New phenological growth stages of garlic (*Allium sativum*)

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Abstract

The advantages of using Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie (BBCH) phenological scales are well-known in the field of agronomy. Currently, specific scales exist for the majority of crops. Although garlic has international importance due to its worldwide cultivation, a specific phenological scale has not been developed; in general, garlic is integrated into the BBCH description for onion. While garlic and onion belong to the same genus, this generalisation should be avoided due to their many differences. The means of propagation of garlic is vegetative, from cloves of the previous cycle, and the concurrence of the bulbing phase and the emergence of the inflorescence (bolting types) cause garlic to perpetually remain in a 'second year stage' of its biological cycle. In contrast, onions and other bulbous Liliaceae that produce seeds undergo biannual development. In addition to this complexity, its physiological complex is strongly influenced by environmental factors, such as temperature and photoperiod; distinct conditions are required for overlapping or simultaneously occurring phases (bulbing/flowering). Nevertheless, ambiguity and lack of consensus exist concerning the start of different phenological phases due to the complex morphology of the bulb (composed of a bulb of bulbs/cloves). During bulbing, for example, two distinct, consecutive processes are involved: the differentiation of lateral buds and inflorescence (bolting types) and the thickening of the storage leaf of each bud (cloves). In the present study, an extended BBCH scale was developed for garlic (*Allium sativum*). Seven principal growth stages divided into secondary growth stages are described in detail and are represented by a two- or three-digit code. Descriptions begin with garlic cloves in a stage of dormancy, destined for planting and end with complete bulb maturity. The most complex growth stages of garlic were described from a morphological and physiological perspective, that is complete bolting types (hard-neck cultivars). Illustrations of different stages are included to clarify the application of the code system. The proposed BBCH garlic scale aims to fill gaps in the knowledge of this important crop and will serve as a useful tool for researchers, technicians and farmers. Thus, experimental findings may be standardised and complementary, which may lead to improvements in management practices and their comparisons.

Keywords

BBCH scale; bulbing; garlic clove; hard-neck cultivars; soft-neck cultivars.

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Introduction

Garlic (*Allium sativum* L.) is one of the earliest domesticated horticultural species. Its first archaeological remains date to circa 6000 BP in Israel (Zohary *et al.*, 2012), and garlic was widely consumed by the first great civilisations of the Old World (Maaβ & Klaas, 1995). In economic terms, it is currently the second most important species of the *Allium* genus worldwide, following onion (Fritsch & Friesen, 2002; Block, 2010), and has a planted surface area of 1.5 million ha (FAOSTAT, 2016). Today, garlic is grown in many countries and climate conditions, ranging from subtropical/mountain tropical to temperate climates (Fritsch & Friesen, 2002), and garlic forms part of the gastronomy of a multitude of cultures (Elzebroek &Wind, 2008; Block, 2010).

Knowledge of crop phenology constitutes a fundamental tool in the development of the agronomical sciences and related fields (Leather, 2010). Such knowledge provides substantial benefits during the management of agricultural systems, enabling the appropriate selection and optimal timing of certain practices, such as fertilization or use of pesticides for controlling pests, diseases and weeds (Feller *et al.*, 2012). Since 1992, the Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie (BBCH) Scale work group has carried out an enormous effort to standardise, describe and compile the phenological growth phases of several cultivated crops and weed species. The BBCH codification system is based on the numerical scale described by Zadoks *et al.* (1974) for cereals. This system has been subsequently improved upon inclusion of monocotyledonous and dicotyledonous species, allowing an easy comparison between species and their main phenological phases (Meier *et al.*, 2009). The basic principle of the BBCH Scale, as described by Hack *et al.* (Meier, 2001), consists of a decimal code that divides growth into principal (first digit) and secondary stages (second digit), although mesostages (centesimal code) may be introduced if necessary (Feller *et al.*, 2012). Currently, these generalised scales have been successfully used worldwide and have formed an essential instrument for many activities related to the agricultural sector (for scientific and technical purposes; agricultural administration; use by official organisations and agricultural businesses for fertilisers, phytosanitary measures and plant breeding), thus allowing the exchange of data and objective information at the global level (Meier *et al.*, 2009).

The current phenological stage for garlic proposed by the BBCH is integrated with onion (Meier, 2001). Although garlic belongs to the same genus as onion, leek and shallot, there are significant differences that render this scale irrelevant for garlic. A more specific scale is required to achieve greater standardisation in the evaluation of developmental stages of this crop. The morphology and phenology of garlic are more complex than the other mentioned species, which is fundamentally due to its particular means of propagation, bulbing and flowering, as the final two occur simultaneously.

During its domestication process, garlic began to lose its capacity to sexually reproduce, and seeds are not produced in the majority of current cultivars (Al-Zahim *et al.*, 1997; Volk *et al.*, 2004). Viable seeds are only produced by some varieties from near of Centre of Origin (Hong & Etoh, 1996; Shemesh *et al.*, 2008) and under specific environmental conditions (Kamenetsky *et al.*, 2004; Shemesh *et al.*, 2008). The current means of garlic propagation is vegetative, from cloves of harvested bulbs (Messiaen *et al.*, 1993). Although in *sensu stricto* the crop cycle begins when cloves are planted, knowledge of the sprouting plant before emergence of the distal portion of its shoot clove is fundamental for understanding, for each particular cultivar, suitable environmental conditions for storage and optimum planting date in the field.

Another difference from cultivated species of the same genus is the need to objectively determine and define the initiation of the bulbing phase, as this represents essential knowledge for crop management (Brewster & Rabinowitch, 1990; Messiaen *et al.*, 1993; Brewster, 2008). In contrast to onion, bulbing of garlic consists of two phases with distinct environmental requirements and associated crop management practices (Takagi, 1990). According to Takagi (1990), the first phase involves the formation of lateral buds at the axils of the youngest leaves due to the differentiation of the shoot apical bud, stopping the plant from growing new leaves. The second phase coincides with the significant growth stage of the bulb, which originates in the storage leaf of each side shoot, yielding the formation of cloves. Under normal conditions, the second or third leaf of side shoots tends to develop, while internal leaves remain as protective sheaths surrounding the dormant vegetative bud that will give rise to a new plant in the following cycle. These two stages are described separately in the BBCH General Scale as principal growth stage 2 (formation of side shoots) and principal growth stage 4 (development of harvestable vegetative plant parts or vegetatively propagated organs), respectively (Meier, 2001).

A third complexity in the study of garlic phenology revolves around the flowering process, described in the BBCH General Scale by principal growth stage 5 (inflorescence emergence) and principal growth stage 6 (flowering). In contrast to onion, these stages overlap with those previously defined during the bulbing process. In addition, not all cultivars completely develop an inflorescence, as many intermediate forms exist (in hard-neck cultivars), or the apical bud may be substituted by a central clove (in soft-neck cultivars). Although this is a genetic characteristic frequently used to classify plant material, distinct environmental conditions may noticeably modify the expression of a single cultivar (Kamenetsky *et al.*, 2004). With regards to the formation and development of an inflorescence, Takagi (1990) and Kamenetsky & Rabinowitch (2001) claim that garlic types can be classified as one of the following: complete bolting, non-bolting and incomplete bolting. The final variety has several subtypes: inflorescence aborted, topsets and scape remain within the bulb, and topset and scape remain enclosed by a pseudostem. In contrast, the optimal environmental conditions necessary for the complete development of the inflorescence (in hard-neck types) are not the same as those for adequate bulbing; there is marked variability between years and regions for the same cultivar in synchronisation between bulbing and flowering. Furthermore, the flower stalk in hard-neck cultivars acts as a sink, competing with the growth of the bulb and reducing its final size.

For these reasons, garlic should have a specific and detailed phenological scale for its study and the application of crop management practices; the BBCH proposal for onion is not suitable. Another equally important factor that justifies this separation is that the temporal coincidence of several of the main growth phases (i.e. bulbing and flowering) makes garlic more similar to the BBCH phenological scales of other crops, like potatoes, which allow for two separate stages to be defined as occurring at the same point in time. Stages in garlic may or may not be simultaneous.

The present proposal to codify and describe garlic phenology according to the BBCH General Scale stems from the need to standardise developmental stages, in agreement with our field work performed since 1996 with several cultivars under distinct environmental conditions and management practices (Castillo *et al.*, 1996; Cabrera *et al.*, 2002; Lopez-Bellido *et al.*, 2004, 2006). Specifically, we have systematically monitored the phenology of several garlic cultivars in different localities of Andalusia (Southern Spain) and Castile-La Mancha (Central Spain) since 2010; these regions encompass the largest crop surface area of garlic in the European Union.

The main cultivars that have been studied belong to Group I (hard-neck cultivars), Group III (soft-neck cultivars), which are both of Western origin (cultivars Spanish Red and Spanish White, respectively) and Groups I–III (hard-neck cultivars) of Eastern origin (Chinese cultivars: White and Violet), according to the classification of Messiaen *et al.* (1993) (Messiaen *et al.*, 1993; Lallemand *et al.*, 1997; Lopez-Bellido & Lopez-Bellido, 2008); these belong to the botanical groups *sativum* and *pekinense* (subgroup), respectively (Maaß & Klaas, 1995; Etoh & Simon, 2002).

Structure of the scale

In contrast to the majority of BBCH scales for species with distinct phases and secondary stages that are clearly recognizable and distinguishable (Feller *et al.*, 2012), changes in the most important growth habits of garlic are hidden; it is necessary to open/dissect the clove to be used as a propagule for planting or the pseudo-stem (group of sheaths enveloping the leaves that surround the apex and lateral shoot/inflorescence) of the plant during its development due to the fact that distancing is not produced between internodes in the true stem or disc (basal plate). Although this practice is not necessary or habitual for the majority of BBCH scales, it may be compared with scales for plants that require soil removal to detect certain phenological stages, as is the case with potatoes (Meier, 2001) or asparagus (Feller *et al.*, 2012) among others. The proposed dissection methodology to reveal hidden stages is quick, simple and can be performed *in situ* (in the field or in storage area of bulbs for planting). Dissection may be performed with a simple knife, observable at plain sight, although amplification with a small hand lens (10× magnification) is recommended to identify several stages (first secondary stages of the main stages: two formation of side shoots and five inflorescence emergence). Thus, greater precision may be achieved in detecting the morphogenesis of a determined organ and consequential changes in main stage (Schwab *et al.*, 2015).

Based on the distinct phases described in the general extended BBCH scale (Meier 2001), we propose a phenological scale for garlic divided into six main Stages: sprouting (stage 0), leaf development (of main shoot, stage 1), formation of side shoots (stage 2), development of harvestable vegetative plant parts (stage 4), inflorescence emergence (only for complete and incomplete bolting types, stage 5), flowering (only complete bolting types, stage 6) and senescence or beginning of dormancy (stage 9). In contrast to the biological cycle of onion, which is 2 years in duration under normal conditions, all phases of garlic occur in the same year, and several principal phases partially or completely overlap depending on the cultivar type. According to Meier *et al.* (2009) and Feller *et al.* (2012), if two or more main stages occur simultaneously, this may be noted by separating their codes with a forward slash; in the case of garlic, coding for overlapping stages is convenient in order to provide better information for adequate crop development. The classic and ambiguous bulbing phase of garlic has been defined according to the model proposed by Takagi (1990), who objectively separates bulbing in two stages with different environmental requirements: formation of lateral buds in axils of the youngest foliage leaves (BBCH stage 2; first bulbing phase) and differentiation of leaf primordia into storage leaves (BBCH stage 4; second bulbing phase). This first stage coincides with the formation of the inflorescence in cultivar types with emission and complete or incomplete development of a floral stalk (BBCH stage 5); only types with complete development will undergo stage 6 (BBCH). Senescence and death of the plant coincide with maturation of the garlic bulb, and both may be included in stage 9 (BBCH). For the development of the garlic plant, the remaining stages of the general BBCH scale are not applicable or are irrelevant, including the following: stem elongation or rosette growth, shoot development (main shoot) (BBCH stage 3), development of fruit (BBCH stage 7) and ripening or maturity of fruit and seed (BBCH stage 4).

Clearly distinguishable secondary stages are defined within each principal stage as specific time frames linked with short development intervals of the plant. To the greatest extent possible, descriptions follow the same pattern in the general BBCH scale and in the specific scale for onion (Meier, 2001), although this is not always possible due to the morphological and phenological peculiarities of garlic. Similar to onion, in addition to a BBCH scale of two digits, a BBCH scale of three digits is also proposed (final digit indicating a mesostage). This is largely due to the number of leaves emitted in stage 1 (leaf development), normally more than 9, resulting in significant physiological and agronomic implications.

Due to the detail of this proposed scale, in terms of the criteria necessary to define secondary stages and the need to dissect plants to observe hidden stages, an explanatory table that details the necessary requirements for appropriately using our specific phenological scale for garlic was created (Table 2). This is in addition to a descriptive table of the phenological developmental stages, similar to the Extended BBCH Scale (Table 1). In Table 2, a variable stage is also presented, which extends from the budding of the clove/emergence until the complete disappearance (consumed or degraded) of the storage leaf (Shimoya, 1970). This phase is proposed as optional and with alphabetical nomenclature due to its peculiarity and importance; it receives greater influences from agronomic factors and crop management practices than from environmental conditions (see section 'Principal growth stage 1: leaf development').

In order to better understand the normal overlap of the described phenological stages, an outline of the complete cycle of a garlic plant under suitable environmental and culture conditions is presented in Figure 1, considering a total of 11 leaves and a complete bolting variety (the most complex case).

Illustrations of the most important secondary stages are included instead of photographs, as these are more practical for identification purposes. Furthermore, in order to aid interpretation, the whole plant was drawn throughout the developmental stages at an approximate scale, similar to the onion phenology proposed by Rey *et al.* (1974). This representation is for a plant with complete omission of inflorescence (of flowers and bulbils/topset), 12 total leaves and lateral buds (cloves) at the axils of the final two leaves. In addition to the plant illustrations, an equatorial cross-section of the bulb is presented, showing the development of the lateral buds/cloves.

Growth stages of garlic plant

Principal growth stage 0: sprouting

As previously cited, garlic is propagated by cloves, beginning with principal growth stage 0 BBCH (00–09 or 000–009; the three-digit code will be used throughout the text). Although this stage begins the months prior to planting, and secondary stages are only distinguishable if cloves are dissected. After the bulb unit matures and becomes senescent, cloves begin a period of deep dormancy (Mann & Lewis, 1956), and growth (lengthwise) of the shoot and growth of new leaves cease (usually 1 bladeless sprout leaf and $\leq$5 leaf primordia) (Takagi, 1990). The duration of this stage depends primarily on genetic factors, which are frequently used to classify garlic types, as well as storage temperature. Only after this period has fully ended can cloves be planted. Because storage temperature and time of exposure to environmental conditions strongly affect the subsequent development of the plant, storage conditions should be carefully controlled. Prolonged temperatures of 5–10^{o}C (>1month) promote a rapid breaking of dormancy; lower or higher temperatures may postpone this and have distinct posterior effects on leaf morphology and crop physiology (Brewster, 2008). Although, for traditionally cultivated varieties well-adapted to garlic production zones, bulbs for planting are stored at ambient temperature (Brewster & Rabinowitch, 1990), Planting is performed after the cloves have completely broken their stage of dormancy under these conditions; however, this physiological process is not well understood (Volk & Rotindo, 2004). According to Takagi (1990), the dormancy of cloves consists of many of the following stages: true dormancy, post-dormancy and completely disappeared dormancy; this last stage begins with the growth of the sprout and ends in sprout emergence (Volk & Rotindo, 2004). From a phenological perspective, these stages may be associated with the length of the clove sprout; as such, bulbs may be evaluated for planting. However, because the sprout grows at the interior of the storage leaf towards its distal point, a lengthwise dissection of the clove is necessary for observation of this stage or period that is hidden from plain sight. Several authors have used the Visual index of dormancy (VID), which measures the growth of the sprout as a percentage with respect to total clove length; i.e. dividing the length of the shoot by the length of the clove and multiplying by 100 (Burba & Gómez 1997; Volk & Rotindo, 2004).

Cloves from a harvested and mature bulb (coinciding with BBCH stage no. 909; see section 'Principal growth stage 9: senescence, beginning of dormancy') should be in a stage of true dormancy, presenting VID values of 20–30% (Volk & Rotindo, 2004), and the sprout/plant will be found in BBCH stage 000 (Figure 2, no. 000). Approximate values of greater than 30% and up to 70% indicate post-dormancy (BBCH 001). According to Burba & Gómez (1997) and our results, at the moment when VID reaches approximately 70% (BBCH 002), cloves are at a suitable developmental stage for planting (Figure 2, no. 002). A VID of 100% (BBCH 003) indicates sprout elongation as the sprout emerges through the pore of the extreme distal point of the storage leaf (BBCH 007), which is visible by observation and without dissection. Under conditions of sufficient soil moisture, roots emitted from the stem or disc would be clearly visible (BBCH 003–007), although their appearance and length depend on the time of exposure of the clove to elevated levels of relative humidity or free water, as well as temperature, in which development does not necessarily coincide with the length of the sprout (Figure 2, no. 003). If already planted, the sprout grows in the direction of the surface protected by bladeless sprout leaves once it emerges from the clove, usually 1 or 2 (BBCH 008), until reaching the soil surface (BBCH 009, Figure 2, no. 009). Initially, during the final secondary stages of BBCH Stage 0 and the beginning of Stage 1 (Figure 2, no. 009–102), root development is more rapid at the convex clove side of the disc, however this begins to equilibrate afterwards, and the plant acquires the typical appearance of a fascicle root system with little branching out (Figure 3, no 105).

Principal growth stage 1: leaf development (main shoot)

For garlic, principal BBCH growth stage 1 is similar to the corresponding stage for onion (Meier, 2001), with the exception of its overlap with principal growth stage 2 (formation of side shoots). In this second phase, the apical meristem ceases to form new leaves; but the final 3–5 leaves develop in the pseudo-stem and are not visible. Once the bladeless leaf appears at the soil surface, the blade leaves produced by the apical meristem begin to emerge continuously, situated at the centre of the disc or stem. These consist of two parts: the inferior portion of the leaf that forms the sheath and the superior section or the blade with photosynthetic functions and a cross-section that forms a V-shape and unites with the ligule (Mann, 1952; Brewster, 2008). Leaves are both opposite and alternate, forming a group of concentric sheaths on a false stem or pseudo-stem. Continuous emission of leaves without distancing between the nodes eventually discontinues, leading to the formation of lateral buds/shoots (in the axils of the final leaves) and the differentiation of the inflorescence from the apex (only in bolting types). This occurs when the plant has been exposed to low, inducing temperatures over a period of time, including exposure of the propagation clove before and after planting (Takagi, 1990). According to Takagi (1990), this phase also requires a minimum plant size and vegetative period to initiate; other environmental and management factors can postpone or hasten this process. Under normal crop conditions, the final number of leaves varies from 10 to 12 (Brewster, 2008; Shalom *et al.*, 2015); however, we have observed that this number can increase or decrease in cultivars unsuited to environmental conditions or due to inadequate culture practices, including date of planting. For these reasons and similar to onion, mesostages have been introduced (three digits) in order to measure and account for the final number of leaves.

Although, the BBCH scale only allows for the total number of visible leaves to be counted, for in-field studies, plants may be grouped according to their development in order to generate more information on the phenological development of garlic. From lesser to more developed, the following stages may be identified: senescent or dry, expanded and unfolded adult leaves (ligule visible), visible young leaves (ligule still hidden in the pseudo-stem and folded), and leaves/leaf primordia hidden in the pseudo-stem (requiring a transversal/lengthwise cut of the false stem to be counted). Differentiation between distinct leaf types in our field work has been of great utility, although the seventh or eighth leaves must be marked early on into order to carry out a precise final count due to the difficulty of counting dry leaves in advanced phenological stages.

Similar to the BBCH scale for onion, a leaf must have a minimum length of 3 cm or more to be counted. In Figure 2, no. 102 represents the emergence of the first two blade leaves from the sprouting bladeless leaf (and a third with length of <3 cm) with an intact storage leaf. Other leaves appear in succession, and as the oldest/outer leaves begin to develop, the storage leaf is consumed until it completely disappears (Figure 3; no. 103–105). According to Shimoya (1970) and Ledesma *et al.* (1997), from the moment the cloves begin to sprout until their complete assimilation or disappearance (depleted, consumed or missing) the storage leaf should be considered in a stage of growth prior to principal growth stage 1 (leaf development), as the garlic plant largely depends on these reserve nutrients until their complete consumption. Although their disappearance is dependent on several factors, such as clove size, functionality during consumption (or the extent of pathogen attacks and pests in soil) and capacity to produce greater vigour in plant growth subsequent to bulb yield; this characteristic is unable to be adapted to the BBCH scale. In Table 2, a sub-stage parallel to growth of leaves is proposed due to the implications of the storage leaf and the time it remains active during the first secondary stages of the principal growth stage 1; its functionality (s) or degradation/disappearance (x) is indicated, along with the number of visible leaves, according to the three-digit

BBCH code. The final stage may be observed in Figure 4, no. 107, in which a plant without the presence of a storage leaf at its base is observed, with a formed pseudo-stem and a total of seven visible leaves in distinct stages of development (first senescent leaf, two expanded and four young leaves without visible ligules).

Principal growth stage 2: formation of side shoots

In contrast to onion, bulbing in garlic is produced in two well-differentiated phases (Takagi, 1990; Shalom *et al.*, 2015), that is formation of side buds/shoots (and flower stalk in bolting types) and subsequent storage-leaf differentiation and development, which form the cloves. After a determined number of hours of inducing temperatures are accumulated, which varies depending on cultivar type and is influenced by other environmental and culture factors, the vegetative bud or apex is differentiated, halting the generation of new leaves. This bud may give rise to the scape/inflorescence (in complete and incomplete bolting types) or form a terminal bud/clove (non-bolting types), causing the appearance of lateral buds in the axils of the final leaves (ontogenesis of the bulb). The number of buds formed per leaf and the number of leaves with buds will provide the final structure of the bulb. This largely depends on cultivar type, although environmental factors can also notably alter this characteristic. Lateral buds form in a centripetal sequence (Mann, 1952; Rahim & Fordham, 1988; Núñez *et al.*, 1997), appearing at the axils of the final 2–3 leaves (fertile leaves) in bolting cultivars. For non-bolting types, lateral buds appear in the final 5–6 leaves, growing in number to half of leaves and continuing to decrease towards the central clove. Due to a variable number of leaves (between 4–6 leaves and leaf primordia) present at the interior of the pseudo-stem in this first bulbing phase (principal growth stage 2: formation of side shoots), this process may be considered to overlap with stage 1 (leaf development; main shoot), and a forward slash is used to indicate their simultaneous occurrence.

Although, as previously indicated, this principal phase is hidden and cannot be detected externally, and the transversal dissection of the basal portion of the pseudo-stem to slightly above the disc or basal plate is necessary (∼1–3 mm). Although several authors have also studied the morphogenesis (ontogenesis) of the bulb by both light (Mann, 1952; Núñez *et al.*, 1997) and scanning electron microscopy (Rahim & Fordham, 1988, 1990), our studies indicate that the initial stages with the first lateral buds can be perfectly differentiated with a binocular microscope. Afterwards, each lateral bud will emit several bladeless leaf primordia that grow by encasing the superior portion and enclosing younger leaves. From this moment, they can be detectable (≥1mm) with a hand-held magnifier or at plain sight by examining the superior portion of the disc once the sheaths have been eliminated or by means of a transversal cross-section of the bulb above the disc. The thickness of leaves throughout this stage would be similar and in accordance with their positioning with respect to the axillary bud; principal growth would be mainly in length, without significant leaf thickening of the shoot by swelling in comparison to other leaves (differentiation of the storage leaf; second bulbing phase). In the final secondary stages, each axillary bud generally reaches an approximate length of 20mm, which varies by cultivar and the position of the bud among the axils of fertile leaves; these develop sooner in the external leaves. From an equatorial cross-section of the bulb, the radius of the crowns of the buds would be nearly half of the external radius.

The secondary stages proposed as the first phase of garlic bulbing are shown in Tables 1 and 2. The 200 BBCH stage would coincide with the beginning of bulb morphogenesis, giving rise to the appearance of the first lateral buds in the fertile leaves; in the case of bolting types, the differentiation and elongation of the stem or flower stalk would arise from the vegetative apical meristem (see section 'Principal growth stage 5: inflorescence emergence'). This secondary stage is difficult to detect at plain sight, although it is clearly differentiated with a binocular microscope. The 201 BBCH stage may be observed after a transversal cross-section, in plain sight or with a hand-held magnifier (Figure 4; no. 110/201; transversal cross-section). Subsequently, for the secondary stages no. 202, 203 and 204, each lateral bud develops several leaves without blades at the interior of the first, enveloping one over another. According to this type of cultivar and when environmental and management conditions are suitable, a total of two or three of these leaves may develop. The most external bladeless leaves will differentiate into dry protective skins, and the most internal one will form the swollen, storage leaf of BBCH stages 4 and 9.

Nevertheless, if environmental conditions are unsuitable for a prolonged period of time (short photoperiods and low temperatures) after differentiation of lateral buds, as many as 2–3 leaves will sprout as blades and appear at the axils of tertiary buds, giving rise to lateral sprouting (secondary growth or branching). Narrow blades overlay the axils of the normal leaves, known as stiff-neck, brooming or branching. The resulting bulbs will have an irregular form (exhibit roughness or be rough bulbs), which represents one of the main quality defects in garlic that farmers seek to avoid (Mann & Minges, 1958; Brewster & Rabinowitch, 1990; Messiaen *et al.*, 1993; Portela, 2001; Cabrera *et al.*, 2002; Lopez-Bellido *et al.*, 2006). In the following secondary stages, that is no. 205 and 206, leaves of each lateral bud, formed and closed at their superior portion, grow mainly in length without evidence of internal bladeless leaf thickening. Although thickening of the basal portion of the pseudo-stem (bulb) may be observed from the exterior, this is not sufficient to objectively evaluate the stage of growth of the garlic plant. In

Principal growth stage 4: development of harvestable vegetative plant parts

According to Takagi (1990), this principal stage corresponds with the second phase of garlic bulbing: differentiation and thickening of the storage leaf of each lateral bud, resulting in the formation of cloves. The determining environmental factor of this phase is the existence of long days (photoperiods); however, this is variable depending on the cultivar and is influenced by other factors that postpone or hasten, although do not inhibit, this process. The most evident external characteristic of this stage is the rapid growth in the equatorial diameter of the bulb, until it reaches its final size. In order to define the secondary stages of this principal stage, the BBCH scale for onion was followed, as it is similar. The stages were divided according to the percentage of volume (measured as the equatorial diameter) with respect to the final size of the bulb.

Since Mann (1952) proposed the Bulbing Ratio (Bulbing Index – BI) as a simple method to determine when bulbing begins, numerous authors have used this method due to the importance of this phase in the growth of garlic (Rahim & Fordham, 1988; Brewster & Rabinowitch, 1990; Argüello *et al.*, 1997; Ledesma *et al.*, 1997; Núñez *et al.*, 1997). This index results from the ratio of the diameter of the neck (pseudo-stem) to the equatorial diameter of the bulb in any given moment; values are never greater than 1 and decrease to the extent that the bulb develops. Normally, the bulbing phase is assumed to begin when values near 0.50 (Argüello *et al.*, 1997), and values decrease to 0.25–0.20 during harvest (Brewster & Rabinowitch, 1990). Ledesma *et al.* (1997) differentiated BI values to an even greater extent and outlined two distinct bulbing phases for soft-neck cultivars. A value of 0.60 indicates the beginning of the morphogenic phase, 0.40 the growth of the bulb and 0.22 its maturation.

Nevertheless, Mann (1952) specifies that in soft-neck cultivars, the BI value indicates the beginning of clove formation (thickening of the storage leaf) in a centripetal form. The relationship of this stage to the appearance of lateral buds is not referenced, although this represents the true beginning of the garlic bulbing phase, as revealed by our field work. Thus, we argue that this index is not a good indicator of bulbing, and we instead propose the more precise observation of the beginning of this phase by means of directly observing lateral buds (see section 'Principal growth stage 2: formation of side shoots'). In particular, we have observed that BI values of 0.5–0.4 coincide with the beginning of differentiation of the storage leaf in lateral buds for several cultivars during different years or environmental conditions (when the 2nd–3rd bladeless leaf that forms each lateral bud begins to thicken); this could be an external morphological index suitable for determining the beginning of this BBCH stage (principal growth stage 4: development of harvestable vegetative plant parts).

Consequently, the exact determination of the first secondary stage of principal growth stage 4 BBCH (development of harvestable vegetative plant parts), as proposed, would imply the need to perform a transversal cross-section of the bulb; the differential thickening of the most internal bladeless leaf of each bud (under normal conditions, the 2nd or 3rd leaf) would be evident. In Figure 5 the secondary stage BBCH no. 400 is illustrated by a plant with all visible leaves and a considerable number of dry leaves; the present stage does not tend to overlap with principal growth stage 1 (leaf development; main shoot). In the transversal cross-section of the bulb next to the illustrated plant, the large surface area of the second leaf in relationship to the first leaf of each lateral bud (clove) may be observed; cloves located at the axil of the most external leaf are more evident. As previously cited, our field work has revealed that BI values close to 0.50–0.45 are reached in this secondary stage, and the external indicator method should be used to determine the start of this phase. To determine the remaining secondary stages, the percentage of the diameter reached in this moment with respect to the final expected diameter of the bulb may be proposed as a principal criterion (Tables 1 and 2); the BI can be used as an alternative measurement to identify this principal stage, progressively lowering throughout from values of 0.5 to 0.2.

During this phase, young visible leaves expand and begin to dry, beginning progressively with the oldest and most external. The highest leaf area index (LAI) values are achieved at the start of this phase, and the process of translocation begins, involving the transport of nutrients synthesised by leaves to the bulb (Ledesma *et al.*, 1997; Lopez-Bellido *et al.*, 2004). For bolting cultivars, this occurs equally at the beginning of this principal stage, when the scape tends to emerge between the final leaf (visible spathe); however, this phase (principal growth stage 5: inflorescence emergence) does not occur completely simultaneously with bulbing (principal growth stages 2 and 4) because environmental conditions necessary for the first phase do not coincide with those required for adequate development of the inflorescence (see section 'Principal growth stage 5: inflorescence emergence').

In Figure 6, a garlic plant (bolting variety) is presented in addition to the equatorial cross-section of a bulb in stages 407 and 409, according to the proposed BBCH scale. In the first stage, the bulb is found at 70% of its final diameter, equivalent to an approximate BI value of 0.35. A large portion of its volume is occupied by the storage leaf of the cloves (transversal cross-section of the bulb). As a cultivation technique, irrigation may be ceased after the initiation of this secondary stage as a means of accelerating the maturation process of the bulb before harvest. In BBCH stage 409, the bulb will have reached its final size with an approximate BI value of 0.25, although the sheaths of the youngest leaves and the protective skins will have a high water content (thickness of sheaths/protective skin <2 mm). At approximately this moment, the loose and lift technique is recommended (for harvest), especially if the bulbs are destined for the fresh market. Because sheaths are still flexible at this point, their breakage must be prevented upon harvesting in order to guarantee the integrity and quality of the bulb. Normally, the plant has 3–5 leaves that are still green in this secondary stage, and it is still erect (before the collapse of the neck/plant fall-down), which allows for an easy harvest, especially for soft-neck cultivars.

Although the plant remains active even after harvest as the bulb has not completely arrived at maturity, the cloves have not yet entered into true dormancy. Therefore, the following principal stage (stage 9: senescence, beginning of dormancy) would develop over the course of the curing phase, above the ground surface and/or in specific dryers for this purpose (see section 'Principal growth stage 9: senescence, beginning of dormancy').

Principal growth stage 5: inflorescence emergence

In cultivars with a floral/inflorescence stalk or scape in complete or incomplete form (hard-neck types), development of the inflorescence stage is expected to be synchronous with BBCH stage 2 (first bulbing phase) and BBCH stage 4 (second bulbing phase), and its presence and growth may offer additional criteria for the identification of secondary stages. Nevertheless, the necessary environmental requirements for the complete development of the floral scape and inflorescence are not similar to those required for adequate bulbing, which has been demonstrated by several authors (Takagi, 1990; Messiaen *et al.*, 1993; Kamenetsky *et al.*, 2004; Brewster, 2008; Shalom *et al.*, 2015). Differences in the development of the floral scape exist within the same cultivar, given different localities/years; an extreme case is represented by hard-neck types that may not develop a floral scape under certain environmental conditions. Therefore, the start of this BBCH stage in garlic enables the evaluation of the response and adaptability of cultivars outside their normal crop conditions as well as of potential variations due to environmental or culture factors in areas of traditional cultivation, which represents a useful tool for agricultural programmes.

In hard-neck cultivars, the development of the floral scape and flowering compete with the growth of the bulb due to the nutrients required by the canopy, reducing the yield of the final harvest. In addition to possible clonal selection within each cultivar from plants with lesser scape development, the suitable moment for manual or mechanical elimination is determined by the stage of growth. This technique is common in certain cultivars and areas (Volk & Rotindo, 2004); if harvested at the right moment, scapes are a valued ingredient in several gastronomic traditions. If scapes are mechanically cut, this is performed while the scape is still erect and just before harvest with a cutting bar (BBCH stage 409). Even if the scape does not receive an additional use after mechanical harvest, this technique enables harvest by machinery.

Development of the inflorescence coincides with the differentiation of lateral buds, as previously detailed (stages 200/500; Figure 1); until the spathe enclosed by the final leaf emerges, these are considered to be hidden secondary stages. The pseudo-stem must be cut to determine its developmental stage. The initial stages may be identified by calculating the percentage of elongation of the scape (stem plus spathe) with respect to the total length of the pseudo-stem (Tables 1 and 2). The apical bud progressively differentiates to the inflorescence as the stem with a single internode grows, which is protected by a bract or spathe, or in the case of incomplete bolting types to the topset bulbils directly (Takagi, 1990; Kamenetsky & Rabinowitch, 2001). This process of floral initiation and differentiation has been addressed in-depth in several studies, including those of Kamenetsky & Rabinowitch (2001, 2002), Kamenetsky *et al.* (2004) and Shemesh *et al.* (2008). Initially, the spathe that wraps the floral primordia has a greater length than the stem, and this relationship reverses as the scape develops. In Figures 4 and 5, the two secondary hidden stages of BBCH stage 5 that coincide (inflorescence emergence) with principal stages 1 and 2 are shown, as previously described: 110/201/500 and 112/206/503.

Although this phase does not precisely coincide with the start of the second bulbing phase (principal growth stage 4: development of harvestable vegetative plant parts), the emergence of the floral scape from above the pseudo-stem may indicate differential thickening of the storage leaf (clove), with a BI value near 0.5. In our work with complete bolting type cultivars and under normal cultivation conditions, we found both of these processes to occur more or less simultaneously (Figure 5; BBCH no. 400/504). After the emergence of the spathe, the development pattern proposed by Messiaen *et al.* (1993) was followed, considering the evolution of its form rather than length, which may be highly variable within the same cultivar (Tables 1 and 2). The development pattern is as follows: appearance of spathe or bract (Figure 5; BBCH no.504); appearance of stalk node and spathe completely visible (BBCH no. 505), spiral or 'pigtail' stage (Figure 6; BBCH no. 507), crooked stem or 'bishop's crook' stage (Figure 6; BBCH no. 507) and erect stage with spathe still closed, with the scape reaching its maximum height (BBCH no. 508). If scape is to be used for culinary purposes, harvest is recommended with a simple pull during its 'pigtail' stage (BBCH no. 506). For mechanical elimination, this may be performed several days before garlic harvest, when scapes are completely erect and above canopy (no. 508 BBCH).

Principal growth stage 6: flowering

This principal stage is exclusive to complete bolting types, and flowers formed during the growth of the scape that are covered by the spathe (principal growth stage 5: inflorescence emergence) have the distinction of being sterile in the majority of cultivars under normal crop conditions; these flowers do not form fruits or seeds (Kamenetsky & Rabinowitch, 2001). During maturation, flowers are substituted by leaf-like bracts and/or topset bulbils (Shemesh *et al.*, 2008); the latter may be used as vegetative propagules, although this practice is not very effective. To adequately describe garlic plant phenology independent of an interest in flowering, this phase has gained importance in recent years due to the harvesting of viable seeds in some cultivars under specific environmental conditions (Shemesh *et al.*, 2008).

Similar to the previous principal stage, flowering begins and approximately coincides with the first secondary stages of principal growth stage 9 (senescence, beginning of dormancy) under normal cultivar conditions; these phases frequently occur in parallel. In garlic, according to the proposed BBCH scale (Table 1 and 2), this begins with the burst of the bract/spathe that covers the umbel inflorescence (Kamenetsky & Rabinowitch, 2001), which is visible, although individual florets are closed (Figure 6; BBCH no. 600). Afterwards, florets open and show their typical structure (Messiaen *et al.*, 1993) during secondary stage no. 601. Once non-fertile flowers have dried, their whorls fall to the ground, and only penduncles attached at the base of the umbel remain between the developed bulbils and then reach their final size (BBCH no. 602). Finally, the skins that cover each bulbil begin to dry, resulting in their characteristic colour (BBCH no. 603). The size of the umbel and the number, shape, colour and dimensions of bulbils are largely dependent on genotype (Messiaen *et al.*, 1993; Kamenetsky *et al.*, 2004).

Principal growth stage 9: senescence, beginning of dormancy

After the garlic bulb has reached its final size, the plant begins to dry until it dies. The bulb matures, and the cloves forming the bulb enter a deep stage of dormancy (Takagi, 1990). This process of senescence can occur even while the crop is still planted in the soil; although, in order to achieve greater quality during production and avoid potential attack of the bulb by pests and diseases, maturation is generally achieved after plants have been harvested from the soil during open-air conditions or in dryers for curing, designed *ex profeso* (Ávila, 1998). During this phase, a retranslocation of nutrients occurs from the portions of the remaining green canopy towards the bulb, except at the storage leaf of each clove (Brewster, 2008). Scientific studies have examined the most appropriate techniques, harvesting dates and optimal conditions for drying in order to achieve the best final commercial production; these techniques are generally carried out by farmers themselves (Ávila, 1998). Due to the particularity of this stage in comparison to the BBCH scale for onion (Meier, 2001), where this phase is included as part of principal growth stage 4 (development of harvestable vegetative plant parts), the inclusion of this stage in garlic is proposed for BBCH stage 9 (senescence, beginning of dormancy), according to the general scale. At the end of this principal stage, the manual cutting of the roots and remaining aerial portion (~1–2 cm above the bulb) is performed, and the final gross crop yield is obtained; after this final weight is constantly maintained over a period of several months.

The principal growth stage begins when 3–5 of the lastly emerging green leaves have begun their senescence and lose their erect stature. For complete bolting-type cultivars and under normal crop conditions, this phase may coincide with the beginning and subsequent development of principal growth stage 6 (flowering), as described in the previous section (Figure 1). In Tables 1 and 2, the BBCH secondary stages proposed for garlic are shown. Stage 900 is the first that coincides with principal stage 6 (Figure 6; BBCH no. 600/900). Afterwards, all the leaves will dry, and the neck or pseudo-stem will collapse, falling over in soft-neck types and remaining erect due to the floral stalk or scape in hard-neck types (BBCH no. 901). At this moment, the different tissues that compose the bulb begin to dry successively, except for the storage leaves of each clove (BBCH no. 903–908). The duration of these secondary stages will fundamentally depend on temperature and bulb aeration. The only objective means of determining the secondary stages is by calculating the percentage weight loss of the bulb from BBCH no. 902 until the complete maturity and drying of the bulb (BBCH no. 909). This usually involves a 10%–30% loss of the initial weight of the bulb, according to the variety and harvesting date. Although this process could be evaluated by addressing the sequential drying of the tissues that compose the bulb; this sequence begins with the gradual drying of the sheaths, which contain water, beginning with the more external ones and moving towards the more interior ones until the consistency and thickness change from an elastic to leathery and brittle texture. This is followed by the drying of the protective skins or protective sheaths of the storage leaf of each clove, which then acquires its final thickness and colour. Finally, the complete disc or stem dries; in the case of hard-neck types, the scape also acquires a brittle consistency. In complete bolting types, this final stage coincides with BBCH secondary stage no. 603 (Tables 1 and 2). The crop technique of manually cutting the roots and canopy remains may be performed during any of the secondary stages, resulting in a quicker drying process. When all tissues cited have acquired a leathery and brittle texture, the final characteristic colour of the sheaths and protective skins of the cloves according to cultivar type is obtained, and a stable and final weight is achieved, the bulb is considered to have arrived at maturity and is in a stage of deep dormancy (BBCH no. 909).

Conclusions

The extended BBCH scale of two and three digits proposed for garlic in the present study aims to fill gaps in the knowledge of this important crop. In previous scientific literature, the ambiguity and lack of consensus over the start of determined stages, such as bulbing, may be resolved if the criteria described in this article are taken into consideration, which may also serve as a referential framework for future studies. The incorporation of garlic phenology within the extended BBCH scale for onion is not effective due to large differences between both species, even though they belong to the same genus. The means of propagation of garlic is vegetative from the cloves of previous cycles, and the bulbing stage coincides with flowering (depending on bolting type). As a result, garlic is perpetually found in a 'second year stage' of its biological cycle in comparison to the typical biannual development of other cultivated Liliaceae bulbs. The apparent complexity of the scale proposed herein addresses the development of complete bolting-type cultivars and the strong influence of environmental factors, mainly temperature and photoperiod, on changes in the growth habits or phenological phases of garlic; similar conditions are not always required for overlapping or simultaneously occurring phases, as phase differences may exist depending on crop conditions. The identification of the phenological stage of garlic, taking into consideration the simultaneity of stages, may be of great utility in evaluating the capacity of a certain cultivar to adapt to distinct local environmental or yearly conditions, as well as in determining ideal crop management practices in terms of optimal dates and times for planting, fertilising, ceasing irrigation and harvesting. Another complexity surrounding the proposed BBCH scale for garlic is the existence of hidden stages and their identification in order to determine certain stages, although these stages may be easily and quickly determined in the field for a considerable number of plants. Furthermore, such determination may be unnecessary given the objective of the evaluation or depending on the cultivar type.

Therefore, the present BBCH scale for garlic and its codification has identified potential variations in the development of the plant given existing cultivar types, from non-bolting (soft-neck cultivars) to complete bolting (hard-neck cultivars), and is intended to be useful for researchers, technicians and farmers that aim to objectively plan or evaluate this crop. Such a scale enables comparison among studies and the valuation of distinct cultivars under specific environmental conditions. It additionally enables the adaptation of new cultivars, optimisation of different crop techniques, study of pests and diseases and application of phytosanitary measures, in addition to wider aspects concerning crop management over the course of the agricultural cycle; that is beginning with the deep dormancy of the bulb until complete maturity and commercialisation.

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TABLES

Table 1: Description of the phenological growth stages of garlic (Allium sativum L.) according to the extended BBCH scale.

BBCH code		
2-digit	***3-digit***	***description***
Principal growth stage 0: sprouting.		
00	000	completely ripening bulbs and cloves after harvest (deeply dormant): VID ≤ 20-30%.
01	001	dormancy diminishment: VID between 20/30-70%.
02	002	breaking of dormancy: VID ≥ 70% (optimum conditions for planting).
03	003	sprout leaf reached the clove tip: VID = 100 %.
07	007	protrude the sprout leaf (bladeless), emergence from clove tip.
08	008	sprout leaf/leaves (1 or 2 usually) growing towards soil surface.
09	009	sprout leaf/leaves breaks through soil surface.
Principal growth stage 1: leaf development (main shoot).		
11	101	1st leaf (blade) folded emerged from sprout leaf/leaves and is clearly visible (> 3 cm).
12	102	2nd leaf (blade) folded clearly visible (> 3 cm).
13	103	3rd leaf (blade) folded clearly visible (> 3 cm).
14	104	4th leaf (blade) folded clearly visible (> 3 cm).
15	105	5th leaf (blade) folded clearly visible (> 3 cm); 1st leaf unfolded.
16	106	6th leaf (blade) folded clearly visible (> 3 cm); old leaves unfolded.

1.	10.	stages continuous till…
	112	or more leaves (blade) clearly visible (folded/unfolded/bent/dry-dead).
Principal growth stage 2: formation of side shoots.		
20	200	start to differentiate laterals shoot in axils of innermost leaves (centripetal sequence).
21	201	1st bladeless leaf of each bud star to close.
22	202	2nd bladeless leaf star to close.
23	203	3rd bladeless leaf star to close.
24	204	lateral buds (2-3 bladeless leaves and shoot inside) star to enlarge.
25	205	length of outer bladeless leaf reach 10 mm.
26	206	length of outer bladeless leaf reach 20 mm.
Principal growth stage 4: development of harvestable vegetative plant parts.		
40	400	the innermost leaf (without blade) of each bud-clove start to swell.
45	405	50 % of expected bulbs diameter reached.
46	406	60% of expected bulbs diameter reached.
48	408	80% of expected bulbs diameter reached.
49	409	100% of expected bulbs diameter reached. Plant still erects and several leaves (3-5) green.
Principal growth stage 5 (only complete and incomplete bolting types): inflorescence emergence.		
50	500	stalk (scape) ≤ 5 mm length from stem basal disc.
51	501	stalk has reached 25% of total length of pseudo-stem.
52	502	stalk has reached 50% of total length of pseudo-stem.
53	503	stalk has reached 75% of total length of pseudo-stem.
54	504	stalk tip clearly visible (> 3 cm).
55	505	stalk node (union point clearly visible > 3 cm).
56	506	stalk shape like a “pigtail”.
57	507	stalk shape like a “bishop’s crook”.
58	508	stalk starts to become erect; 100% of the expected length of flower stalk reached.
Principal growth stage 6 (only complete bolting types): flowering.		
60	600	spathe burst; inflorescence visible.
61	601	florets open.
62	602	petals dry or fallen and bulbils reach final size.
63	603	all florets fall and bulbils show dry protective skin.
Principal growth stage 9: senescence, beginning of dormancy.		
90	900	last 5-3 leaves start bent over.
91	901	leaves dry and dead; psedo-stem collapse and plant fall (only soft-neck types).
92	902	neck, last sheaths surrounding the cloves, clove skin, disk and scape star to dry.
94	904	bulb loss 40 % of final weight losses until maturity.
97	907	bulb loss 70 % of final weight losses until maturity.
99	909	bulb reach final weight (ripening) and cloves in dormant.

Table 2: Explanatory description of the phenological growth stages of garlic (Allium sativum L.) according to the extended BBCH scale.

BBCH code			
2-digit	***3-digit***		***description***
Principal growth stage 0: sprouting. Longitudinal cut of clove is required until 03/003 secondary stage.			
00	000		completely ripening bulbs and cloves after harvest (deeply dormant): VID* ≤ 20-30%.
01	001		dormancy diminishment: VID between 20/30-70%.
02	002		breaking of dormancy: VID ≥ 70% (optimum conditions for planting).
03	003		sprout leaf reached the clove tip: VID = 100 %.
07	007		protrude the sprout leaf (bladeless), emergence from clove tip.
08	008		sprout leaf/leaves (1 or 2 usually) growing towards soil surface.
09	009		sprout leaf/leaves breaks through soil surface.
**Visual Index of Dormancy (VID): percentage of shoot elongation and is calculated by dividing the length of the shoot by length of the clove and multiplying by 100.*			
Principal growth stage 1: leaf development (main shoot).			
11	101	(s*)	1st leaf (blade) folded emerged from sprout leaf/leaves and is clearly visible (> 3 cm).
12	102	(s)	2nd leaf (blade) folded clearly visible (> 3 cm).
13	103	(s)	3rd leaf (blade) folded clearly visible (> 3 cm).
14	104	(s)	4th leaf (blade) folded clearly visible (> 3 cm).
15	105	(s/x)	5th leaf (blade) folded clearly visible (> 3 cm); 1st leaf unfolded**.
16	106	(s/x)	6th leaf (blade) folded clearly visible (> 3 cm); old leaves unfolded.
1.	10.	(s/x)	stages continuous till…
	112	(x)	or more leaves (blade) clearly visible (folded/unfolded/bent/dry-dead).
* (s) functional storage leaf at different degrees of deplete; and (x) consumed or missing storage leaf. ** a leaf is unfolded when its ligule is visible.			
Principal growth stage 2: formation of side shoots (development of lateral buds-cloves; 1st bulbing phase). Cut of plant 1-3 mm above basal stem disc (cross section) is required. Overlap with stages 1 and 5.			
20	200		start to differentiate laterals shoot in axils of innermost leaves (centripetal sequence)*; each bud 0.5 mm diameter (hidden stage).
21	201		all lateral shoots differentiate in axils of innermost leaves; 1st bladeless leaf of each bud star to close (hidden stage).
22	202		2nd bladeless leaf star to close (hidden stage).
23	203		3rd bladeless leaf star to close (hidden stage).
24	204		lateral buds (2-3 bladeless leaves and shoot inside) star to enlarge; the wideness of outer bladeless leaf is thicker than inner ones (hidden stage).
25	205		length of outer bladeless leaf reach 10 mm; no thickness difference between leaves of same bud) (hide stage).
26	206		length of outer bladeless leaf reach 20 mm; no thickness difference between leaves of same bud) (hide stage).
* with hidden stage, cross section cut of plant is necessary. 200 secondary stage detectable by binocular microscope; and for 201, 202 and 203 stages observation through hand magnifier is advisable.			
Principal growth stage 4: development of harvestable vegetative plant parts (storage-leaf differentiation from lateral bubs and development of cloves and bulb; 2nd bulbing phase). Cut of forming bulb (cross section of equatorial bulb diameter) is advisable. Overlap with stage 5.			
40	400		the innermost leaf (without blade) of each bud-clove start to swell (hidden stage)*; the innermost bladeless leaf start to be thicker (hidden stage). Bulbing Index (BI)** reach values around 0.50-0.45 (visible stage). All leaves visible; maximum LAI.
45	405		50 % of expected bulbs diameter reached. progressive drying of leaves; BI decrease.
46	406		60% of expected bulbs diameter reached.

48	408	80% of expected bulbs diameter reached. Cease the irrigation.
49	409	100% of expected bulbs diameter reached. Plant still erects and several leaves (3-5) green; optimal harvest time (1-2 mm thick sheaths).
* with hidden stage, cross section cut of bulb (equatorial) is necessary. ** bulbing index (BI): ratio between bulb neck diameter and bulb diameter at the middle of the bulb.		
Principal growth stage 5 (only complete and incomplete bolting types): inflorescence emergence (development flower stalk from shoot apex; only bolting types). Cut of pseudo-stem (longitudinal section) is required until inflorescence protecting bract (spathe) is visible between the last youngest leaves. Overlap with stages 1, 2 and 4.		
50	500	stalk (scape)* ≤ 5 mm length from stem basal disc (hidden stage**).
51	501	stalk has reached 25% of total length of pseudo-stem (hidden stage).
52	502	stalk has reached 50% of total length of pseudo-stem (hidden stage).
53	503	stalk has reached 75% of total length of pseudo-stem (hidden stage).
54	504	stalk tip clearly visible (> 3 cm).
55	505	stalk node (union point clearly visible > 3 cm).
56	506	stalk shape like a “pigtail”.
57	507	stalk shape like a “bishop’s crook”.
58	508	stalk starts to become erect; 100% of the expected length of flower stalk reached (spathe closed).
* stalk (scape) length include stem and inflorescence bract (spathe). ** with hidden stage longitudinal cut of pseudo-stem is necessary.		
Principal growth stage 6 (only complete bolting types): flowering (from spathe burst to top set bulbils be mature). Overlap with stage 9.		
60	600	spathe burst; inflorescence visible.
61	601	florets open.
62	602	petals dry or fallen and bulbils reach final size.
63	603	all florets fall and bulbils show dry protective skin.
Principal growth stage 9: senescence, beginning of dormancy (all leaves dead and bulb dry). Overlap with stage 6.		
90	900	last 5-3 leaves start bent over.
91	901	leaves dry and dead; psedo-stem collapse and plant fall under its own weight (only soft-neck types).
92	902	neck, last sheaths surrounding the cloves, clove skin, disk and scape star to dry.
94	904	bulb loss 40 % of final weight losses until maturity*.
97	907	bulb loss 70 % of final weight losses until maturity; all sheaths and skins dry.
99	909	bulb reach final weight (ripening) and cloves in dormant; all bulb tissues dry less storage leaf of each clove. Sheaths and skins acquire the final color.
* the bulb, to reach of ripening and the cloves fall on deeply dormant, need to loss between 20-30 % of weight from harvest.		

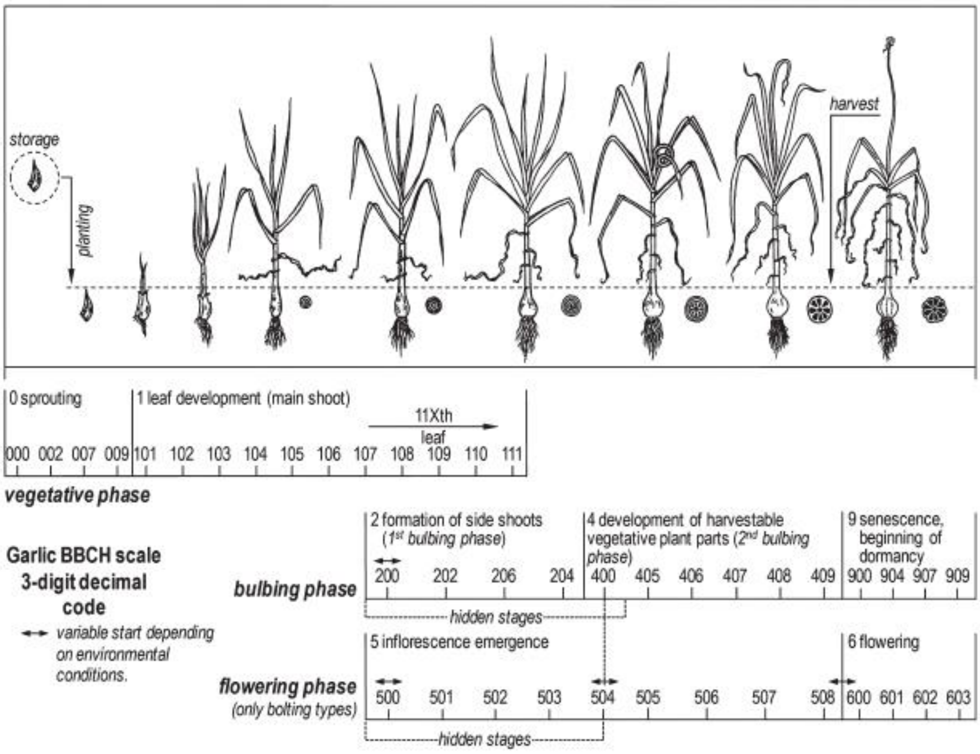

Figure 1 Schematic diagram of garlic (complete bolting or hard neck type) growth and development according to extended BBCH scale (three-digit code) with overlap of principal growth stages.

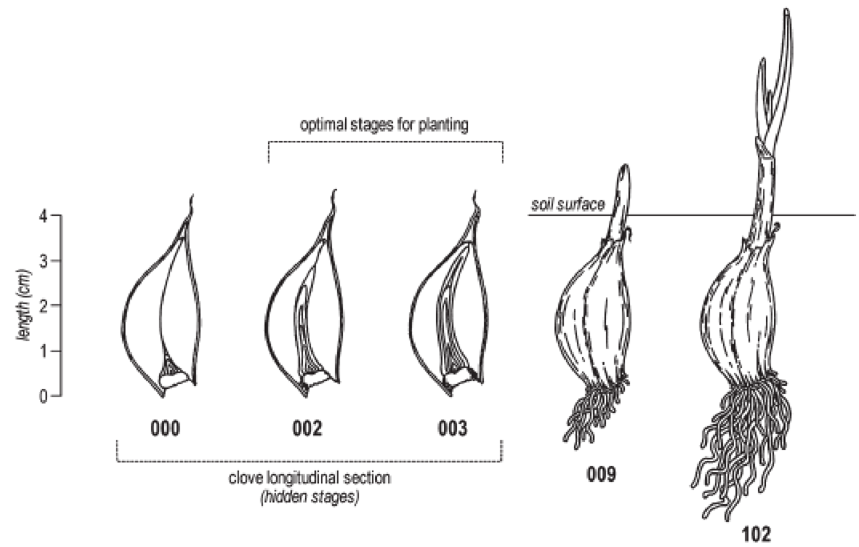

Figure 2 Principal growth stages 0 and 1: completely ripening bulbs and cloves after harvest (deeply dormant) VID ≤20%–30% (000); breaking of dormancy VID ≥70% (optimum conditions for planting) (002); sprout leaf reached the clove tip VID = 100%. (003); sprout leaf breaks through soil surface (009); and second leaf (blade) folded clearly visible (>3 cm) (102).

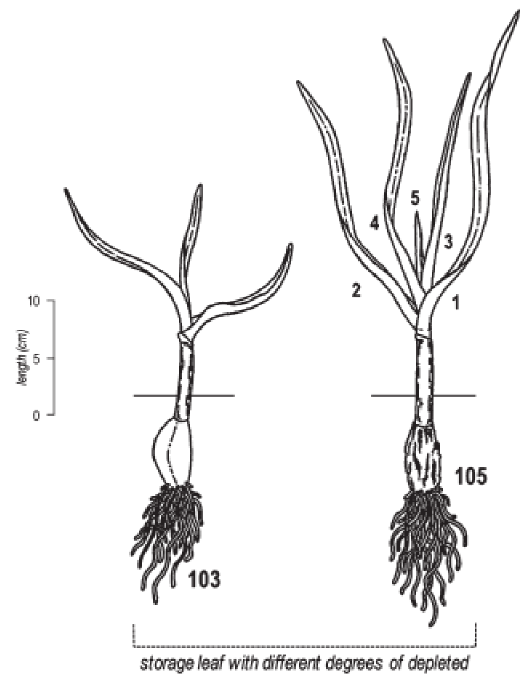

Figure 3 Principal growth stage 1: third leaf (blade) folded clearly visible (103); and fifth leaf folded clearly visible and first leaf unfolded (105) with functional storage leaf yet.

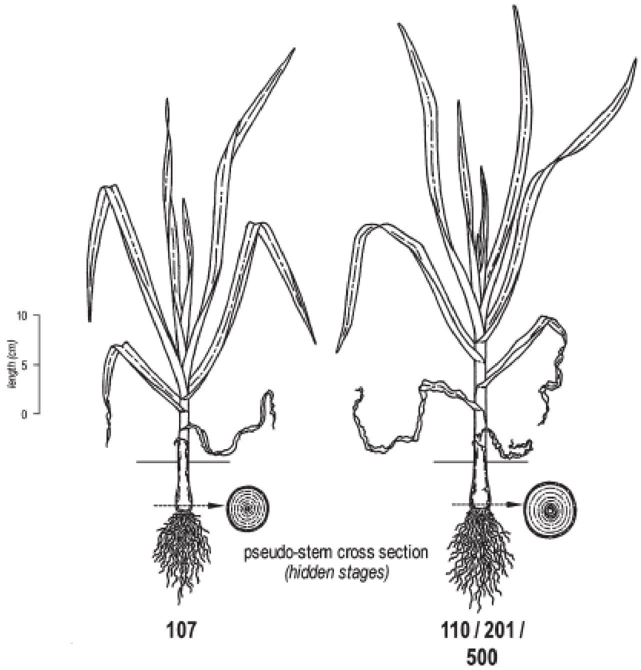

Figure 4 Principal growth stages 1, 2 and 5 (overlaps): seventh leaf (blade) folded clearly visible, old leaves unfolded and storage leaf consumed (107); and 10th leaf folded clearly visible, first bladeless leaf of each lateral bud starts to close and stalk (scape) ≤5 mm length from stem basal disc (110/201/500, respectively; overlapped stages).

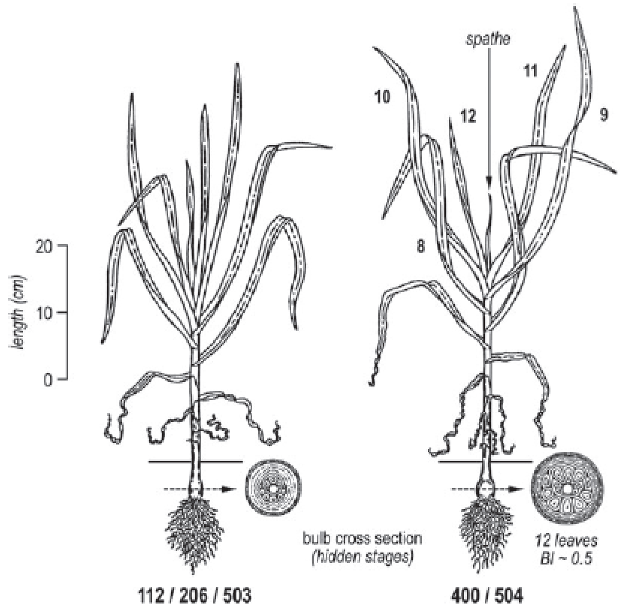

Figure 5 Principal growth stages 1, 2 and 5 (overlaps): 12th leaf (blade) folded clearly visible, length of outer bladeless leaf of lateral shoot reach 20 mm and stalk (scape) reach 75% of total length of pseudo-stem (112/206/503, respectively; overlapped stages); all leaves visible, the innermost leaf of each lateral bud-clove start to swell (BI ~ 0.5) and stalk tip clearly visible (> 3 cm) (400/504, respectively; overlapped stages).

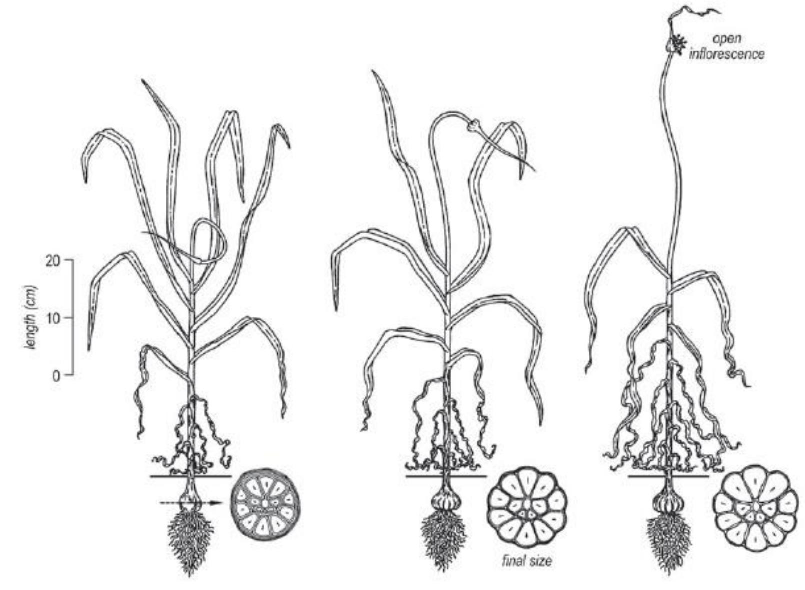

Figure 6 Principal growth stages 4, 5, 6 and 9 (overlaps): 70% of expected bulbs diameter reached, stalk shape like a 'pigtail' (407/506, respectively; overlapped stages); 100% of expected bulbs diameter reached, plant still erect and several leaves (3–5) green, and stalk shape like a 'bishop's crook' (409/507, respectively; overlapped stages); and spathe burst with inflorescence/umbel visible and last 5–3 leaves start bent over (600/900, respectively; overlapped stages).