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Phenological growth stages of hemp (*Cannabis sativa* L.): codification and description according to the BBCH scale

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The current paper discusses the characteristics of principal growth stages of hemp (*Canabis sativa*), provides a brief description of these stages and of the coding system according to the BBCH scale. The growing season of hemp is divided into nine principal growth stages: germination and sprouting (0), leaf development (1), formation of lateral shoots (2), stem elongation (3), inflorescence emergence (5), flowering (6), development of fruit (7), ripening of fruit (8) and senescence (9). The principal growth stages are subdivided into secondary stages based on their main distinctive features. The classification system of hemp growth stages presented in the paper is designed for hemp growers and researchers, including plant breeders, physiologists, entomologists and other agricultural producers. Using the uniform coding system of the phenological stages of hemp is a valuable tool to ensure a more efficient planning and implementation of crop and soil management practices and techniques.

Keywords: BBCH-scale, *Cannabis sativa* L., dioecious hemp, monoecious hemp, phenological growth stages

INTRODUCTION

Hemp (*Cannabis sativa* L.) has been grown for over 5,000 years for multiple purposes. Its fibre can be used for manufacturing of clothes, insulating material, or as a composite material (Karus, Vogt, 2004). Besides, hemp has been suggested by various researchers for the production of briquettes (Mankowski, Kolodziej, 2008), bioethanol (Tutt, Olt, 2011), biogas (Prade et al., 2011) and biodiesel (Rehman et al., 2013). Furthermore, it has been shown to be suitable for crop rotation due to its phytoremediation characteristics (Linger et al., 2002).

The BBCH (Biologische Bundesantalt, Bundessortenamt and CHemische Industrie, Germany) scale is a system for the uniform coding of phenologically similar stages (stages of growth and development in ontogeny) in different species of dicotyledonous and monocotyledonous plants (Meier, 2001). The scale was based on a widely used decimal scale for grains and rice published by Zadoks et al. (1974). Taken as a basis, different specific BBCH scales have been developed for a range of plant species, such as rapeseed (Lancashire et al., 1991), coffee (Arcila-Pulgarin et al., 2002), camelina (Martinelli, Galasso, 2011).

The basic principles of the BBCH system are as follows:

– To identify and describe external (morphological) features of the phenological stages that are easily recognizable visually;

– As a rule, unless otherwise is indicated, only the main stem is taken into consideration;

– Principal and secondary stages can occur simultaneously. In this case, they are indicated using a slash (e.g. 16/22);

– A period between two specific stages is indicated using a dash (e.g. 51–69);

– A stage begins if it is determined in at least 50% of the plants (Meier, 2001).

In hemp, primarily, the following stages of growth and development are recognized: germination and emergence, vegetative stage, flowering and seed formation, senescence (Mediavilla et al., 1998), germination stage, stage of slow growth, rapid growth period, period between growth of flower buds in the leaf axis and the time when the first flowers open, flowering, growth of the achene (Bócsa, Karus, 1998), etc.

The uniform coding system of the hemp phenology is important for the correct timing of management practices, such as fertiliser application, pest, disease and weed control, in studying adaptability to different climatic conditions and in developing breeding programmes. However, there is no data on the BBCH scale for the growth and development stages of hemp (*Cannabis sativa* L.) in the sources known to us, including the BBCH monograph (Meier, 2001), review on the use of the scale for different species or crops (Meier et al., 2009). Meanwhile, there have been attempts made to code phenological stages passed by hemp during ontogenesis (Mediavilla et al., 1998; Vyrovets et al., 2012). However, these systems are very different from the conventional BBCH coding system.

The current paper proposes the individual codes by the BBCH scale of phenological growth and development stages of hemp (*Cannabis sativa* L.).

METHODS AND CONDITIONS

The system of phenological stages of hemp and individual codes by the BBCH scale were developed based on a long-term observation of growth and development stages of this species. First, we recorded the qualitative and quantitative changes in plant growth and development, beginning, duration and end of stages, and then made a generalization. A lot of modern varieties of monoecious and dioecious hemp, samples from the National (Ukrainian) Hemp Collection of Genetic Resources, including wild and local varieties and inbred lines, and hybrids were used in the investigation. Varieties of different genetic origin, created in different countries, were used for the studies. In dioecious forms of hemp the phenological stages of male and female seed plants were investigated, and in monoecious forms of hemp the phenological stages of monoecious female seed plants (main sexual type) were studied.

RESULTS AND DISCUSSION

In order to standardize the coding of phenological stages of growth and development, we offer a system of growth and development stages, individual codes in accordance with the BBCH scale and the comments (explanations) shown in the Table. They have been developed on the basis of the general BBCH scale (Hack et al., 1992; Meier, 2001) and on the authors' experience of many years in conducting biological and breeding research on hemp.

Table. **Phenological stages of growth and development of hemp (*Cannabis sativa* L.), individual codes by the BBCH-scale**

Code	Description
Principal growth stage 0: Germination, sprouting	
00	Dry seeds
01	Beginning of seed imbibition
03	Seed imbibition complete
05	Radicle (root) emerged from seed
06	Elongation of radicle, formation of root hairs and lateral roots
07	Hypocotyl with cotyledons or shoot breaking through seed coat
08	Hypocotyl with cotyledons growing towards soil surface
09	Emergence: cotyledons break through soil surface

Table **(continued)**

Code	Description
Principal growth stage 1: Leaf development[1]	
10	Cotyledons completely unfolded; first leaves separated
11	1 true leaf pair (simple)
12	2 true leaf pairs (compound)
13	3 true leaf pairs (compound)
14	4 true leaf pairs (compound)
15	5 true leaf pairs (compound)
16	6 true leaf pairs (compound)
17	7 true leaf pairs (compound)
18	8 true leaf pairs (compound)
19	9 and more true leaf pairs (compound)
Principal growth stage 2: Formation of lateral shoots[2]	
21	First lateral shoot visible
25	Several lateral shoots in the base of leaf
Principal growth stage 3: Stem elongation[3]	
31	Stem 10% of final length
32	Stem 20% of final length
33	Stem 30% of final length
34	Stem 40% of final length
35	Stem 50% of final length
36	Stem 60% of final length
37	Stem 70% of final length
38	Stem 80% of final length
39	Stem 90% of final length
Principal growth stage 5: Inflorescence emergence[4, 5]	
51	First individual flower buds of male flowers visible
55	Bulk appearance of male flower buds
59	Leaves of simple calyciform 5-part perianth of male flowers separated but buds still closed

1 In hemp, not only opposite leaf aestivation with bifolia stem nodes, but the combination of opposite, alternate, ringworm leaf aestivation and unifoliate, bifoliate, trifoliate, tetrafoliate stem nodes may be observed. In this case not the number of true leaves, but the number of stem nodes shall be determined. The principal growth stage 1 occurs simultaneously with the principal growth stage 3.

2 The principal stage of growth 2 occurs simultaneously with principal growth stages 17–19.

3 Hemp reaches more than 50% of the final stem length (growth stages 36–39) in principle growth stages 5 and 6.

4 Principal growth stage 4 is absent in hemp.

5 For female flowers, principal growth stage 5 (budding) is quite difficult to determine; usually it occurs at a similar time as that for male flowers.

Table **(continued)**

Code	Description
Principal growth stage 6: Flowering[6]	
60	First individual flowers open
62	20% of flowers open
63	30% of flowers open
64	40% of flowers open
65	Full flowering: 50% of flowers open
67	Flowering finishing: 70% of flowers open, many male flowers fallen, fruit set visible
69	End of flowering
Principal growth stage 7: Development of fruit[7]	
71	10% of fruits have reached final size and coloration
72	20% of fruits have reached final size and coloration
73	30% of fruits have reached final size and coloration
74	40% of fruits have reached final size and coloration
75	50% of fruits have reached final size and coloration
76	60% of fruits have reached final size and coloration
77	70% of fruits have reached final size and coloration
78	80% of fruits have reached final size and coloration
79	Nearly all fruits have reached final size and coloration
Principal growth stage 8: Ripening of fruit[8]	
81	Beginning of ripening
83	30% of ripe fruits
85	50% of ripe fruits
87	70% of ripe fruits
89	Fully ripe, beginning of fruit abscission
Principal growth stage 9: Senescence[9]	
91	Shoot development completed, top leaves still green
93	Beginning of top leaves falling or dying out
95	50% of top leaves fallen or died out
97	End of leaf fall, plants dying out
99	Harvested product

[6] The flowering stage in populations of monoecious hemp forms has to be determined separately for male and female flowers on the main sex – monoecious female seed plant (has compact inflorescences with female flowers dominating over male); in dioecious hemp forms, the flowering stage has to be determined separately for male flowers of male hemp and female flowers of female seed hemp.

Growth stages 67–69 usually occur simultaneously with growth stages 71–75.

[7] Stages 75–79 usually occur simultaneously with growth stages 81–85. Stages of fruit development in populations of monoecious forms of hemp shall be determined on monoecious female seed plants; in dioecious hemp it shall be determined on female seed plants, for growth stage 7 is absent in male plants.

[8] The stage of ripening in populations of monoecious hemp forms shall be determined on monoecious female seed plants; in dioecious hemp forms, it shall be determined on female seed plants, for growth stage 8 is absent in male plants.

[9] Stages 91–93 usually occur simultaneously with growth stage 89.

CONCLUSIONS

The developed system of phenological stages of hemp (C*annabis sativa* L.) growth and development and the individual codes by the BBCH scale may be recommended for use in the fields of agronomy, plant breeding, physiology, pathology, and entomology. Using the uniform coding of phenological stages of hemp will promote more effective planning and management of scientific experiments and practice. It will allow a precise determination of herbicide and insecticide application timing, foliar application of macro- and micronutrients, periods of intensive growth, formation of seeds, artificial isolation and hybridization.

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Sergey Mishchenko, Jurij Mokher, Iryna Laiko, Natalija Burbulis, Hanna Kyrychenko, Svetlana Dudukova

SĖJAMOSIOS KANAPĖS (*CANNABIS SATIVA* L.) AUGIMO TARPSNIŲ KODAVIMAS PAGAL BBCH SISTEMĄ

S a n t r a u k a

Straipsnyje aptariami pagrindinių kanapės augimo tarpsnių požymiai, pateikiamas jų trumpas aprašymas ir kodavimo sistema pagal BBCH skalę. Kanapės vegetacijos periodas yra suskirstytas į devynis pagrindinius augimo tarpsnius: sėklų dygimas ir daigai (0), lapų formavimasis (1), šoninių stiebų formavimasis (2), stiebo augimas (3), butonizacija (5), žydėjimas (6), vaisių formavimasis (7), vaisių brendimas (8) ir senėjimas (9). Pagrindiniai augimo tarpsniai suskirstyti į potarpsnius nurodant jų pagrindinius skiriamuosius požymius. Straipsnyje pateikiama kanapės auginimo tarpsnių klasifikacinė sistema naudinga kanapės augintojams ir mokslininkams (selekcininkams, fiziologams, entomologams ir t. t.). Rekomenduojama naudoti agronomijos, augalų selekcijos, fiziologijos, patologijos ir entomologijos sričių mokslininkams ir agrarinio sektoriaus darbuotojams. Vieningos sėjamosios kanapės fenologinių tarpsnių kodavimo sistema užtikrins efektyvesnį agrotechnologinių priemonių planavimą ir naudojimą.

Raktažodžiai: BBCH skalė, *Canabis sativa* L., dvinamė kanapė, fenologiniai augimo tarpsniai, vienanamė kanapė