# Comparison of phytophenological data: a proposal for converting between GFI and BBCH scales

*Giovanna Puppi[1*], Anna Letizia Zanotti[1]*

**Abstract:** *Phenological scales used in the past were not standardized: in different countries different methods were followed and these are often still in use today: for example Italian Botanists usually make the phenological observations by means of the GFI key, adopted in 1993 by the Italian Phenological Gardens, or by Marcello's Key. The comparability of data collected with different methods is a serious problem, so, in the last 20 years the scientific community has directed significant efforts toward the standardization of sampling methods and phenological scales: in Europe, the BBCH scale (Meier, 1997) has been generally adopted. Although the BBCH and GFI scales have different structures, several stages are corresponding. We present a method for the conversion between BBCH and GFI scales, based on the numerical relationship between the codes of the respective stages: in the reproductive cycle the relation is well approximated by a sigmoid function, while in the leaf development, by a linear function. The presented method also allows the fractional values of the stages to be converted (e.g. the average value of a population).*
**Keywords:** *Phenological scales, BBCH, GFI, growth stages, flowering, leafing*

**Riassunto:** *I rilievi fenologici in campo si effettuano avvalendosi di protocolli e scale (chiavi) fenologiche, che in passato non erano standardizzati. In paesi e in ambienti scientifici diversi si sono affermate scale di rilievo diverse: ad esempio in Italia tra i botanici è in uso la chiave GFI adottata nel 1993 dai Giardini Fenologici Italiani, o la scala "Marcello". L'uso di chiavi diverse crea problemi di confrontabilità dei dati, così, negli ultimi 20 anni si è cercato di convergere verso una soluzione standard a livello internazionale, rappresentata dalla scala centesimale BBCH (Meier, 1997). La scala BBCH è costruita in modo diverso rispetto alla scala GFI, tuttavia è possibile trovare corrispondenze nella descrizione di alcuni stadi. Qui viene presentata una ipotesi di conversione numerica tra la chiave GFI e la BBCH, che si basa sulle relazioni tra i valori numerici degli stadi delle due scale: per il ciclo riproduttivo la relazione si può approssimare con una funzione sigmoide e per lo sviluppo fogliare con una retta. Questa soluzione permette di convertire non solo gli stadi principali della chiave GFI, ma anche i valori frazionari (ad es. valori medi su vari individui).*
**Parole chiave:** *Scale fenologiche, BBCH, GFI, stadi di sviluppo, fioritura, fogliazione*

## INTRODUCTION

Phenology, *"the study of the timing of recurring biological events"*, is today largely an applied science, related to agriculture, forestry, climatology, human health, biomonitoring, etc.

In the 1990s the interest in phenological research increased substantially, because many studies showed that the timing of life cycle events provide a good indicator for climate change impacts (Schwartz, 2003). The growing importance of phenology for climate monitoring is also visible in the 4th assessment report of the IPCC (2007) and WMO Commission for Climatology (2007) and moreover, in the guidelines of the WCRP (World Climate Research Programme) where recommended methods for undertaking phenological observations are stated (Koch, 2010).

This renewed interest in Phenology has increased the demand for long series of data and the international cooperation at continental level. In Europe a great amount of phenological data were recorded in the past, but with quite different histories and traditions of observations (Menzel, 2003; Nekovar *et al.*, 2008; Koch, 2010): the observation methods, the coding systems, the monitoring guidelines were different among countries, and thus we now have a large data set at a continental level, without the homogeneity necessary for many applications.

The plans for establishing a global phenological network were started in 1993 by the Phenology Study Group of the ISB (International Society for Biometeorology) and then in 1996 the Global Phenological Monitoring Program (GPM) was completed. A main objective of the GPM was to increase cooperation and to provide standard methods as a basis for communication and research (Bruns *et al.*, 2003).

In the last decade, European projects have been set up to facilitate the integration between networks

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and the creation of one single database (EPN over the 2001-2003 period; Cost Action 725 over the 2004-2009 period). In all the cited projects (GPM, EPN, COST 725, PEP 725) phenological phases are defined according to the BBCH code, which classifies the plant growth phases of a large number of species on the base of a standardized system.
The Biologische Bundesanstalt Bundessortenamt, Chemische Industrie BBCH scale (Meier, 1997) is an internationally recognized standard in the agricultural sector. All cultivated plants with economic importance have their appropriate scales. For other species, the general BBCH scale can be used. The principal scale, characterized by ten principal growth stages, forms the framework within which the individual scales are developed (Tab. 1). The secondary growth stages 1 to 9 correspond to the respective ordinal numbers or percentage values. For example stage 3 could represent: 3rd true leaf, 3rd tiller, 3rd node or 30% of the final length or size typical of the species or 30% of the flowers open. The combination of the principal and the secondary stages, results in the two-digit code: for some cases a three-digit scale is presented alongside the two-digit scale.
This involves the inclusion of the so-called mesostage between the principal and the secondary stage, which provides a further subdivision (Meier, 2001).

| Codes of Principal Stages | Description |
|---|---|
| 0 | Germination/sprouting/bud development |
| 1 | Leaf development (main shoot) |
| 2 | Formation of side shoots/ tillering |
| 3 | Stem elongation or rosette growth/ shoot elongation (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 seeds |
| 9 | Senescence, beginning of dormancy |

**Tab. 1** - Principal growth stages of the BBCH scale.
*Tab. 1 - Stadi principali della scala BBCH.*

**Phenological scales in Italy**
In Italy, the oldest phenological networks dates from the end of 19th century (Puppi and Zanotti, 2009) and are mainly related to meteorological networks. The international network (Belgium, The Netherlands, Germany, France, Italy) directed by the Belgian astronomer Adolphe Quetelet from 1840 to 1870, had several collaborators in Italy and a number of Italian scientists followed its methods (Caruel, Serpieri and others). Quetelet's protocol, with detailed instructions for the observations, was printed in 1853 by the Royal Academy of Sciences (Demarée and Chuine, 2006; Demarée, 2009).
Some years later (1876-1884), in 4 provinces of Northern Italy (Vicenza, Venice, Padua, Bologna) a phenological network was organized and directed by A. Da Schio in the years 1876-1884: a few phenophases (First leaf extended, Flowering, First fruit ripening, Leaves fall) were observed in a large number of common species (102). In 1885 the network was enlarged to the entire nation (Ministero per l'Agricoltura, 1887) with agro-meteorological aims.
In the same period, the first European Phenological network, also including Northern Italy, was established under the direction of Egon Ihne (1883-1941). Several standard phenophases were observed: b= beginning of flowering; BO= beginning of leaf unfolding; f= first fruit ripe ; W=green wood (more than 50% of leaves completely opened); LV= autumn colouring (more than 50% of leaves changed, including those fallen).
In all the above-mentioned cases, a limited set of developmental phases was considered: in fact the purpose of the observations, was to indentify the date of occurrence of selected phenophases, in order to compare different sites and years (for bio-meteorological purposes), rather than to describe the developmental rhythm of species (biological research).
The Italian Phenological Network started at the beginning of the 20th century (1922-1936) under the direction of the mathematician M. Minio and was later renewed (from 1953 to 1965) by the naturalist A. Marcello, one of the most important Italian phenologists.
Marcello conceived a new method to assess the flowering development (Marcello, 1935) using a set of 3 binary codes (+=present and 0=absent): the first code was referred to flower buds, the second to open flowers, the third to faded flowers. So, for instance, if a plant begins to flower, it is coded by the sequence ++0, because of the presence of flower buds and open flowers, at the same time with the absence of faded flowers; hence, if a plant is in full bloom it is coded by +++ (or 0+0), and if all the flowers are faded, the code is 00+ (end of flowering). The 7 stages of the Marcello's Key ($\overline{000}$,

+00, ++0, +++, 0++, 00+, 000), are sequential in time and cover the whole flowering development, from the beginning to the end. The attractiveness of the method lies in its simplicity: all the phases are easily individuated and every case can be classified unambiguously.
Marcello's Key had a great success in Italy: it was adopted in the Italian Phenological Network (1953-1965) and was largely utilised by many scientists even after the closing of the network.
After several decades, a similar approach was applied to fruit development by Arrigoni (1977).
In the mid '80s a new sequential key for describing vegetative development was proposed by a group of phenologists of the University of Bologna (Puppi *et al.*, 1985; Puppi, 1989).
This sequential key described all the vegetative stages of the cycle of plants and was inspired by previous European keys (Ellenberg, 1954, 1956; Dierschke, 1972).

**The GFI scale**

In 1982 the first Italian Phenological Garden was founded at S. Pietro Capofiume near Bologna, with the purpose to join the IPG (International Phenological Gardens) network. In the following years other Gardens were added and finally, in 1993, the network of the "Giardini Fenologici Italiani" (GFI) was officially set up (Malossini, 1993). Besides the phases required by the IPG (BO = beginning of leaf unfolding,, M= May shoot, J= St.John's sprout, LV= autumn colouring, BF= leaf fall, B= beginning of flowering, AB= full flowering, F= first fruit ripe) in the Italian Gardens complete observations of the plant cycles were made by means of two new scales, reproductive and vegetative, named GFI (Tab. 2): the reproductive scale, in 12 stages, was the combination of the Marcello's and Arrigoni's keys, while the vegetative one, in 14 stages, was derived from that of the Bologna group (Puppi, 1989). The GFI scales

| Codes of stages | Description |
|---|---|
| R 1 | Flower buds (or inflorescences) visible, but not developed (+00) |
| R 2 | Flower buds ready to open, petals just visible (aments developed but immature) (+00) |
| R 3 | Flower buds and open flowers (immature and pollinating aments) (++0) |
| R 4 | Full flowering: buds, open flowers and faded flowers (pollinating aments) (+++, 0+0) |
| R 5 | Flower fading: open flowers together with withered ones; (pollinating and spent aments) (0++) |
| R 6 | End of flowering: only withered flowers (spent aments) (00+) |
| R 7 | Beginning of ovary growing (000) |
| R 8 | Beginning of fruit development (size) |
| R 9 | Fruits developed but mostly unripe |
| R10 | Fruits mostly fully ripe |
| R11 | Beginning of fruit fall and seeds dispersal |
| R12 | Fruits spent or fallen; end of seeds dispersal |
| V 1 | Bud dormancy |
| V 2 | End of bud swelling |
| V 3 | Bud breaking: swollen and opening buds with folded leaves |
| V 4 | Open buds and first young leaves with unfolded blade |
| V 5 | Young leaves unfolded, not yet full size |
| V 6 | Young leaves unfolded together with leaves fully expanded |
| V 7 | Leaves fully developed |
| V 8 | Beginning of leaf discolouring |
| V 9 | Leaves mostly discoloured |
| V10 | Beginning of leaf dryness |
| V11 | Leaves mostly dried up |
| V12 | Beginning of leaf fall |
| V13 | Leaves mostly fallen |
| V14 | End of leaf fall, plants dormant |

**Tab. 2** - Growth stages of the GFI scale (Italian Phenological Gardens).
*Tab. 2 - Stadi fenologici della scala GFI (Giardini Fenologici Italiani).*

## Scheda osservazioni fenologiche – Angiosperme legnose – parte II

**Giardino fenologico di**……

Specie…… Varietà…… Nome comune……

Famiglia…… Posizione…… Età…… Provenienza……

Osservazioni……..

### Norme di rilevamento e note

Le rilevazioni fenologiche vanno effettuate su singoli individui di ciascuna specie con cadenza settimanale. Il rilevamento consiste nell'identificazione della fase fenologica (talora si verifica la compresenza di più fasi) in cui si trova l'individuo. Le fasi fenologiche (fenofasi) da rilevare sono indicate nella relativa chiave di rilevamento. Osservazioni: spazio riservato alle osservazioni che non rientrano nelle tipologie previste dagli altri settori della scheda: fitopatie (malattie fungine, attacchi di insetti, virosi, batteriosi, danni provocati dalla grandine, dal gelo, dal vento, dalle lepri, danni accidentali,ecc.), operazioni colturali (potatura, trattamenti antiparassitari, concimazioni, irrigazioni, diradamento, spollonatura, ecc.). Non vanno segnalate le normali cure del giardino come fresatura, zappatura, rasatura erba, ecc..

### Chiave di rilevamento

| | |
|---|---|
| **V01 Gemme in riposo:** le gemme non hanno ancora iniziato ad ingrossarsi | **R01 Boccioli e amenti presenti ma poco sviluppati:** i boccioli o gli amenti sono ben visibili ma non hanno ancora completato il loro sviluppo |
| **V02 Gemme rigonfie prossime alla schiusura:** le gemme sono rigonfie ma non lasciano ancora vedere le foglioline sottostanti | **R02 Boccioli prossimi alla schiusura, rigonfi, con petali visibili; amenti sviluppati ma immaturi:** i boccioli sono prossimi alla schiusura, è visibile il colore dei petali; gli amenti sono completamente sviluppati, quelli maschili hanno stami con antere intatte che non emettono polline |
| **V03 Gemme rigonfie assieme a gemme aperte, con foglioline ripiegate:** sono visibili le foglioline nelle prime gemme aperte; le foglioline non hanno ancora disteso il lembo | **R03 Boccioli rigonfi e fiori aperti; amenti immaturi e amenti maturi:** compresenza di boccioli nei quali è visibile il colore dei petali e fiori aperti; gli amenti sono completamente sviluppati: quelli maschili, in parte, emettono polline |
| **V04 Gemme appena aperte assieme a foglioline a lembo disteso:** le gemme sono quasi tutte aperte e hanno già emesso le prime foglioline; parte di esse hanno il lembo disteso | **R04 Piena fioritura: boccioli, fiori aperti, fiori sfioriti; amenti maturi:** fiori sbocciati, pistilli e stami pronti per l'impollinazione; amenti maturi: quelli maschili hanno antere aperte che emettono polline |
| **V05 Foglie giovani a lembo disteso:** le giovani foglie hanno spinato il lembo che inizialmente era ripiegato dentro le gemme | **R05 Inizio sfioritura: fiori aperti e fiori appassiti; amenti maturi e amenti sfioriti:** i fiori e gli amenti hanno quasi completato la fioritura |
| **V06 Foglie giovani insieme a foglie adulte:** alle giovani foglie con lembo aperto si accompagnano foglie completamente sviluppate | **R06 Completa sfioritura:** fiori appassiti; amenti sfioriti: la fioritura è stata completata e sulla pianta rimangono solo fiori appassiti o amenti sfioriti |
| **V07 Foglie adulte:** le foglie sono completamente sviluppate | **R07 Allegagione:** inizio ingrossamento ovari; gli ovari fecondati sono visibil e hanno iniziato a trasformarsi in frutti |
| **V08 Inizio della decolorazione fogliare:** le foglie assumono colorazioni diverse dal verde (es. virano dal rosso al giallo), per fenomeni di senescenza | **R08 Inizio fruttificazione:** sono visibili sia ovari ingrossati che frutti in fase di accrescimento |
| **V09 Foglie prevalentemente decolorate:** la maggior parte delle foglie ha cambiato colore | **R09 Frutti evidenti ma in prevalenza immaturi;** i frutti sono ben visibili, ma immaturi |
| **V10 Inizio disseccamento foglie:** le foglie, dopo aver mutato colore, iniziano a disseccarsi | **R10 Culmine della fruttificazione:** i frutti sono maturi e cambiano consistenza (intenerimento dei carnosi e indurimento dei secchi) |
| **V11 Foglie prevalentemente disseccate:** la maggior parte delle foglie è disseccata | **R11 Frutti in parte caduti, degenerati o secchi:** completata la maturazione i frutti sono in parte caduti, degenerati o secchi |
| **V12 Inizio caduta foglie:** alcune foglie sono cadute, la chioma è ancora folta | **R12 Presenza di soli frutti residui:** i frutti sono tutti caduti, degenerati o secchi |
| **V13 Foglie prevalentemente cadute:** la maggior parte delle foglie è caduta e la chioma è visibilmente diradata | |
| **V14 Piante completamente spoglie:** tutte le foglie sono cadute e la pianta è spoglia | |

**Fig. 1** - Survey form adopted by the Italian Phenological Gardens. Guidelines and phenological scales (Botarelli and Sacchetti 1998, page 13).

*Fig. 1 - Scheda fenologica adottata dai Giardini Fenologici Italiani (II parte). Norme di rilevamento e scale fenologiche. (Botarelli e Sacchetti 1998, pag. 13).*

(Malossini, 1993, Botarelli and Sacchetti, 1998), still adopted today in the Italian Phenological Gardens (Fig. 1), were widely utilized in Italy also in phenological research on wild plants (Zanotti and Puppi, 2000; Chiesura Lorenzoni, 2003; Zanotti *et al.*, 2003; Bianchi and Drigo, 2009, Delleani *et al.*, 2009; etc.).

**AIMS**

The aim of this study is to realize a framework of conversion between the BBCH and the "GFI-Angiosperme legnose" (woody Angiosperms) scales. The conversion is necessary to allow comparisons between Italian and European data, and to enhance the value of many decades of phenological observations.

**METHODS**

The method consists of four steps:

1) Investigation of all the reliable correspondences between GFI and BBCH phenophases on the basis of their descriptions.
2) Building of the numerical relationships between the codes of the two scales, approximating by the best-fit function the points identified in step 1.
3) Use of the functions found in step 2 in order to calculate the remaining correspondences.
4) Test of the correspondences found in step 3, comparing the definitions of the phases.

Despite GFI is a qualitative scale, and vice-versa the BBCH is mostly quantitative (Meier, 2001), the method described above should be enforceable, since the two scales have a substantial affinity. In fact, both the phenological scales are largely sequential, having a continual succession of phases over time. In other words, the growing stages are identified as progressive steps of one developmental process, which can be represented by a function (stages versus time). Therefore we suppose that the growing functions of BBCH and GFI are substantially similar and thus comparable.

In the curve fitting process we tested several mathematical function (linear, logarithmic, polynomial, sigmoid functions, etc.) by regression analysis, selecting the one that showed the best fit to the series of the data points.

**RESULTS**

First of all we analyzed the gross relation between the GFI phases and BBCH stages: from this preliminary analysis some BBCH principal growth stages (2, 3, 4) were set aside, because they are missing in the GFI key.

Then we analyzed separately the correspondences in:

a) Flower bud development, Flowering, Fruit development and ripening (BBCH= 5 to 8; GFI= R1 to R12)
b) Bud and leaf development (BBCH= 0 and 1; GFI= V1 to V6)
c) Senescence and leaf fall (BBCH= 9; GFI= V7 to V14)

The definitions of stages generally refer to the BBCH general scale (Meier, 2001), except for a few cases, where specific scales (Fruits: Pome fruits, Stone fruits, Currants, Grape) are considered.

**a) Flower bud development, Flowering, Fruit development and ripening**

After an accurate analysis of the definitions of reproductive stages, the following biunique correspondences were singled out:

GFI=R2 (*Flower buds ready to open (petals just visible)*) corresponds to BBCH=59 (*Inflorescence fully emerged, first flower petals visible (in petalled forms)*)

GFI=R4 (*Full flowering: buds, open flowers and faded flowers*) corresponds to BBCH=65 (*Full flowering: 50% of flowers open, first petals may be fallen*)

GFI=R5 (*Flower fading: open flowers together with withered ones*) corresponds to BBCH=67 (*Flower finishing: majority of petals fallen or dry*)

GFI=R6 (*End of flowering, only withered flowers*) corresponds to BBCH=69 (*End of flowering: fruit set visible*)

GFI=R7 (*Beginning of ovary growing*) could correspond to BBCH=71 (*Ovary growing, beginning of fruit growth* (see Stone Fruit and Currant scales))

GFI=R10 (*Fruits mostly fully ripe*) corresponds to BBCH=89 (*Fully ripe: fruit shows fully ripe colour, beginning of fruit abscission*)

The remaining GFI phases have a range of correspondence with several BBCH stages:

GFI=R1 corresponds to BBCH= 51 to 55
GFI=R3 corresponds to BBCH= 61 to 64
GFI=R8 corresponds to BBCH= 72 to 77(78)
GFI=R9 corresponds to BBCH= (78) 79 to 87

Note that R11 (*Beginning of fruit fall and seeds dispersal*) and R12 phases (*Fruits spent or fallen, end of seeds dispersal*) aren't represented in the BBCH scale: in these cases, following the BBCH guidelines, new three-digit codes could be proposed (for example R11=BBCH 895; R12= BBCH 899).

Afterward, we analysed the relationship between

the two scales, putting the numerical values of the corresponding stages in a graph (Fig. 2): the two scales appear to have a non-linear relationship and it seems justifiable to approximate the points by a sigmoid function.
We tested the logistic equation: $Y=K/(1+e^{(a-bx)})$, where x= BBCH stages, Y= GFI phases, K= upper asymptote, a= constant (distance from the origin), b= speed of variation.
The best fit function shows a very high value of correlation coefficient ($R^2$= 0.999 **): the values of parameters are: K=10.2 ; a= 11.98; b= 0.1787.
We then examined the GFI phases with uncertain correspondence (R1, R3, R8, R9): the estimated values in BBCH were calculated by the best fit equation (Tab. 3) and the reliability of the correspondences was checked. Therefore, the best fit logistic function seems to be adequate for calculating the correspondences of the reproductive stages.

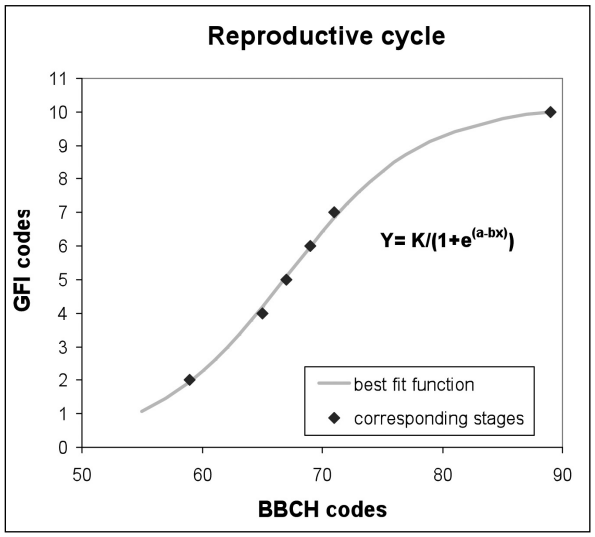


**Fig. 2** - Relationship between the reproductive codes of BBCH and GFI. The points of the corresponding stages are approximated by a sigmoid function:
$Y= K/(1+e^{(a-bx)})$, where: X= BBCH stages, Y= GFI phases, K= upper asymptote, a= constant (distance from the origin), b= speed of variation.
The drawn line is the best fit function: the value of correlation coefficient is high and significant (R2= 0.9992 **); the values of the parameters are: K= 10.2; a=1198; b=0.1787.
*Fig. 2 - Relazioni tra i codici numerici delle scale BBCH e GFI. I punti relativi agli stadi corrispondenti sono approssimati con una funzione sigmoide: $Y= K/(1+e^{(a-bx)})$, dove poniamo: X= stadi BBCH, Y= stadi GFI, K= asintoto superiore, a= costante (distanza dall'origine), b= velocità di variazione.*
*La linea disegnata è quella della migliore funzione approssimante: il valore del coefficiente di correlazione è alto e significativo (R2= 0.9992 **); i valori dei parametri sono: K= 10.2; a= 11.98; b= 0.1787.*

| GFI R codes | BBCH codes | BBCH estimated values |
|---|---|---|
| 2 | 59 | 59 |
| 4 | 65 | 65 |
| 5 | 67 | 67 |
| 6 | 69 | 69 |
| 7 | 71 | 71 |
| 10 | 89 | 89 |
| 1 | | 55 |
| 3 | | 62 |
| 8 | | 74 |
| 9 | | 78 |

**Tab. 3** - GFI-BBCH conversion table of the reproductive cycle. Recognized correspondences between stages are reported in the first and second columns: the correspondences of the last four GFI codes are undefined. The BBCH values in the third column are calculated by the best fit function of figure 2.
*Tab. 3 - Tabella di conversione GFI-BBCH per il ciclo riproduttivo. Nella seconda colonna sono riportati gli stadi BBCH riconosciuti come esattamente corrispondenti a stadi GFI: mancano le corrispondenze delle ultime quattro fasi GFI, in quanto non chiaramente definite. Nella terza colonna sono riportati i valori di BBCH calcolati con la funzione di figura 2.*

**b) Bud and leaf development**
The same procedure was applied also to the beginning of the vegetative cycle, from "*Winter dormancy*" to "*First leaves fully expanded*".
The following biunique correspondences were found:
GFI=V1 (*Bud dormancy*) corresponds to BBCH=00 (*Winter dormancy*)
GFI=V2 (*End of bud swelling*) corresponds to BBCH=03 (*End of bud swelling*)
GFI=V4 (*Open buds and first leaves with unfolded blade*) corresponds to BBCH=11 (*First leaf, leaf pair, or whorls, unfolded*)
GFI=V6 (*Young leaves unfolded together with leaves fully expanded)* corresponds to BBCH=19 (*first leaves fully expanded* (see BBCH for Fruits))
while the remaining GFI phases have a range of correspondence with several stages:
GFI=V3 (*Bud breaking: swollen and open buds with folded leaves*) corresponds to BBCH=7 to 10
GFI=V5 (*Young leaves unfolded, not yet full size*) corresponds to BBCH=12 to 18.
In this case the relationship between the two scales appears to be linear, so it seems justifiable to approximate the points by a linear function (Fig. 3) as: Y=a+bX
The best fit equation shows a high value of

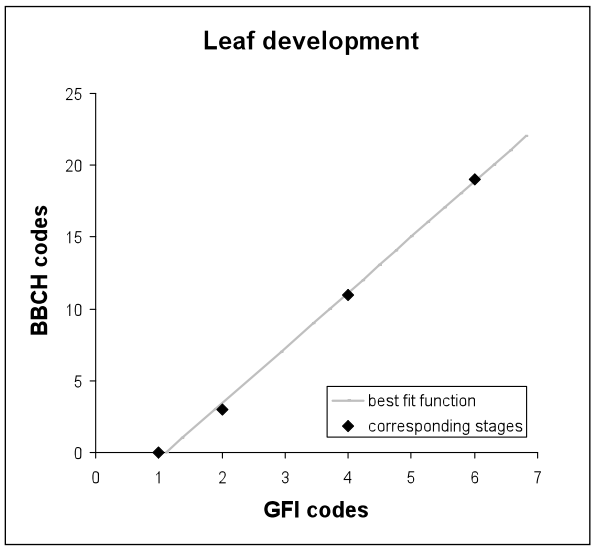


**Fig. 3** - Relationship between GFI and BBCH codes of Leaf development. The points of the corresponding stages are approximated by a linear function. The value of correlation coefficient is high and significant (R2= 0.998 **): the values of parameters are: cost= - 4.254 and slope= 3.847.
*Fig. 3 - Relazioni tra i codici numerici delle scale BBCH e GFI dello sviluppo fogliare. I punti relativi agli stadi corrispondenti sono approssimati con una funzione lineare: il coefficiente di correlazione è alto e significativo (R2= 0.998 **): i valori dei parametri sono: intercetta= - 4.254; pendenza= 3.847.*

correlation coefficient ($R^2$= 0,998 **): the values of parameters are: a=-4,254 ; b=3,847.
We then examined the GFI phases with uncertain correspondence (R1, R3, R8, R9): the estimated values of BBCH were calculated by the best fit equation and the reliability of the correspondences was checked. The results are reported in Tab. 4.

**c) Senescence and leaf fall**
The numerical method could not be applied to the declining phases of the vegetative cycle, because the growing stages are not strictly sequential. To fix a precise sequentiality in leaf discolouring and falling is problematic because of the phenological differences between species: for example some trees become almost completely yellow (or red) before the beginning of leaf fall (*Ginkgo, Acer, Fagus, etc.*), while the foliage of others never become completely yellow because the beginning of discolouring is immediately followed by the start of leaf fall (*Sambucus*).
In the GFI, sequentiality is highly fragmented: V8-9 refer to leaf discolouring, V10-11 to leaf desiccation, and V12-13 to leaf fall, but it is well known that leaf desiccation and fall are alternative rather than sequential events. Moreover, even if V8

| Vegetative cycle | GFI V codes | BBCH codes | BBCH estimated values |
|---|---|---|---|
| Leaf development | 1 | 0 | 0 |
| | 2 | 3 | 3 |
| | 4 | 11 | 11 |
| | 6 | 19 | 19 |
| | 3 | | 7 |
| | 5 | | 15 |
| Leaf senescence and fall | 7 | 91 | |
| | 8 | 92 | |
| | 10 or 12 | 93 | |
| | 9 | 94 | |
| | 11 or 13 | 95 | |
| | 14 | 97 | |

**Tab. 4** - GFI-BBCH conversion table of the Leaf development and senescence. Recognized correspondences between stages are reported in the first and second columns of data: the correspondences of the V3 and V5 GFI codes are undefined. The BBCH values in the third column of data are calculated by the best fit function of figure 3: the function cannot be applied to the last part of vegetative cycle (senescence).
*Tab. 4 - Tabella di conversione GFI-BBCH per lo sviluppo e la senescenza fogliare. Nella seconda colonna di dati sono riportati gli stadi BBCH riconosciuti come esattamente corrispondenti a stadi GFI: mancano le corrispondenze delle ultime fasi GFI V3 e V5, in quanto non chiaramente definite. Nella terza colonna sono riportati i valori di BBCH calcolati con la funzione di figura 3: la funzione non è applicabile alla ultima parte del ciclo fogliare (senescenza).*

(*Beginning of leaf discolouring*) always precedes V12 (*Beginning of leaf fall*), however in certain species, leaf fall (V12) can begin earlier than the discolouring of the majority of leaves (V9).
In the BBCH, sequentiality is almost achieved, but some phases are lacking or seem to be ambiguous. Moreover we notice that the second numbers of the code lose their quantitative meaning: only BBCH 95 maintains a link to the corresponding quantity "*50% of leaves fallen*".
The stage "*Beginning of leaf discolouring*" is lacking in the general scale, but is coded as 92 in the Fruit trees scales. The stage 93 is generally defined as "*Beginning of leaf fall*". The stage "*50% of leaves discoloured*" is lacking in the general scale, but in the Stone-fruit scale appears curiously coupled with leaf fall (BBCH 95); recently Bruns *et al.* (2003) proposed to use BBCH 94 for the stage "*50% of leaves discoloured*". Finally BBCH 97 is defined as "*end of leaf fall, above ground parts of plants dead or dormant*".
Nevertheless we found reasonable correspondences between the definitions of stages (Tab. 4):
GFI V7 (*Leaves fully developed*) may correspond to BBCH 91 (*Foliage still fully green*)
GFI V8 (*Beginning of leaf discolouring*) corresponds to BBCH 92
GFI V9 (*Leaves mostly discoloured*) may be assigned to BBCH 94 (Bruns *et al.*, 2003)
GFI V10 and V12 may be assigned to BBCH 93
GFI V11 and V13 may be assigned to BBCH 95
GFI V14 (*End of leaf fall, plants dormant*) corresponds to BBCH 97.

## CONCLUSIONS

The numerical method for converting between GFI and BBCH scales here presented, is based on the sequential character of both the phenological keys and on their substantial affinity. The method is suitable for the larger part of the developmental cycle and shows several main advantages. First of all, the conversion of each stage is evaluated both singly, and considering the whole growing process. Then, having set up a rational and objective procedure, makes it possible to single out unambiguously the most uncertain correspondences between phases. Moreover, the use of mathematical functions enables the conversion even of the fractional GFI stages (derived from calculations of the average values of plant populations).
This method is inapplicable to the last part of the vegetative cycle, because the sequence of the senescence stages is based on different criteria in the two scales. In the latter case similar stages have to be compared and paired off singly, taking into consideration the phenological behaviour of the observed plant species or groups.
The importance of the conversion between GFI and BBCH scales is increased by the fact that the GFI includes older Italian keys (Marcello, etc.): in this way, a great amount of old phenological data, collected in the first part of the 20th century, could be compared with the European historical pheno-series.

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