Annales Universitatis Paedagogicae Cracoviensis
Studia Naturae, 6: 203–225, 2021, ISSN 2543-8832
DOI: 10.24917/25438832.6.12

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Phenological growth stages and BBCH-identification keys of Jerusalem artichoke (*Helianthus tuberosus* L.)

Introduction

The growth stages of development of particular plant species were constructed and proposed by many authors around the world since decades. Chen (2013) indicates that the tradition of observation and recording the phenological events of many cultivated and ornamental plants in ancient times were occurred. The interesting plant species that is being rediscovered today is Jerusalem artichoke, topinambour (*Helianthus tuberosus* L.). Both, the growing attention of scientists in the context of its interesting physiological, biochemical and genetic predispositions invasive plant (Balogh, 2008; Tokarska-Guzik et al., 2012), resistant to salt stress (Zhang et al., 2016), quite difficult to correctly identify *H. tuberosus* and *H. strumosus* L. and their natural hybrids – they both produce tubers from all the other species of the *Helianthus* genus (Kays, Nottingham, 2008), as well as the growing interest in this plant as a raw material in the food industry (high inulin content, an easily hydrolysable fructan (Barhatova et al., 2015), component of sophisticated alcoholic beverages (Rossini et al., 2016), health-promoting properties of tubers (Cieślik, Filipiak-Florkiewicz, 2000; Kulczyński, Gramza-Michałowska, 2016; Radovanovic et al., 2014), make this plant nowadays more and more noticeable. Additionally, the energy sector approves this plant as an energetic crop (bioethanol and biofuel production, pellets production due to a large amount of biomass produced per unit area with a satisfactory caloric value (Kowalczyk-Juśko et al., 2012; Johansson et al., 2015; Sawicka et al., 2019; Bedzo et al., 2020). There are also other applications (such as blasting in forest frames as an alternative food for wild animals (Dreszczyk, Brzezowska, 2008), especially wild boars, a substrate medium for the production of mushrooms and shunts (Đorđević et al., 2010), or for industry processes with the use of microorganisms laboratory cultures (Meng et al., 2021) make this plant more and more famous.

However, each multi-purpose plant has its limitations, among which it should be noted: invasive nature (high inulin content, thanks to which the tubers winter in the soil down to −30°C, rapid growth and early growth of the aboveground parts shading the surface, vegetative reproduction mostly climatic zones, remains in the position despite herbicidal fallow (Balogh, 2008; Tokarska-Guzik et al., 2012; Pacanoski, Mehmeti, 2020). The increasing number of papers according Jerusalem artichoke in Web of Science (from 1910 to 2000: 615 articles, 2001–2010: 221 articles, 2011–2015: 292 articles, 2016–2020: 480 articles) and agricultural events focusing on Jerusalem artichoke (Stapor, 2020) is gathering more and more people interested in this plant around the world. More information about origin, history of discover and various naming of this plant can be found in *The Biology and chemistry of Jerusalem artichoke* (Kays, Nottingham, 2008). Detailed information about probiotic and pharmaceutical properties of this plant was published by Mystkowska et al. (2015), its multipurpose use was provided by Sawicka et al. (2012), and energy properties of the plant announced Gao et al. (2016). Recently, the very valuable review, with a whole view on this plant appeared (Rossini et al., 2019).

The aim of the study is to focus on the growth and development of Jerusalem artichoke (*H. tuberosus*) plants grown from the tubers in temperate climate zone and propose a BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemicsche Industrie) identification key, which is expected for unification academic and practical discussion about this plant. Due to the fact that in our climate the seeds are not fully developed and their role in propagation of the plant is negligible, the proposed BBCH key describes all development phases except the ripening of seeds phase (is omitted).

The developmental biology of Jerusalem artichoke – state of the art

The general strategy of Jerusalem artichoke (JA) is to invests actual carbon and nutrients early in its development into stem (Incoll, Neales, 1970), branch, and leaf growth, facilitating the exploitation of aboveground resources. Later in the developmental cycle carbon and nutrients are allocated to rhizomes and tubers (McLaurin et al., 1999), enabling the species to spread alongside, i.e. colonising new areas. The success of its allocation patterns is in simultaneous synchronization of the below- and aboveground biomass growth and development (Fig. 1). The plants produce considerable amounts of aboveground biomass, which acts for carbohydrates reservoir although it has C3 photosynthetic mode (Podlaski et al., 2017).

Helianthus tuberosus plants have a strong photoperiod response (short-day plant) (Terzić et al., 2012). One of the first research exploring photoperiod phenomenon in plants was based on Jerusalem artichoke species (Garner, Allard, 1923). Shortly, photoperiodic plants identify day length in the leaves and then transfer the signal (florigen) to the shoot apex for the onset of the formation of inflorescence. The day length also affects the start of formation tubers (i.e. tuberisation). Typically initiation of tuberisation

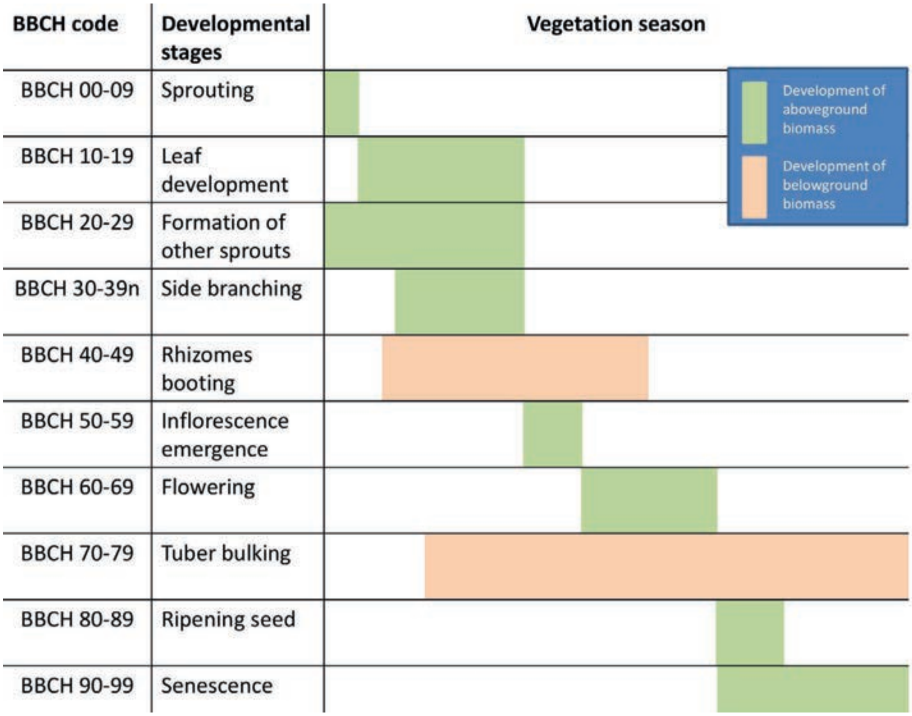


Fig. 1. General view on developmental stages of Jerusalem artichoke (*Helianthus tuberosus* L.)

begins from 5 to 13 weeks after emergence (Swanton, Cavers, 1989; Hay, Offer, 1992; McLaurin et al., 1999).

Generally, the development of aboveground biomass goes through successive phases, from the sprouting, full side branching (BBCH 39n), to full drying off the plant (BBCH 98). The belowground development starts with roots development (BBCH 04), then rhizome development (BBCH 40-49), and tuber development (BBCH 70-79).

The BBCH system of monitoring physiological scales in plants

Any lively discussion between people from different regions needs a common language. Except for the known need to communicate in the same language, it is nonetheless necessary to think about the same phenomena in the same way, especially when the discussion concerns a dynamic process in biological systems, additionally modified by environmental processes influenced in various intensity in every point on the world map. Scientists' passion, farmer's needs, and entrepreneurs' interests underlie the universal BBCH scale (Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie) currently in force (Meier, 2018). The Monograph did not appear at once (Meier et al., 2009). Many interesting works on this topic (Troitzky, 1925; Fleckinger, 1948; Feekes, 1941; Large, 1954) were published through the 20th century, to meet the demands of 1) unification and clarification of definitions of concepts in botanical scientific discussion, 2) simplification the decision making in process of plant protection by farmers and avoid the misunderstanding between farmers and agrochemical companies or agricultural insurance agents, and 3) development of agrometeorology. However, a real acceleration of universal concepts describing phenological stages during plant development occurred after a publication scale by Zadoks et al. (1974). The authors presented an adjusted and refined numeric decimal scale for such plants like cereals and rice, which gave the direct base for currently wide-spread used BBCH scale.

The BBCH coding system is an improvement of the Zadoks et al. (1974) coding system, it includes also the dicotyledoneous plants and more monotyledoneous plants species. The first publication of the BBCH codes of some crops (Bleiholder et al., 1989) (appears in working group consisted of staff members from four chemical companies) was the first step to join the forces in 1991 with German scientists (from The Federal Biological Research Centre for Agriculture and Forestry, BBA), who published booklets describing phenological stages of particular crops (Meier, 1985). The first outcome of this cooperation was the principles of the enhanced general BBCH scale (Hack et al., 1992), which was the base for members of this group for publishing (with experts in each crop) the "extended BBCH scales for specific crops" in various branch journals. The first BBCH Monograph edited by Meier (1997) was published in four languages and describes the phenological development stages of 27 crops and wild plants. Adamczewski and Matysia (2005) published the BBCH scale in Polish, after earlier published work (e.g. Gąsowski, Ostrowska, 1993). Milestone for the international acceptance of the BBCH codes used in plant protection management process was the decision for establishing the BBCH scale mandatory for all official plant protection trials made in 2004 and 2006 by EPPO (*European and Mediterranean Plant Protection Organization*) (Meier et al., 2009).

Nowadays the BBCH Monograph (Meier, 2018) includes 48 identification keys for crops and additional key for weeds (Dicotyledons, Graminae, Monocotyledons, Perennial plants). Recently, the developmental biology of many other crops has been described in a key on the BBCH scale, e.g. to harmonize production processes (Rajan et al., 2011; Zhao et al., 2019; Singh et al., 2021). Although, despite of multi-purpose use and increased awareness of *H. tuberosus* species, there is a lack of official BBCH identification key describing phenological growth stages of *H. tuberosus*. In this article, developmental biology of Jerusalem artichoke in temperate climate was presented. The phenological stages of this plant were proposed in the obligatory BBCH identification key.

Material and methods

Experimental site and plant material

The plants were grown in experimental field located in Experimental Station in Krakow – Mydlniki (50°05′08.5″N; 19°51′08.3″E; University of Agriculture in Kraków, Poland) in 2020. During the 7 months (mid-April to mid-November 2020) growth and development of *Helianthus tuberosus* plants (cv. Rubik) were monitored. The seed tubers were intentionally left in the field previous autumn (November 2019) as an irregular population close to the natural one. In spring, plants were chosen and monitored during the vegetation season (completely random assignment was applied). The soil was unfertilized and characterised a well moisture content during whole vegetation period (due to impact of an neighbourhood of underground watercourse).

The BBCH scale

The BBCH principal growth stages were the basis for these considerations (Tab. 1).

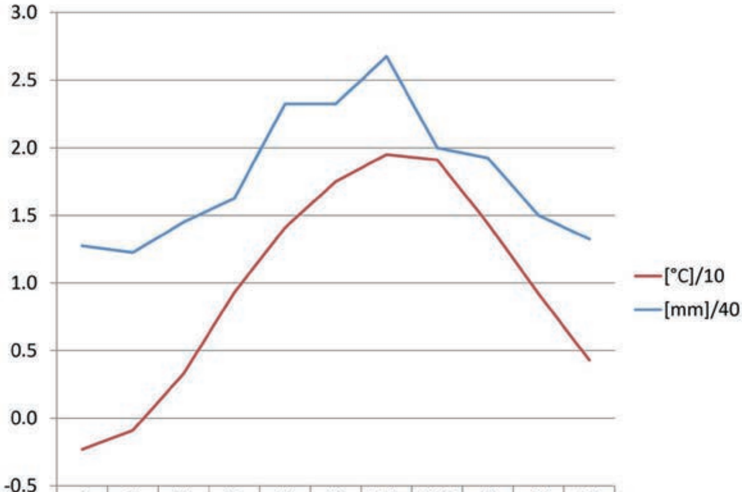
Tab. 1. Principal growth stages of *Helianthus tuberosus* L. according to BBCH scale (after Meier et al., 2009)

Stage (number 0–9)	Description
0	Germination / sprouting / bud development
1	Leaf development (main shoot)
2	Formation of side shoots/tillering
3	Stem elongation or rosette growth/shoot development (main shoot)
4	Development of harvestable vegetative plant parts or vegetatively propagated organs / booting (main shoot)
5	Inflorescence emergence (main shoot) / heading
6	Flowering (main shoot)
7	Development of fruit
8	Ripening or maturity of fruit and seed
9	Senescence, beginning of dormancy

Meteorological data

The observations were carried out with the background of weather conditions in temperate climate (Poland). The meteorological data was obtained from ClimateData.org (2020). The graphical relation of mean temperatures [°C] and total precipitation values [mm] for each month were reported as a Gaussen-Walter climatogram with Łukasiewicz modification (Walter, 1976; Łukasiewicz, 2006) (Fig. 2).

The rule for the construction of such a graph is that the values of mean temperature and total precipitation are plotted with maintaining a ratio of 1°C to 4 mm of precipitation. This balance determines the difference between precipitation and evapotranspiration. It helps to read off the amount of evapotranspiration and thus estimate the excess or shortage of precipitation for plants on a local scale (Treder et al., 2018).



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
[°C]/10	-0.2	-0.1	0.3	0.9	1.4	1.8	2.0	1.9	1.4	0.9	0.4
[mm]/40	1.3	1.2	1.5	1.6	2.3	2.3	2.7	2.0	1.9	1.5	1.3

Fig. 2. Gaussen-Walter climatogram for the studied area (in months January–November 2020)

Results

The stages of phenological phases of *Helianthus tuberosus* was constructed for temperate climate zone (Tab. 2 – Appendix 1).

Principal growth stage 0: sprouting

Helianthus tuberosus tubers have endodormancy, which means that an internal mechanism prevents sprouting even though the environmental conditions may be suitable. It is linked with the conditions (winter months) of their region of origin (temperate zone, continental climate).

The main shoot develops from apical bud located on the belowground seed tuber (Fig. 3A–B). There are possible other lateral sprouts growing from the same tuber at the same time (from axillary buds), but the plant seems to develop lateral sprouts a little bit later so as not to inhibit the growth of the main shoot. Because some tubers are located fairly deep in the ground, the length of the first sprout may achieve even 30 cm (BBCH 08, Fig. 3B), due to high vitality and affluence of substances in tubers. Sprouts after reaching a suitable cumulative temperatures grow in the soil quite fast regardless of weather conditions.

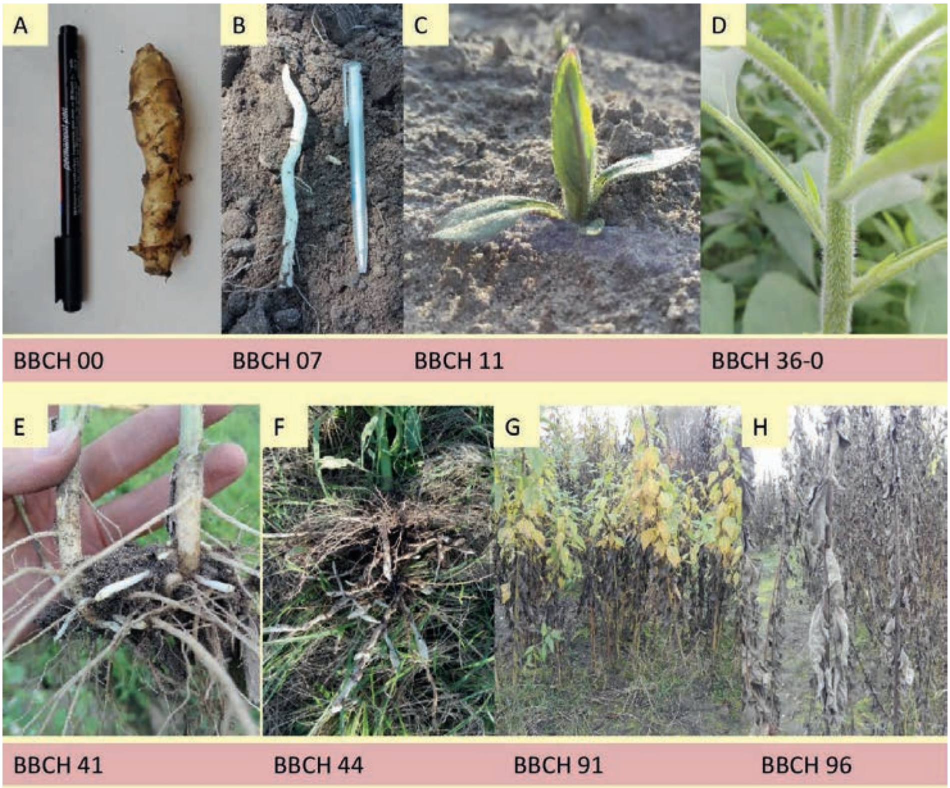


Fig. 3. The examples of some phenological stages of proposed BBCH coding system for Jerusalem artichoke (*Helianthus tuberosus* L.) (Photo. A. Kliszcz)

Principal growth stage 1: leaf development (main shoot)

The main shoot (stem) grows quite fast and tends to shade the stand. The development of aboveground leafy biomass realizes quickly. When the plant meets favourable weather, it generates next leaves pair in each new week. Leaves are numerous, with the opposite arrangement in the lower third, alternate above. In the studies about the dynamics of this stage, it will be worth to mark with an asterix the last pair of the leaves with opposite arrangement (e.g. BBCH16*).

Generally, the number of leaves pairs depend on biotope richness, and to a lesser extent on the weather conditions. Once the side branches appear from the apical buds in any leaves pair, the development of the plant shall be determined in accordance with appropriate next phase (BBCH 3_).

Principal growth stage 2: formation of other sprouts

This stage occurs not always here. Generally, the plant skips with its development from leaf development phase (BBCH 1_) to the next phase (BBCH 3_). The strategy of formation of other stems (lateral sprouts) from the underground parts of the plant (tuber, rhizomes, underground part of the main stem) seems to be linked with the need for more photosynthetic area within the plant, what constitutes their carbohydrate supply for new tubers or it is a result of mechanically injured belowground stem. The number of shoots that emerge are linked with e.g. shape of tuber and it is variety depended. The tuber more branched produces more shoots (tubers branched vs. tuber with apical dominance) (Kays, Nottingham, 2008). The formation of other sprouts from the tuber also depends on the depth at which the tuber is located, tuber size and number of its axillary buds. In general, since the delineation of the sources of additional stems is unclear, all shoots that came above the ground surface after the main shoot drop into one category.

It is worth to notice that the emergence of other sprouts (stems) may appear during the whole vegetative phase. The final number of stems is constituted at the end of the growing season, when the plant enters the senescence phase.

Principal growth stage 3: stem elongation and development of lateral branches on main shoot (side branching)

In this stage the development of the stem and upper leaves continues. Side branching appears simultaneously on the main shoot from the bottom of the plant.

The presence and degree of branching depend on the variety, plant population density, and other factors (like branch location on the plant, photosynthetic potential, environmental factors). The lateral branches are formed in the axils of the leaves, starting at the base of the plant. At each node, there is commonly two opposite-located lateral branches. Very rare is the triple, when three leaves emerge from one node. Rapid growth of branches on the plant diminishes in the middle of growth cycle and again increases when axillary buds start to developing into flowering branches. Vertical development of the plant is terminated by flower bud formation at the apex of the stems.

Not all BBCH codes may occur during the development of the plant in this stage. As soon as the next axillary buds begin to develop in the next (upper) pair of leaves on the plant, the BBCH code is counted there (e.g. BBCH 32-1 move to BBCH 33-0, even if the leaf development on the lower branch continues). The size of axillary buds should be at least 2 cm to be considered as the next level of this development phase (Fig. 3D).

Typically, every next node with leaves pair generates the twin opposite branches, but it depends on the plant's current needs (e.g. shading, processes of translocating carbohydrates). The plant may omit some pairs of leaves without developing any branches there. If this is the case for the third pair of leaves, the BBCH 33-0 remains until a fourth pair of leaves has developed and the axillary buds in the axils of this leaves appear. Another case may arise when fourth pair of leaves has already hosted emerging twin branches (e.g. already with two leaves each), then the BBCH 33-_ is valid until in the axis of the fifth pair of leaves appear new axillary buds.

Principal growth stage 4: rhizomes booting

The plant starts to form rhizomes in the early stages of biomass acquisition and accumulation (from 1.5 to 8 weeks after emergence; Fig. 3E). The underground portion of the stem (4 to 5 cm below the soil surface) is the basis for the emergence of rhizomes. They grow in a slight downward angle (Fig. 3F) with internodes length varying substantially among clones (Kays, Nottingham, 2008).

Principal growth stage 5: inflorescence emergence

The shift between vegetative and generative phase in Jerusalem artichoke (short-day clones) is strongly dependent on photoperiod. The inflorescence appears in the specific location on the plant of JA (i.e., the top of the stem and later – on branch apices) and their formation involves temporal order.

Because of that the BBCH coding system for this phase was focused on first appeared examples of top inflorescence, and then on branched-located ones (e.g. BBCH 51 -> BBCH 52, 53). Long-cycle varieties (ca. 9 months vegetation) often produce buds but no flowers (Denoroy, 1996), and their aerial parts are moving then straight on to senescence phase (BBCH 9_).

Principal growth stage 6: flowering

The flowering is starting from the top of the main shoot (BBCH 61-65) and will proceed to the bottom (along with side shoots embedded on the main shoot, i.e. BBCH 66-69). Flower stalks have frequently between 10 and 15 cm for Rubik cultivar, depending on closeness to the plant axis. This paper focus on domesticated clone (cv. Rubik), and it was observed that in temperate climate (Fig. 2) it takes ca. 21 days for the plants to proceed flowering (from the tight bud stage (BBCH 51) to senescence stage (BBCH 90)). The detailed visualisation of chronological sequence of flowering phase of single flower was presented in the book concerning the biological and chemical issues of JA plants (Kays, Nottingham, 2008). The BBCH scale required the flowering sequence of all flowers on the plant due to the fact that JA plants produce many flowers (not a single one as the sunflower produces). And for that reason presented BBCH scale includes the whole flowering biology of this plant with the background of single flower development steps.

Principal growth stage 7: tuber bulking

While tuber initiation appears to be in part controlled by carbohydrate supply, tuber bulking is strongly modulated by photoperiod, even in clones that are day neutral for flowering (Kays, Nottingham, 2008). Cumulative temperature is linearly correlated with tuber number, and cumulative degree days (≥ 520 degree days) can be used for predicting the onset of tuberisation (Spitters et al., 1988). In the cross section tuber could be divided (from exterior to interior) into: epidermis, cortex, outer medulla, inner medulla, and pith (Mazza, 1985). Shortly after the beginning of flowering, remobilization of nutrients from canopy into the developing tubers begins. Photoperiod and carbohydrate supply are a critical factors in the tuberisation response. Simultaneously with the proceeding bulking stages of the tuber, the dormancy onset occurs. The onset of dormancy is progressing gradually. Firstly, into dormancy enter rhizomes and small, young tubers, with more and more areas of the tuber establishing dormant. The larger, more mature tubers enter into dormancy at the end within the whole plant. Although, the initiation of dormancy in large tuber may occur even the tuber is not fully filled (Kays, Nottingham, 2008).

Principal growth stage 8: ripening seed

Flowers are often sterile (domesticated clones). Swanton et al. (1992) stated that most of the JA plants have no more than 5 seeds per flower head. According to Westley (1993) only a 44 % of mature seeds are capable of germination, whereas only 33% are able for reproduction – during the first season (wild clones). In this phase, the increased translocation of the assimilates to the tubers takes place, and this coincides with and affect the seed ripening as well. Because the propagation of the plant by the seed is of marginal importance, and it occurs when the plant is drying off (transfer of the symbionts to the tubers, i.e. tuber bulking, Fig. 3G–H), no special phase was assessed for process regarding seeds ripening.

Principal growth stage 9: senescence

The drying off of the whole plant occurs when the belowground part of the plant enters dormancy. The process of senescence accompanies the plant virtually throughout the entire growing season. The first leaves on the main stem senesced firstly, and it happens well before it starts blooming. Some authors argue this fact that the plant shades the lower leaves as it grows (Zubr, 1988).

The meteorological data (Fig. 2) shows no shortages of water in the studied period, i.e. the precipitation line is above the line representing the temperature, Such ratio (1°C to 4 mm precipitation) is proposed by Łukasiewicz (2006) for climate conditions in Poland (temperate). Therefore, the plants had favourable conditions for development during whole vegetation season.

Discussion

The Jerusalem artichoke (*Helianthus tuberosus* L.) is an aged tuber crop with a lately aroused attraction following its multipurpose usage (Cao et al., 2008; van Wyk, Wink, 2008; Ma et al., 2011; Maj et al., 2013; Mystkowska, Zarzecka, 2013). The growth of plants and certain developmental phenomena are governed by a few main factors: the total amount of heat a plant received during a certain period, the portion of various wavelengths from sunlight, number of days with sunlight and the duration of the day, richness of soil and their sufficient moisture (Biggs et al., 2007; Kocsis et al., 2007; Puangbut et al., 2012; Ruttanaprasert et al., 2014). However, the developmental biology of wild, domesticated, and intermediate clones differ significantly, but general overview of phenological stages of Jerusalem artichoke seems to be constant (Fig. 1). The plant have to go through all stages to produce tubers (Fig. 3A), a main propagules for next growing season. However, the development of this species is realised in two parallel directions: vegetative and generative (Pawłowski, Jasiewicz, 1971; Vaughan, Geissler, 2001). This complicates the naming of its developmental stage. Dual naming can be a solution. When the side branching phase continues, the rhizomes booting occurs, and then the proper description could be e.g. BBCH 38-2/46. Similarly, as the tubers fill, the aboveground biomass withers (it could be written as BBCH 78/97). Of course, the codes can be used individually to indicate only the state of the aerial vegetative biomass (respectively, BBCH 38-2, or BBCH 97). But for detailed ecological studies of this plant it is beneficial to use dual nomenclature. This paper focuses on domesticated clone (cv. Rubik), which belongs to the group of short-day clones.

The first attempt to name and standardise Jerusalem artichoke (JA) developmental biology stages was made by Paungbut et al. (2015). However, they designed their own system without using the BBCH codes. They arrange all development of JA into three main groups of stages: Vegetative stages (V), Reproductive stages (R), and Tuberisation stages (T). The authors cultivated the plants in Thailand (tropical area) in 2011–2012, and observed developmental biology of JA during opposite seasons, both, the early-rainy season and the drier post-rainy season. There are 15 phases in their concept (adding to this number of pairs of leaves on the main stem, depending on the nodes produced; shortly, if the main stem develops 12 leaves pairs, there will be 25 phases in total). The BBCH codes allow for a more accurate description of each phase through careful observation of plant morphology. Therefore, in presented concept according to BBCH codes there are at least 100 various phases, which precisely define every moment of development (e.g. BBCH 3_ is describing side branching). More detailed descriptions of the JA plants are already included in the phenotype studies of the various clones of this species (Diederichsen, 2010), which is no necessary to include it in BBCH system formation.

It is worth to note that with modified biotope features (unfavourable conditions), the length of developmental stages could be shorten (e.g. the time of bulking tubers) or abandoned (the flowering phase does not always occur). Additionally, the genetic features play a pivotal role as well (Kays, Kultur, 2005; Skiba, Sawicka, 2016) and also wild vs. domesticated clones develop with different dynamics (Feher et al., 1999; Breton et al., 2017). For example, Serieys et al. (2010) examined 142 clones of JA deposited in INRA library and stated that 80% of them perform the flowering phase between September and October, and 10% of them did not enter this phase at all. On the other hand, the biomass enhancement and its dynamics could be induced with richness of site or fertilisation level (Bogucka et al., 2021). Interesting research on the dynamics of nutrient uptake was carried out by Izsaki and Németh (2013). The authors examined two varieties of JA and stated that in both cases the maximum nutrient uptake was recorded on the 155th day of vegetation, which corresponds with beginning of 7th phase (BBCH 70-79), i.e. tubers bulking.

Manipulation of duration of development processes could be intentionally forced in agricultural practice, which is targeted on high-quality, plentiful tubers yield. In literature the manipulation of planting date (Puangbut et al., 2012), mowing date of plant top (Acar et al., 2011), dates of pruning radius (Gao et al., 2018), harvest time and storage (Saengthongpinit, Sajjaanantakul, 2005) or another agrotechnical treatments are known (Puttha et al., 2013; Dias et al., 2016; Gao et al., 2019). Therefore, the proper managing of the plantation of topinambur plants seems to be an important factor for high yield of tubers in many agroecosystems.

Conclusion

The scale for coding the phenological growth stages of *Helianthus tuberosus* L. species is needed. This plant becomes more and more popular because of its multi-purpose use and ease of cultivation in all types of soil all over the world. The latest edition of BBCH Monograph (Meier, 2018) does not cover this need. Jerusalem artichoke has many desirable growing traits such as cold and drought tolerance, wind and sand resistance, saline tolerance, strong fecundity and high pest and disease resistant.

Generally, the development of aboveground biomass goes through successive phases, from the sprouting, full side branching (BBCH 39n), to full drying off of the plant (BBCH 98). The belowground development starts with roots development (BBCH 04), then rhizome development (BBCH 40-49), and tuber development (BBCH 70-79). It is worth to notice that the development of the plant from a point (BBCH 49) realises in two parallel directions: vegetative and generative, i.e. when at least one rhizome starts to thicken at its end, it means that the plant begun a generative phase.

The concern about their developmental biology is also essential for managing the termination strategies for this genus, as the JA is an invasive plant in most ecosystems. Therefore growing attraction of this plant force their key in BBCH coding system to harmonize discussion about this plant in the future.

Acknowledgements

The research was financed by the Ministry of Science and Higher Education of Poland.

Conflict of interest

The author declares no conflict of interest.

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Appendix 1

Tab. 2. Phenological growth stages of *Helianthus tuberosus* L. according to the BBCH scale

BBCH code (2-digit)	Description of the development from the tuber
Principal growth stage 0: Sprouting	
00	Innate or enforced dormancy, tuber not sprouted
01	Beginning of sprouting: first sprout visible (< 1 mm)
02	End of dormancy: sprout 2–3 mm
03	First (main) sprout further growth (< 1 cm)
04	Beginning of root formation; first sprout further growth (< 5 cm)
05	First sprout further growth (< 15 cm)
06	First sprout further growth (< 15 cm)
07	First sprout further growth (< 20 cm)
08	First sprout further growth (< 30 cm and more)
09	Breakthrough sprouts on the ground
Principal growth stage 1: Leaf development (main shoot)	
10	The first pair of leaves begins photosynthesis (leaves are still rolled up, but green)
11	First pair of leaves fully developed
12	Second pair of leaves fully developed
13	Third pair of leaves fully developed
14	Fifth pair of leaves fully developed
15	Seventh pair of leaves fully developed
16	Ninth pair of leaves fully developed
17	Eleventh pair of leaves fully developed
18	Thirteenth pair of leaves fully developed
19	Fifteenth pair of leaves fully developed
19n	Sixteenth (and further) pair of leaves fully developed
Principal growth stage 2: Formation of other sprouts	
20	Only the main shoot is visible above the ground
21	The first side shoot appears above the ground
22	The second side shoot appears above the ground
2..	The next side shoots appear above the ground
Principal growth stage 3: Development of lateral branches on main shoot (Side branching)	
30	Beginning of developing lateral branches: the first (twin) axillary buds appear in the axils of the first pair of leaves on the main shoot
31-1	The first pair of developed leaves growing out from the axils of the first pair of leaves on the main shoot
31-2	The second pair of developed leaves growing out from the axils of the first pair of leaves on the main shoot
31-…	Successive pairs of developed leaves growing out from the axils of the first pair of leaves on the main shoot

32-0	The first (twin) axillary buds appear in the axils of the second pair of leaves on the main shoot
32-1	The first pair of developed leaves growing out from the axils of the second pair of leaves on the main shoot
32-..	Successive pairs of developed leaves growing out from the axils of the second pair of leaves on the main shoot
33-0	The first (twin) axillary buds appear in the axils of the third pair of leaves on the main shoot
33-1	The first pair of developed leaves growing out from the axils of the third pair of leaves on the main shoot
33-..	Successive pairs of developed leaves growing out from the axils of the third pair of leaves on the main shoot
34-0	The first (twin) axillary buds appear in the axils of the fifth pair of leaves on the main shoot
34-1	The first pair of developed leaves growing out from the axils of the fifth pair of leaves on the main shoot
34-..	Successive pairs of developed leaves growing out from the axils of the fifth pair of leaves on the main shoot
35-0	The first (twin) axillary buds appear in the axils of the seventh pair of leaves on the main shoot
35-1	The first pair of developed leaves growing out from the axils of the seventh pair of leaves on the main shoot
35-..	Successive pairs of developed leaves growing out from the axils of the seventh pair of leaves on the main shoot
36-0	The first (twin) axillary buds appear in the axils of the ninth pair of leaves on the main shoot
36-1	The first pair of developed leaves growing out from the axils of the ninth pair of leaves on the main shoot
36-..	Successive pairs of developed leaves growing out from the axils of the ninth pair of leaves on the main shoot
37-0	The first (twin) axillary buds appear in the axils of the eleventh pair of leaves on the main shoot
37-1	The first pair of developed leaves growing out from the axils of the eleventh pair of leaves on the main shoot
37-..	Successive pairs of developed leaves growing out from the axils of the eleventh pair of leaves on the main shoot
38-0	The first (twin) axillary buds appear in the axils of the thirteenth pair of leaves on the main shoot
38-1	The first pair of developed leaves growing out from the axils of the thirteenth pair of leaves on the main shoot
38-..	Successive pairs of developed leaves growing out from the axils of the thirteenth pair of leaves on the main shoot
39-0	The first (twin) axillary buds appear in the axils of the fifteenth pair of leaves on the main shoot
39-1	The first pair of developed leaves growing out from the axils of the fifteenth pair of leaves on the main shoot
39-..	Successive pairs of developed leaves growing out from the axils of the fifteenth pair of leaves on the main shoot
39n-0	The first (twin) axillary buds appear in the axils of the sixteenth (or successive) pair of leaves on the main shoot

Principal growth stage 4: Rhizomes booting	
40	The first rhizome starts to grow
41	The other rhizomes start to develop
42	The rhizomes elongate
43	The rhizomes still elongate and start to branch
44	The rhizomes elongate and branch still (< 30 cm from plant)
45	The rhizomes elongate and branch still (< 50 cm from plant)
46	The rhizomes elongate and branch still (< 80 cm from plant)
47	The rhizomes elongate and branch still (< 100 cm from plant)
48	Rhizomes are developed and most of them have not thickened ends yet
49	The ends of most rhizomes start to thicken (rhizome tips to twice the diameter of subtending rhizome)
Principal growth stage 5: Inflorescence emergence	
50	Inflorescence not visible
51	Inflorescence just visible between youngest leaves on the main shoot (tight bud stage) (peduncles elongate)
	Inflorescence just visible on the upper branches (50% branches on the top have inflorescence just visible); tight bud stage (peduncles elongate)
	Inflorescence just visible on the lower branches; tight bud stage (peduncles elongate)
52	First top ligules (ray flower corollas) exposed and green (peduncles elongate)
53	Most top ligules exposed and green (peduncles elongate)
54	Ligules on the upper branches exposed and green (peduncles elongate)
55	Most top ligules exposed and green (peduncles elongate)
56	Ligules on the upper branches exposed and green (peduncles elongate)
57	Ligules on the lower branches exposed and green (peduncles elongate)
58	Ligules on the top and upper branches yellow-green (inflorescence still closed)
59	Most ligules on the plant are yellow-green (inflorescence still closed)
Principal growth stage 6: Floweringi	
60	Top ligules beginning to unroll (disk flower corollas yellow and closed)
61	First top ligules open
62	First top ligules with emerging anthers from the corolla
63	Additional anthers and first stigmas emerging on outer whorls on the top ligules
64	About half of top disk flowers open with stigmas emerged
65	All of the top disk flowers open with stigmas emerged (in bloom)
66	Third part of disk flowers in lateral branches (from the top) are in bloom (outer whorl flowers on the top displaying initial stigma senescence)
67	Two thirds of disk flowers on lateral branches (from the top) are in bloom (top ligules wilting and initial drying)
68	80% of disk flowers on lateral branches (from the top) are in bloom
69	End of flowering: almost all disc flower have finished flowering on the plant, ray florets dried
Principal growth stage 7: Tubers bulking	
70	Tubers bulking (10% of all)
71	Tubers bulking (20% of all)
72	Tubers bulking (30% of all)
73	Tubers bulking (40% of all)

74	Tubers bulking (50% of all)
75	Tubers bulking (60% of all)
76	Tubers bulking (70% of all)
77	Tubers bulking (80% of all)
78	Tubers bulking (90% of all)
79	Tubers are full (100%), maximum of the total tuber mass reached
Principal growth stage 8: Ripening seed[ii]	
Principal growth stage 9: Senescence	
90	40% of aboveground green parts of the plant has dried up
91	50% of aboveground green parts of the plant has dried up
92	60% of aboveground green parts of the plant has dried up
93	70% of aboveground green parts of the plant has dried up
94	80% of aboveground green parts of the plant has dried up
95	90% of aboveground green parts of the plant has dried up
96	100% of aboveground green parts of the plant has dried up
97	Aboveground biomass has > 20% moisture w/w
98	Aboveground biomass has < 20% moisture w/w
99	Tuber harvested, dormancy

[i] a synthesis of an inflorescence development after Kays and Nottingham (2008) (changed)

[ii] seed is developing along the tuber bulking

Fazy rozwojowe słonecznika bulwiastego (*Helianthus tuberosus* L.) w propozycji oznaczeń skali BBCH

Streszczenie

Celem pracy było zbadanie i standaryzacja faz rozwojowych słonecznika bulwiastego (*Helianthus tuberosus* L.), rosnącego w klimacie umiarkowanym, na podstawie klucza oznaczeń BBCH. Tego rodzaju analizę wykonano po raz pierwszy, co było oczekiwane w dyskursie naukowym, jak i praktycznym. Rosnące zainteresowanie tym gatunkiem, zarówno z punktu widzenia naukowego, jak i utylitarnego, stawia potrzebę nazwania jego poszczególnych stadiów rozwojowych oraz ich standaryzacji w zakresie nomenklatury. Słonecznik bulwiasty jest rośliną o wielokierunkowym wykorzystaniu w różnych gałęziach przemysłu. Surowcem w przemyśle spożywczym są bulwy, które gromadzą znaczne ilości inuliny – łańcuchowego polimeru fruktozy, o istotnych właściwościach probiotycznych. Dzięki temu bulwy są cennym składnikiem żywności funkcjonalnej, substratem w produkcji farmaceutyków, czy napojów alkoholowych, a także pozwalają na przetrwanie gatunku w środowisku w okresie zimowym. Formowanie się bulw zachodzi przez znaczną część rozwoju ontologicznego gatunku (BBCH 49) i związane jest głównie z fotoperiodem, sumą temperatur efektywnych oraz obecnością nadziemnej biomasy rośliny, z której zachodzi alokacja asymilatów do bulw w okresie rozwoju generatywnego. Spośród wielu innych zastosowań, roślina ta jest wykorzystywana jako surowiec energetyczny, gdyż naturalnie wyschnięta biomasa nadziemna, pod koniec sezonu wegetacyjnego, zawiera niską zawartość wody i plasuje ten gatunek w środku listy roślin energetycznych.

Key words: topinambour, BBCH scale, phenological stages

Received: [2021.06.02]

Accepted: [2021.09.17]