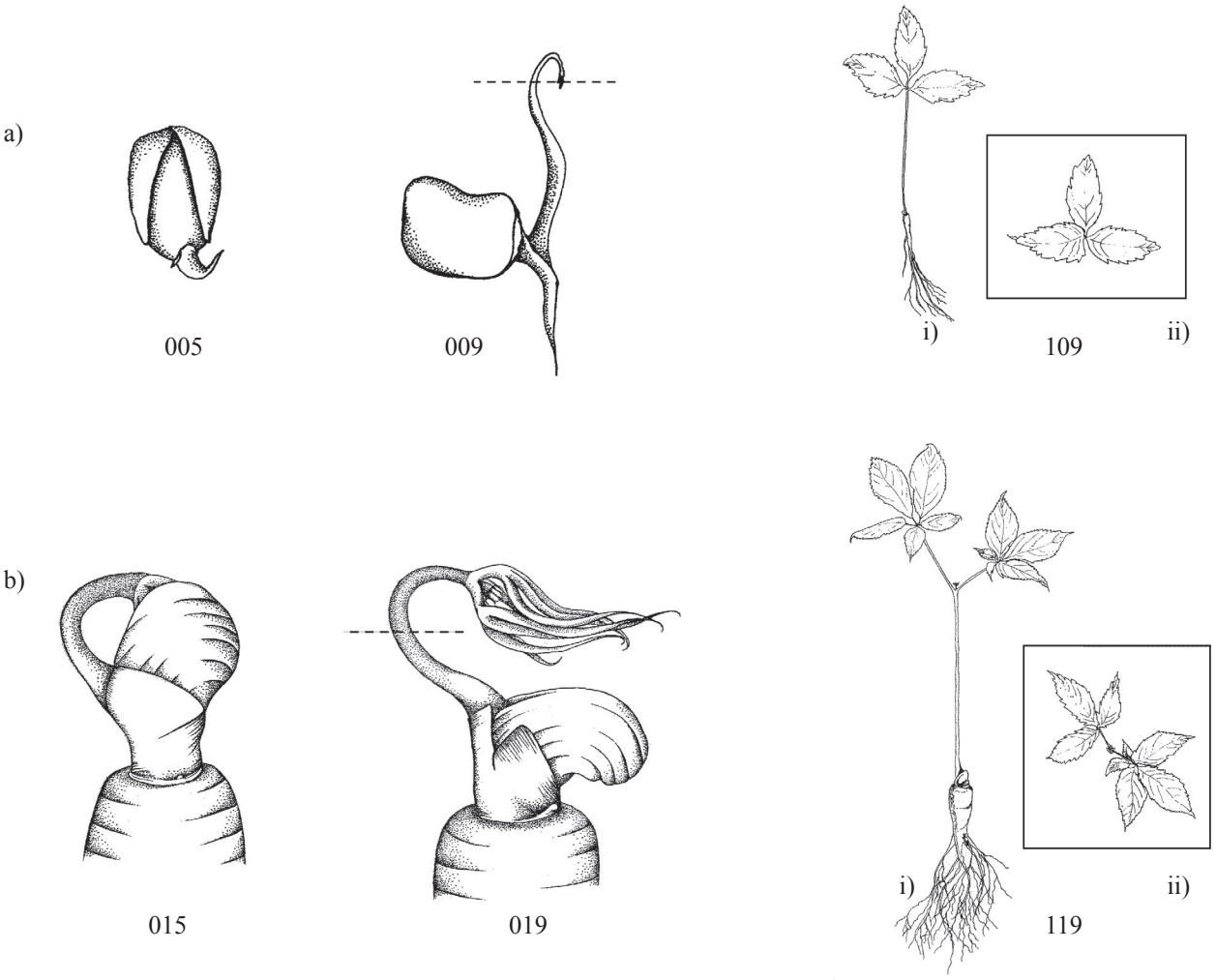

Fig. 1. Development within the Principal growth stages 0 and 1 for a), development from seed, and b), development from the perennating bud on the rhizome. The resulting plants, a seedling in a, i) with a trifoliate leaf, and a 2-yr-old plant in b, i) with two pentafoliate leaves are shown when crop canopy is completed (codes 109 and 119): top views of these plants are shown in the boxes (ii). Descriptions of the codes are given in Table 1.

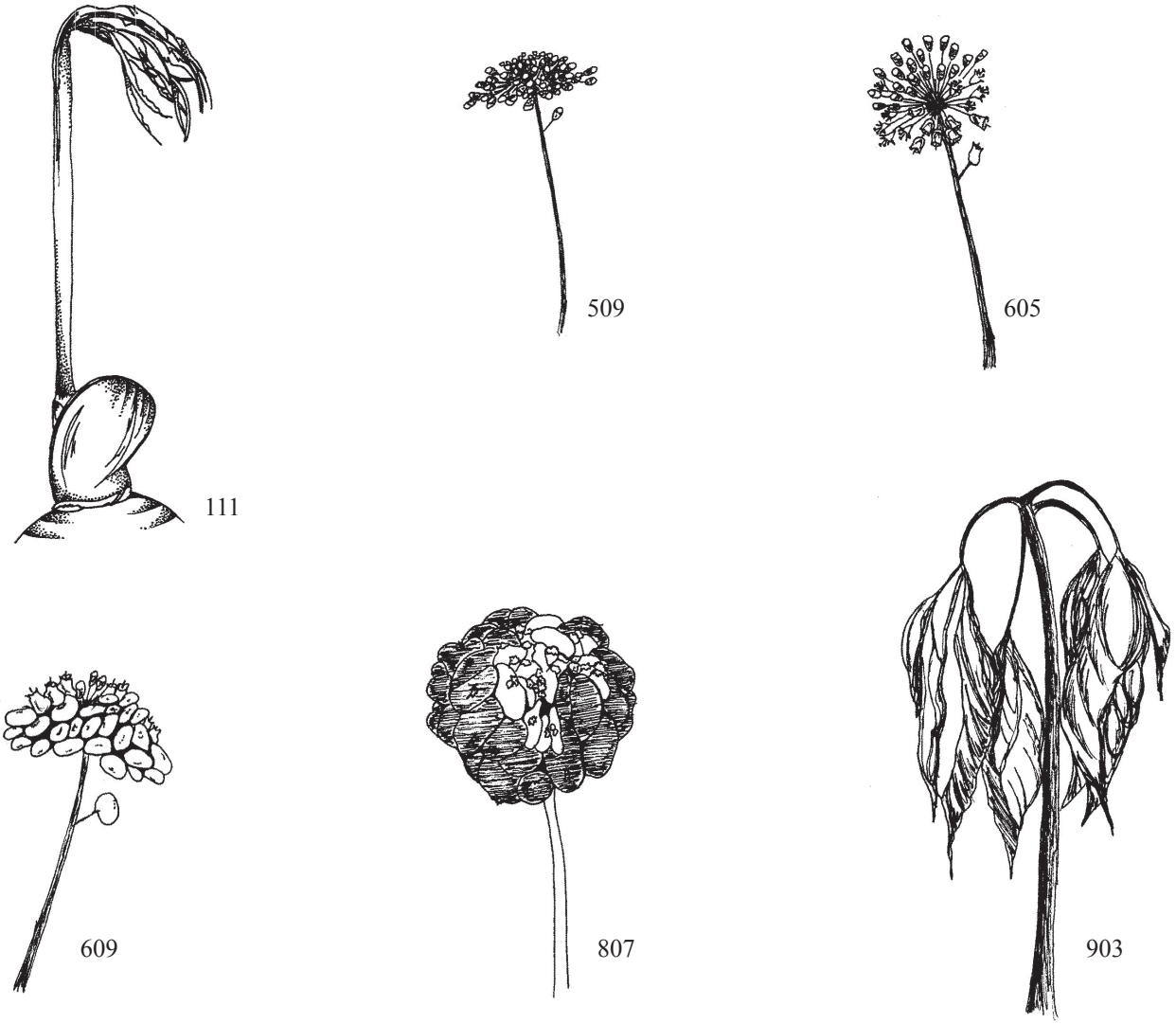

Fig. 2. Six important developmental stages and their codes in the BBCH scale. Descriptions of the codes are given in Table 1, and their application to agrochemical usage is given in Table 2.

elongates, the enlarged cotyledonary node emerges and the hooked epicotyl grows towards the soil surface (stage 007). This seedling shoot has a trifoliate leaf differentiated during the elongation phase of embryo development. Emergence follows a hypogeous pattern with the cotyledons remaining in the soil and only the epicotyl emerging (stage 009, Fig. 1a).

Second and third-year ginseng stems and inflorescences arise from an apical perennating bud (stage 010) on the underground rhizome on top of the root following an obligatory cold period to satisfy dormancy (Lee *et al*., 1985). Once soil temperature reaches about 8°C (Lee *et al*., 1986), in late April-early May, the perennating bud swells (stage 013) and becomes active. The membranous bud scales enclosing the shoot primordium separate exposing the hooked stem (stage 015, Fig. 1b). This hooked stem emerges from the bud scales and grows towards the soil surface (stage 017). Emergence is complete when the hooked stem breaks through the soil surface, exposing folded leaves, and if developed, a single umbellate inflorescence (stage 019, Fig. 1b). Two-yr-old plants usually have an aerial shoot terminating in a whorl of two, 3-5- foliate leaves, and rarely an inflorescence; three-year-old plants usually have three, 3-5-foliate leaves, and an inflorescence.

Principal growth stage 1: Leaf development (crop canopy)

Leaf development and establishment of the crop canopy is vital for ginseng which is an herbaceous perennial. In seedlings, the reserves for leaf development come from the seed; in older plants root reserves are metabolised and dry matter content of the roots declines by 30-50%. Leaf development follows, the crop canopy is established, and photosynthesis recovers the root weight losses as well as increasing root weight through the growing season (Proctor *et al*., 1998). Development of both the seedling and mature plant canopies takes about

Table 1. *Phenological stages of North American ginseng*

	Principal growth stage 0: Germination/Bud Development
	Development from seed
000	Moist seed, embryo within seed fully grown.
003	Cracked seed.
005	Radicle emerged *c*. 2 mm from seed coat (Fig. 1a).
007	Hooked epicotyl broken through seed coat and growing towards the soil surface.
009	Emergence: hooked epicotyl breaks through the soil surface (Fig. 1a).
	Development from rhizome (2nd and 3rd year)
010	Innate dormancy, perennating bud not enlarged.
013	Perennating bud swollen.
015	Hooked stem just visible outside bud scales (Fig. 1b).
017	Hooked stem with folded leaves enclosing the inflorescence fully emerged from the bud scales and growing towards the soil surface.
019	Emergence: hooked stem with folded leaves enclosing the inflorescence breaks through the soil surface (Fig. 1b).
	Principal growth stage 1: Leaf development (crop canopy)
101	Seedling growth: leaflets are folded; the petiole has reached 20% of the expected height; beginning of crop canopy.
105	Most leaves are unfolded; the petiole has reached 50% of the expected height.
109	All trifoliate leaves are unfolded and horizontal; the petiole has reached maximum height; crop canopy is complete (Fig. 1a).
111	Growth from bud (2nd and 3rd year): leaves are folded, enclosing the inflorescence; the aerial stem has reached 20% of the expected height; beginning of crop canopy (Fig. 2).
115	Most leaves are unfolded; the aerial stem has reached 50% of the expected height.
119	All pentafoliate 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. 1b).
	Principal growth stage 4: Root and perennating bud formation
400	Root initiation: swelling and elongation of the radicle to form a taproot.
403	30% of expected yearly root weight reached; perennating bud 30% of expected length.
407	70% of expected yearly root weight reached; perennating bud 70% of expected length.
409	Maximum yearly root growth reached; perennating bud has reached maximum length.
	Principal growth stage 5: Peduncle elongation and inflorescence development
501	Peduncle has reached about 10% of its expected length and inflorescence about 10% of its expected diameter.
505	Peduncle has reached about 50% of its expected length and inflorescence about 50% of its expected diameter.
509	Peduncle has reached maximum height and inflorescence its maximum diameter (Fig. 2).
	Principal growth stage 6: Flowering and fruit set
600	First open flowers.
601	Beginning of flowering: 10% of the flowers in the inflorescence open.
605	Full flowering: 35% of the flowers in the inflorescence open, 15% of fruit set (Fig. 2).
607	Most petals fallen, 75% of fruit set.
609	End of flowering in the inflorescence, most fruit set (Fig. 2).
	Principal growth stage 7: Development of fruit based on seed head diameter
700	First berries visible.
701	10% of the berries have reached full size.
705	50% of the berries have reached full size.
709	90% of the berries have reached full size, seed head of maximum diameter.

Cont...

Table 1 cont...

	Principal growth stage 8: Ripening of fruit based on fruit colour
800	All fruit green.
801	Beginning of fruit reddening.
805	50% of fruit red.
807	70% of fruit red (Fig. 2).
809	Fruit fully ripe, beginning of fruit abscission.
	Principal growth stage 9: Senescence
902	Beginning of leaf yellowing.
903	Most of the leaves yellowish and drooping (Fig. 2).
905	Leaves abscise, onset of stem yellowing.
907	Stems dead, erect and persisting.
909	Harvestable product: root.

4 wk.

The aerial shoot of the seedling is a single trifoliate leaf and at stage 101 the three leaflets are partially unfolded and contributing to crop canopy development. As leaflet unfolding and petiole extension continue the seedling reaches about 40 mm or 50% of its expected height (stage 105). At full extension of the petiole the three trifoliate leaflets, joined at the terminus of the petiole, are horizontal and crop canopy is complete (stage 109, Fig. 1a). The leaflets are elliptical, serrate and have small, unbranched trichomes along the upper surface of the midrib.

In 2nd and 3rd year plants the aerial shoot, which has arisen from the perennating bud, separates from the bud scales and grows vertically. The leaves are folded and, as the plant is now reproductive, an inflorescence is enclosed in the leaves (stage 111, Fig. 2). Only 20-50% of two-year-old plants have inflorescences. The aerial shoot grows and the leaves unfold at about half of full height – about 100 and 220 mm for 2 and 3-yr-old plants respectively (stage 115). At full extension of the aerial stem all the trifoliate and pentafoliate leaves are unfolded and horizontal (Hughes & Proctor, 1981; Proctor & Bailey, 1987) and crop canopy is complete. If an inflorescence is present it is on an erect short peduncle (stage 119, Fig. 1b).

Principal growth stage 4: Root and perennating bud formation

One of the characteristics of North American ginseng identified and illustrated in Figs 1 and 2 is a persistent fleshy perennial storage, fusiform primary root which is often irregularly branched (Proctor & Bailey, 1987; Anderson *et al*., 1993; Wen, 2001). Root colour ranges from cream to yellow. Transverse wrinkles (rings) on the root are attributed to contractile activity which ensures that the root, the rhizome and the perennating bud are kept below the soil surface to prevent freeze damage. The rhizome is short (< 5 cm), and normally unbranched, with a single apical bud composed of three membranous, distichous (two ranked, two rows) bud scales that enclose the shoot primordium.

Seasonal root dry weight gain for ginseng seedlings is about 0.2 g, and 2 and 3.5 g for 2 and 3-yr-old roots respectively (Proctor *et al*., 1998). Root initiation in seedlings (stage 400) occurs as crop canopy (stage 109) is attained. In mature plants root weight gain starts about mid-June. As root weight increase is essentially linear over the growing season from mid-June to mid-September (Proctor *et al*., 1998), stage 403 and 407 can be predicted as mid-July and mid-August respectively. The perennating bud in seedlings is initiated between the cotyledons, and in mature plants arises from the rhizome. Stage 403 and 407 are similar for buds and roots, as perennating bud length increase parallels root weight increase.

Principal growth stage 5: Peduncle elongation and inflorescence development

This principal growth stage is similar to stage 1 in taking about one month. Fiebig *et al*. (2001) have addressed inflorescence development. In 3-yr-old plants peduncles emerge and grow in June to 140 to 180 mm. Inflorescence growth is rapid in June, and slow for the remainder of the growing season. When initial growth of the peduncle shows a separation from the node, from which both the peduncle and pedicels arise, stage 501 is reached. By about mid-June the erect elongating peduncle and the expanding inflorescence will have reached 50% of expected growth (stage 505). Both peduncle elongation and inflorescence diameter are maximized by the end of June (stage 509, Fig. 2) although inflorescence diameter increases slowly due mostly to the expansion of setting fruit. Proctor (1986) has addressed inflorescence variation.

Principal growth stage 6: Flowering and fruit set

Flowering begins in the last two weeks of June

and continues to late July (Fiebig *et al*., 2001). During this 6 wk flowering period no more than 35% of flowers are open at any one time. The first flowers to open (stage 600) are those on the periphery of the umbellate inflorescence. When about 10% of the flowers are open, flowering is considered started (stage 601). In 3-yr-old plants there are 32 to 79 flowers in an inflorescence (Fiebig *et al*., 2001). Full flowering is when 35% of the flowers are open and 15% of the fruit have set (stage 605, Fig. 2). Flowers continue to open and fruit set until most petals have fallen and 75% of the fruit are set (stage 607). At the end of flowering most of the fruit, which are green, will have set (stage 609, Fig. 2).

Principal growth stage 7: Development of fruit based on seed head diameter

The fruit of ginseng is a drupe, normally containing two seeds. Fruit set is rapid, but fruit growth is slow, from early July to mid-August. Stage 700 is reached when all berries are visible. Berry growth continues and the peripheral berries appear slightly larger (stage 701). The seed head diameter increases and by late July has reached 50% of its final size (stage 705). Further expansion occurs until maximum diameter is reached in mid-August (stage 709).

Principal growth stage 8: Ripening of fruit based on fruit colour

Once the fruit has reached maximum maturity, at 6-7 wk after flowering starts, they are still green (stage 800). Gradually the fruit start to change colour from green to red (stage 801). The fruit on the periphery of the seed head change colour first. As the colour intensifies and more fruit become red stages 805 and 807 (Fig. 2) are reached. At stage 807 most of the fruit in the seed head are red and ready for picking. The fruit then turns dark red (stage 809) and will readily abscise. This principal growth stage lasts for a period of 3-4 wk.

Principal growth stage 9: Senescence

Following fruit picking, or abscission, there is a 3-4 wk period when the foliage remains green. Seedling plants, which did not have fruit, start to show leaf yellowing (stage 902) during this period. Mature plants show similar symptoms slightly later. Leaf duration of ginseng plants is 100-200 days. The yellowing of the leaves continues and they droop (stage 903, Fig. 2). Leaf abscission occurs and the stems turn yellow (stage 905). In commercial practise this stage is used as the time when all top growth and straw mulch on the raised soil beds can be removed in preparation for root harvest. If the plant canopy is not removed all leaves abscise and the stems turn brown, but remain erect and persist (stage 907). The other part of the plant that remains is the root, the harvestable product (stage 909).

Discussion

As mentioned above, disease is a major constraint to ginseng production so agrochemicals are applied for disease control. The BBCH scale proposed here can be applied readily to instructions for timing of agrochemical application (Table 2) with use of the related illustration (Figs. 1 and 2). Some agrochemical applications are based on time after first crop emergence and not related to the development of the fungal pathogen or of crop phenology. With acceptance of the use of the BBCH scale, and its refinement for use with ginseng, better timing of applications of agrochemicals should be possible.

Also, as mentioned above, ginseng grown in commerce is still essentially a wild species, the industry being based on plants taken from their native woodland habitat (Proctor & Bailey, 1987). Hence, the BBCH-scale reported here is based on plants differing widely in their genetic make-up, and morphological and horticultural characteristics. Programs to develop recognised ginseng cultivars have been initiated. With the introduction of such cultivars distinct patterns of development and phenological characters may arise which may necessitate re-evaluation of the BBCH codes proposed here.

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Table 2. *Examples of applications of several agrochemicals to North American ginseng for disease control in relation to the proposed BBCH scale (Table 1 and Figs 1 and 2)*

Target disease	Active agrochemical	Instructions on timing[a]	BBCH scale
Alternaria leaf spot	Chlorothalonil	Apply when 20% of crop emerged	101, 111
Alternaria leaf blight	Iprodione	Apply at seed formation	609
Phytophthora root rot	Fosetyl-Al	At first full canopy	109, 119
		At seed formation	609
		Make the final application prior to senescence when there is 50% green in the foliage	903

[a] Instructions are based on recommendations taken from Anon. (2001)

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