

The `germinationmetrics` Package: A Brief Introduction

Aravind, J., Vimala Devi, S., Radhamani, J., Jacob, S. R., and Kalyani Srinivasan

2025-12-14

ICAR-National Bureau of Plant Genetic Resources, New Delhi.

Contents

Overview	1
Installation	1
Version History	3
Germination count data	3
Single-value germination indices	4
Non-linear regression analysis	33
Four-parameter hill function	33
Wrapper functions	45
Citing <code>germinationmetrics</code>	60
Session Info	60
References	61

Overview

The package `germinationmetrics` is a collection of functions which implements various methods for describing the time-course of germination in terms of single-value germination indices as well as fitted curves.

The goal of this vignette is to introduce the users to these functions and get started in describing sequentially recorded germination count data. This document assumes a basic knowledge of R programming language.



Installation

The package can be installed using the following functions:

```
# Install from CRAN
install.packages('germinationmetrics', dependencies=TRUE)

# Install development version from Github
devtools::install_github("aravind-j/germinationmetrics")
```

Then the package can be loaded using the function

```
library(germinationmetrics)
```

Welcome to `germinationmetrics` version 0.1.9

```
# To know how to use this package type:
  browseVignettes(package = 'germinationmetrics')
  for the package vignette.

# To know whats new in this version type:
  news(package='germinationmetrics')
  for the NEWS file.

# To cite the methods in the package type:
  citation(package='germinationmetrics')

# To suppress this message use:
  suppressPackageStartupMessages(library(germinationmetrics))
```

Version History

The current version of the package is 0.1.9. The previous versions are as follows.

Table 1. Version history of `germinationmetrics` R package.

Version	Date
0.1.0	2018-04-17
0.1.1	2018-07-26
0.1.1.1	2018-10-16
0.1.2	2018-10-31
0.1.3	2019-01-19
0.1.4	2020-06-16
0.1.5	2021-02-17
0.1.6	2022-06-15
0.1.7	2022-08-28

To know detailed history of changes use `news(package='germinationmetrics')`.

Germination count data

Typically in a germination test, the germination count data of a fixed number of seeds is recorded at regular intervals for a definite period of time or until all the seeds have germinated. These germination count data can be either partial or cumulative (Table 2).

Table 2 : A typical germination count data.

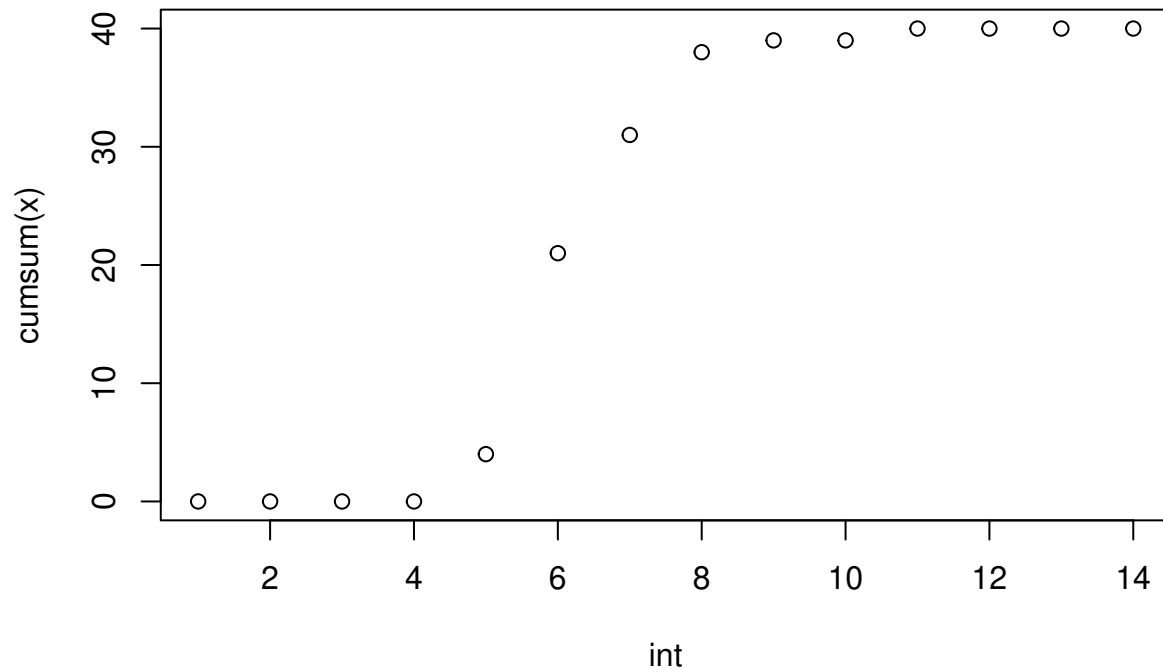
intervals	counts	cumulative.counts
1	0	0
2	0	0
3	0	0
4	0	0
5	4	4
6	17	21
7	10	31
8	7	38
9	1	39
10	0	39
11	1	40
12	0	40
13	0	40
14	0	40

The time-course of germination can be plotted as follows.

```
data <- data.frame(intervals = 1:14,
                  counts = c(0, 0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0))

# Partial germination counts
x <- data$counts
# Cumulative germination counts
y <- cumsum(x)
# Time intervals of observations
```

```
int <- data$intervals  
plot(int, cumsum(x))
```



Single-value germination indices

The details about the single-value germination indices implemented in `germinationmetrics` are described in Table 3.

Table 3 : Single-value germination indices implemented in `germinationmetrics`.

Germination index	Function	Details	Unit	Measures	Reference
Germination percentage or Final germination percentage or Germinability (GP)	GermPercent	It is computed as follows. $GP = \frac{N_g}{N_t} \times 100$ Where, N_g is the number of germinated seeds and N_t is the total number of seeds.	Percentage (%)	Germination capacity	ISTA (2015)
Peak germination percentage (PGP)	PeakGermPercent	It is computed as follows. $PGP = \frac{N_{max}}{N_t} \times 100$ Where, N_{max} is the maximum number of seeds germinated per interval.	Percentage (%)	Germination capacity	Vallance (1950); Roh et al. (2004)
Time for the first germination or Germination time lag (t_0)	FirstGermTime	It is the time for first germination to occur (e.g. First day of germination). $t_0 = \min \{T_i : N_i \neq 0\}$ Where, T_i is the time from the start of the experiment to the i th interval and N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval)	time	Germination time	Edwards (1932); Czabator (1962); Goloff and Bazzaz (1975); Labouriau (1983a); Ranal (1999); Quintanilla et al. (2000)
Time for the last germination (t_g)	LastGermTime	It is the time for last germination to occur (e.g. Last day of germination) $t_g = \max \{T_i : N_i \neq 0\}$ Where, T_i is the time from the start of the experiment to the i th interval and N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval)	time	Germination time	Edwards (1932)
Time spread of germination or Germination distribution	TimeSpreadGerm	It is the difference between time for last germination (t_g) and time for first germination (t_0). $Time\ spread\ of\ germination = t_g - t_0$	time	Germination time	Al-Mударis (1998); Schrader and Graves (2000); Kader (2005)
Peak period of germination or Modal time of germination (t_{peak})	PeakGermTime	It is the time in which highest frequency of germinated seeds are observed and need not be unique. $t_{peak} = \{T_i : N_i = N_{max}\}$ Where, T_i is the time from the start of the experiment to the i th interval, N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval) and N_{max} is the maximum number of seeds germinated per interval.	time	Germination time	Ranal and Santana (2006)

Germination index	Function	Details	Unit	Measures	Reference
Median germination time (t_{50}) (Coolbear)	t50	<p>It is the time to reach 50% of final/maximum germination. With argument method specified as "coolbear", it is computed as follows.</p> $t_{50} = T_i + \frac{(\frac{N+1}{2} - N_i)(T_j - T_i)}{N_j - N_i}$ <p>Where, t_{50} is the median germination time, N is the final number of germinated seeds, and N_i and N_j are the total number of seeds germinated in adjacent counts at time T_i and T_j respectively, when $N_i < \frac{N+1}{2} < N_j$.</p>	time	Germination time	Coolbear et al. (1984)
Median germination time (t_{50}) (Farooq)	t50	<p>With argument method specified as "farooq", it is computed as follows.</p> $t_{50} = T_i + \frac{(\frac{N}{2} - N_i)(T_j - T_i)}{N_j - N_i}$ <p>Where, t_{50} is the median germination time, N is the final number of germinated seeds, and N_i and N_j are the total number of seeds germinated in adjacent counts at time T_i and T_j respectively, when $N_i < \frac{N}{2} < N_j$.</p>	time	Germination time	Farooq et al. (2005)
Mean germination time or Mean length of incubation time (\bar{T}) or Germination resistance (GR) or Sprouting index (SI) or Emergence index (EI)	MeanGermTime	<p>It is the average length of time required for maximum germination of a seed lot and is estimated according to the following formula.</p> $\bar{T} = \frac{\sum_{i=1}^k N_i T_i}{\sum_{i=1}^k N_i}$ <p>Where, T_i is the time from the start of the experiment to the ith interval, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval), and k is the total number of time intervals.</p> <p>It is the inverse of mean germination rate (\bar{V}).</p> $\bar{T} = \frac{1}{\bar{V}}$	time	Germination time	Edmond and Drapala (1958); Czabator (1962); Smith and Millet (1964); Gordon (1969); Gordon (1971); Mock and Eberhart (1972); Ellis and Roberts (1980) Labouriau (1983a); Ranal and Santana (2006)

Germination index	Function	Details	Unit	Measures	Reference
Variance of germination time (s_T^2)	VarGermTime	<p>It is computed according to the following formula.</p> $s_T^2 = \frac{\sum_{i=1}^k N_i (T_i - \bar{T})^2}{\sum_{i=1}^k N_i - 1}$ <p>Where, T_i is the time from the start of the experiment to the ith interval, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval), and k is the total number of time intervals.</p>	time ⁻¹	Germination time	Labouriau (1983a); Ranal and Santana (2006)
Standard error of germination time ($s_{\bar{T}}$)	SEGermTime	<p>It signifies the accuracy of the calculation of the mean germination time. It is estimated according to the following formula:</p> $s_{\bar{T}} = \sqrt{\frac{s_T^2}{\sum_{i=1}^k N_i}}$ <p>Where, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval) and k is the total number of time intervals.</p>	time	Germination time	Labouriau (1983a); Ranal and Santana (2006)
Mean germination rate (\bar{V})	MeanGermRate	<p>It is computed according to the following formula:</p> $\bar{V} = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k N_i T_i}$ <p>Where, T_i is the time from the start of the experiment to the ith interval, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval), and k is the total number of time intervals. It is the inverse of mean germination time (\bar{T}).</p> $\bar{V} = \frac{1}{\bar{T}}$	time ⁻¹	Germination rate	Labouriau and Valadares (1976); Labouriau (1983b); Ranal and Santana (2006)

Germination index	Function	Details	Unit	Measures	Reference
Coefficient of velocity of germination (<i>CVG</i>) or Coefficient of rate of germination (<i>CRG</i>) or Kotowski's coefficient of velocity	CVG	It is estimated according to the following formula. $CVG = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k N_i T_i} \times 100$ $CVG = \bar{V} \times 100$ Where, T_i is the time from the start of the experiment to the i th interval, N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), and k is the total number of time intervals.	% time ⁻¹	Germination rate	Kotowski (1926), Nichols and Heydecker (1968); Bewley and Black (1994); Labouriau (1983b); Scott et al. (1984)
Variance of germination rate (s_V^2)	VarGermRate	It is calculated according to the following formula. $s_V^2 = \bar{V}^4 \times s_T^2$ Where, s_T^2 is the variance of germination time.	time ⁻²	Germination rate	Labouriau (1983b); Ranal and Santana (2006)
Standard error of germination rate ($s_{\bar{V}}$)	SEGermRate	It is estimated according to the following formula. $s_{\bar{V}} = \sqrt{\frac{s_V^2}{\sum_{i=1}^k N_i}}$ Where, N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), and k is the total number of time intervals.	time ⁻¹	Germination rate	Labouriau (1983b); Ranal and Santana (2006)
Germination rate as the reciprocal of the median time (v_{50})	GermRateRecip	It is the reciprocal of the median germination time (t_{50}). $v_{50} = \frac{1}{t_{50}}$	time ⁻¹	Germination rate	Went (1957); Labouriau (1983b); Ranal and Santana (2006)
Speed of germination (S) or Germination rate Index or index of velocity of germination or Emergence rate index (Allan, Vogel and Peterson; Erbach; Hsu and Nelson) or Germination index (AOSA)	GermSpeed	It is the rate of germination in terms of the total number of seeds that germinate in a time interval. It is estimated as follows. $S = \sum_{i=1}^k \frac{N_i}{T_i}$ Where, T_i is the time from the start of the experiment to the i th interval, N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), and k is the total number of time intervals. Instead of germination counts, germination percentages may also be used for computation of speed of germination.	% time ⁻¹ or count time ⁻¹	Mixed	Throneberry and Smith (1955); Maguire (1962); Allan et al. (1962); Kendrick and Frankland (1969); Bouton et al. (1976); Erbach (1982); AOSA (1983); Khandakar and Bradbeer (1983); Hsu and Nelson (1986); Bradbeer (1988); Wardle et al. (1991)

Germination index	Function	Details	Unit	Measures	Reference
Speed of accumulated germination ($S_{accumulated}$)	GermSpeedAccumulate	<p>It is the rate of germination in terms of the accumulated/cumulative total number of seeds that germinate in a time interval.</p> <p>It is estimated as follows.</p> $S_{accumulated} = \sum_{i=1}^k \frac{\sum_{j=1}^i N_j}{T_i}$ <p>Where, T_i is the time from the start of the experiment to the ith interval, $\sum_{j=1}^i N_j$ is the cumulative/accumulated number of seeds germinated in the ith interval, and k is the total number of time intervals.</p> <p>Instead of germination counts, germination percentages may also be used for computation of speed of germination.</p>	% time ⁻¹ or count time ⁻¹	Mixed	Bradbeer (1988); Wardle et al. (1991); Haugland and Brandsaeter (1996); Santana and Ranal (2004)
Corrected speed of germination or Corrected germination rate index (\hat{S})	GermSpeedCorrected	<p>It is computed as follows.</p> $S_{corrected} = \frac{S}{FGP}$ <p>Where, S is the germination speed computed with germination percentage instead of counts and FGP is the final germination percentage or germinability.</p> <p>It can also be computed from speed of accumulated germination (computed with germination percentage).</p> $\hat{S}_{accumulated} = \frac{S_{accumulated}}{FGP}$ <p>Where, $S_{accumulated}$ is the speed of accumulated germination computed with germination percentage instead of counts and FGP is the final germination percentage or germinability.</p>	time ⁻¹	Mixed	Evetts and Burnside (1972)
Weighted germination percentage (WGP)	WeightGermPercent	<p>It is estimated as follows.</p> $WGP = \frac{\sum_{i=1}^k (k - i + 1) N_i}{k \times N} \times 100$ <p>Where, N_i is the number of seeds that germinated in the time interval i (not cumulative, but partial count), N is the total number of seeds tested, and k is the total number of time intervals.</p>	Percentage (%)	Mixed	Reddy et al. (1985); Reddy (1978)
Mean germination percentage per unit time (\overline{GP})	MeanGermPercent	<p>It is estimated as follows.</p> $\overline{GP} = \frac{GP}{T_k}$ <p>Where, GP is the final germination percentage, T_k is the time at the kth time interval, and k is the total number of time intervals required for final germination.</p>	% time ⁻¹	Mixed	Czabator (1962)

Germination index	Function	Details	Unit	Measures	Reference
Number of seeds germinated per unit time \bar{N}	MeanGermNumber	It is estimated as follows. $\bar{N} = \frac{N_g}{T_k}$ Where, N_g is the number of germinated seeds at the end of the germination test, T_k is the time at the k th time interval, and k is the total number of time intervals required for final germination.	count time ⁻¹	Mixed	Khamassi et al. (2013)
Timson's index [$\sum 10$ (Ten summation), $\sum 5$ or $\sum 20$] or Germination energy index (GEI)	TimsonsIndex	It is the progressive total of cumulative germination percentage recorded at specific intervals for a set period of time and is estimated in terms of cumulative germination percentage (G_i) as follows. $\Sigma k = \sum_{i=1}^k G_i$ Where, G_i is the cumulative germination percentage in time interval i , and k is the total number of time intervals. It also estimated in terms of partial germination percentage as follows. $\Sigma k = \sum_{i=1}^k g_i(k-j)$ Where, g_i is the germination (not cumulative, but partial germination) in time interval i (i varying from 0 to k), k is the total number of time intervals, and $j = i - 1$.	Percentage (%)	Mixed	Grose and Zimmer (1958); Timson (1965); Lyon and Coffelt (1966); Chaudhary and Ghildyal (1970); Negm and Smith (1978); Brown and Mayer (1988); Baskin and Baskin (1998); Goodchild and Walker (1971)
Modified Timson's index (Σk_{mod}) (Labouriau)	TimsonsIndex	It is estimated as Timson's index Σk divided by the sum of partial germination percentages. $\Sigma k_{mod} = \frac{\Sigma k}{\sum_{i=1}^k g_i}$	no unit	Mixed	Ranal and Santana (2006)
Modified Timson's index (Σk_{mod}) (Khan and Unger)	TimsonsIndex	It is estimated as Timson's index (Σk) divided by the total time period of germination (T_k). $\Sigma k_{mod} = \frac{\Sigma k}{T_k}$	% time ⁻¹	Mixed	Khan and Ungar (1984)

Germination index	Function	Details	Unit	Measures	Reference
George's index (<i>GR</i>)	GermRateGeorge	It is estimated as follows. $GR = \sum_{i=1}^k N_i K_i$ Where N_i is the number of seeds germinated by i th interval and K_i is the number of intervals(eg. days) until the end of the test, and k is the total number of time intervals.	count time	Mixed	George (1961); Tucker and Wright (1965); Nichols and Heydecker (1968); Chopra and Chaudhary (1980)
Germination Index (<i>GI</i>) (Melville)	GermIndex	It is estimated as follows. $GI = \sum_{i=1}^k \frac{ (T_k - T_i) N_i }{N_t}$ Where, T_i is the time from the start of the experiment to the i th interval (day for the example), N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), N_t is the total number of seeds used in the test, and k is the total number of time intervals.	time	Mixed	Melville et al. (1980)
Germination Index (<i>GI_{mod}</i>) (Melville; Santana and Ranal)	GermIndex	It is estimated as follows. $GI_{mod} = \sum_{i=1}^k \frac{ (T_k - T_i) N_i }{N_g}$ Where, T_i is the time from the start of the experiment to the i th interval (day for the example), N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), N_g is the total number of germinated seeds at the end of the test, and k is the total number of time intervals.	time	Mixed	Melville et al. (1980); Santana and Ranal (2004); Ranal and Santana (2006)
Emergence Rate Index (<i>ERI</i>) or Germination Rate Index (Shmueli and Goldberg)	EmergenceRateIndex	It is estimated as follows. $ERI = \sum_{i=i_0}^{k-1} N_i (k - i)$ Where, N_i is the number of seeds germinated in the i th time interval (not the accumulated number, but the number corresponding to the i th interval), i_0 is the time interval when emergence/germination started, and k is the total number of time intervals.	count	Mixed	Shmueli and Goldberg (1971)

Germination index	Function	Details	Unit	Measures	Reference
Modified Emergence Rate Index (ERI_{mod}) or Modified Germination Rate Index (Shmueli and Goldberg; Santana and Ranal)	EmergenceRateIndex	<p>It is estimated by dividing Emergence rate index (ERI) by total number of emerged seedlings (or germinated seeds).</p> $ERI_{mod} = \frac{\sum_{i=i_0}^{k-1} N_i(k-i)}{N_g} = \frac{ERI}{N_g}$ <p>Where, N_g is the total number of germinated seeds at the end of the test, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval), i_0 is the time interval when emergence/germination started, and k is the total number of time intervals.</p>	no unit	Mixed	Shmueli and Goldberg (1971); Santana and Ranal (2004); Ranal and Santana (2006)
Emergence Rate Index (ERI) or Germination Rate Index (Bilbro & Wanjura)	EmergenceRateIndex	<p>It is the estimated as follows.</p> $ERI = \frac{\sum_{i=1}^k N_i}{\bar{T}} = \frac{N_g}{\bar{T}}$ <p>Where, N_g is the total number of germinated seeds at the end of the test, N_i is the number of seeds germinated in the ith time interval (not the accumulated number, but the number corresponding to the ith interval), and \bar{T} is the mean germination time or mean emergence time.</p>	count time ⁻¹	Mixed	Bilbro and Wanjura (1982)
Emergence Rate Index (ERI) or Germination Rate Index (Fakorede)	EmergenceRateIndex	<p>It is estimated as follows.</p> $ERI = \frac{\bar{T}}{FGP/100}$ <p>Where, \bar{T} is the Mean germination time and FGP is the final germination time.</p>	time count ⁻¹	Mixed	Fakorede and Ayoola (1980); Fakorede and Ojo (1981); Fakorede and Agbana (1983)
Peak value(PV) (Czabator) or Emergence Energy (EE)	PeakValue	<p>It is the accumulated number of seeds germinated at the point on the germination curve at which the rate of germination starts to decrease. It is computed as the maximum quotient obtained by dividing successive cumulative germination values by the relevant incubation time.</p> $PV = \max\left(\frac{G_1}{T_1}, \frac{G_2}{T_2}, \dots, \frac{G_k}{T_k}\right)$ <p>Where, T_i is the time from the start of the experiment to the ith interval, G_i is the cumulative germination percentage in the ith time interval, and k is the total number of time intervals.</p>	% time ⁻¹	Mixed	Czabator (1962); Bonner (1967)

Germination index	Function	Details	Unit	Measures	Reference
Germination value (<i>GV</i>) (Czabator)	GermValue	<p>It is computed as follows.</p> $GV = PV \times MDG$ <p>Where, <i>PV</i> is the peak value and <i>MDG</i> is the mean daily germination percentage from the onset of germination. It can also be computed for other time intervals of successive germination counts, by replacing <i>MDG</i> with the mean germination percentage per unit time (\overline{GP}). <i>GV</i> value can be modified (GV_{mod}), to consider the entire duration from the beginning of the test instead of just from the onset of germination.</p>	% ² time ⁻²	Mixed	Czabator (1962); Brown and Mayer (1988)
Germination value (<i>GV</i>) (Djavanshir and Pourbiek)	GermValue	<p>It is computed as follows.</p> $GV = \frac{\sum DGS}{N} \times GP \times c$ <p>Where, <i>DGS</i> is the daily germination speed computed by dividing cumulative germination percentage by the number of days since the onset of germination, <i>N</i> is the frequency or number of DGS calculated during the test, <i>GP</i> is the germination percentage expressed over 100, and <i>c</i> is a constant. The value of <i>c</i> is decided on the basis of average daily speed of germination ($\frac{\sum DGS}{N}$). If it is less than 10, then <i>c</i> value of 10 can be used and if it is more than 10, then value of 7 or 8 can be used for <i>c</i>. <i>GV</i> value can be modified (GV_{mod}), to consider the entire duration from the beginning of the test instead of just from the onset of germination.</p>	% ² time ⁻¹	Mixed	Djavanshir and Pourbeik (1976); Brown and Mayer (1988)
Coefficient of uniformity of germination (<i>CUG</i>)	CUGerm	<p>It is computed as follows.</p> $CUG = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k (\overline{T} - T_i)^2 N_i}$ <p>Where, \overline{T} is the mean germination time, T_i is the time from the start of the experiment to the <i>i</i>th interval (day for the example), N_i is the number of seeds germinated in the <i>i</i>th time interval (not the accumulated number, but the number corresponding to the <i>i</i>th interval), and <i>k</i> is the total number of time intervals.</p>	time ⁻²	Germination uniformity	Heydecker (1972); Bewley and Black (1994)
Coefficient of variation of the germination time (CV_T)	CVGermTime	<p>It is estimated as follows.</p> $CV_T = \sqrt{\frac{s_T^2}{\overline{T}}}$ <p>Where, s_T^2 is the variance of germination time and \overline{T} is the mean germination time.</p>	no unit	Germination uniformity	Gomes (1960); Ranal and Santana (2006)

Germination index	Function	Details	Unit	Measures	Reference
Synchronization index (\bar{E}) or Uncertainty of the germination process (U) or informational entropy (H)	GermUncertainty	<p>It is estimated as follows.</p> $\bar{E} = - \sum_{i=1}^k f_i \log_2 f_i$ <p>Where, f_i is the relative frequency of germination ($f_i = \frac{N_i}{\sum_{i=1}^k N_i}$), N_i is the number of seeds germinated on the ith time interval, and k is the total number of time intervals.</p>	bit	Germination synchrony	Shannon (1948); Labouriau and Valadares (1976); Labouriau (1983b)
Synchrony of germination (Z index)	GermSynchrony	<p>It is computed as follows.</p> $Z = \frac{\sum_{i=1}^k C_{N_i,2}}{C_{\Sigma N_i,2}}$ <p>Where, $C_{N_i,2}$ is the partial combination of the two germinated seeds from among N_i, the number of seeds germinated on the ith time interval (estimated as $C_{N_i,2} = \frac{N_i(N_i-1)}{2}$), and $C_{\Sigma N_i,2}$ is the partial combination of the two germinated seeds from among the total number of seeds germinated at the final count, assuming that all seeds that germinated did so simultaneously.</p>	no unit	Germination synchrony	Primack (1985); Rana and Santana (2006)

Examples

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40)
z <- c(0, 0, 0, 0, 11, 11, 9, 7, 1, 0, 1, 0, 0, 0)
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----
```

```
GermPercent(germ.counts = x, total.seeds = 50)
```

```
GermPercent()
```

```
[1] 80
```

```
PeakGermPercent(germ.counts = x, intervals = int, total.seeds = 50)
```

```
[1] 34
```

```
# For multiple peak germination times
```

```
PeakGermPercent(germ.counts = z, intervals = int, total.seeds = 50)
```

```
Warning in PeakGermPercent(germ.counts = z, intervals = int, total.seeds = 50):
Multiple peak germination times exist.
```

```
[1] 22
```

```
# From cumulative germination counts
```

```
#-----
```

```
GermPercent(germ.counts = y, total.seeds = 50, partial = FALSE)
```

```
[1] 80
```

```
PeakGermPercent(germ.counts = y, intervals = int, total.seeds = 50,
                 partial = FALSE)
```

```
[1] 34
```

```
# For multiple peak germination times
```

```
PeakGermPercent(germ.counts = cumsum(z), intervals = int, total.seeds = 50,
                 partial = FALSE)
```

```
Warning in PeakGermPercent(germ.counts = cumsum(z), intervals = int,
total.seeds = 50, : Multiple peak germination times exist.
```

```
[1] 22
```

```
# From number of germinated seeds
```

```
#-----
```

```
GermPercent(germinated.seeds = 40, total.seeds = 50)
```

```
[1] 80
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40)
z <- c(0, 0, 0, 0, 11, 11, 9, 7, 1, 0, 1, 0, 0, 0)
int <- 1:length(x)
```

```

# From partial germination counts
#-----
FirstGermTime(germ.counts = x, intervals = int)

FirstGermTime(), LastGermTime(), PeakGermTime(), TimeSpreadGerm()

[1] 5
LastGermTime(germ.counts = x, intervals = int)

[1] 11
TimeSpreadGerm(germ.counts = x, intervals = int)

[1] 6
PeakGermTime(germ.counts = x, intervals = int)

[1] 6
# For multiple peak germination times
PeakGermTime(germ.counts = z, intervals = int)

Warning in PeakGermTime(germ.counts = z, intervals = int): Multiple peak
germination times exist.

[1] 5 6
# From cumulative germination counts
#-----
FirstGermTime(germ.counts = y, intervals = int, partial = FALSE)

[1] 5
LastGermTime(germ.counts = y, intervals = int, partial = FALSE)

[1] 11
TimeSpreadGerm(germ.counts = y, intervals = int, partial = FALSE)

[1] 6
PeakGermTime(germ.counts = y, intervals = int, partial = FALSE)

[1] 6
# For multiple peak germination time
PeakGermTime(germ.counts = cumsum(z), intervals = int, partial = FALSE)

Warning in PeakGermTime(germ.counts = cumsum(z), intervals = int, partial =
FALSE): Multiple peak germination times exist.

[1] 5 6

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-----
t50(germ.counts = x, intervals = int, method = "coolbear")

```



```
t50()
```

```
[1] 5.970588
```

```
t50(germ.counts = x, intervals = int, method = "farooq")
```

```
[1] 5.941176
```

```
# From cumulative germination counts
```

```
#-----  
t50(germ.counts = y, intervals = int, partial = FALSE, method = "coolbear")
```

```
[1] 5.970588
```

```
t50(germ.counts = y, intervals = int, partial = FALSE, method = "farooq")
```

```
[1] 5.941176
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)  
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)  
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----  
MeanGermTime(germ.counts = x, intervals = int)
```

```
MeanGermTime(), VarGermTime(), SEGermTime(), CVGermTime()
```

```
[1] 6.7
```

```
VarGermTime(germ.counts = x, intervals = int)
```

```
[1] 1.446154
```

```
SEGermTime(germ.counts = x, intervals = int)
```

```
[1] 0.1901416
```

```
CVGermTime(germ.counts = x, intervals = int)
```

```
[1] 0.1794868
```

```
# From cumulative germination counts
```

```
#-----  
MeanGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6.7
```

```
VarGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 1.446154
```

```
SEGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.1901416
```

```
CVGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.1794868
```

```

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-----
MeanGermRate(germ.counts = x, intervals = int)

MeanGermRate(), CVG(), VarGermRate(), SEGermRate(), GermRateRecip()

[1] 0.1492537
CVG(germ.counts = x, intervals = int)

[1] 14.92537
VarGermRate(germ.counts = x, intervals = int)

[1] 0.0007176543
SEGermRate(germ.counts = x, intervals = int)

[1] 0.004235724
GermRateRecip(germ.counts = x, intervals = int, method = "coolbear")

[1] 0.1674877
GermRateRecip(germ.counts = x, intervals = int, method = "farooq")

[1] 0.1683168
# From cumulative germination counts
#-----
MeanGermRate(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.1492537
CVG(germ.counts = y, intervals = int, partial = FALSE)

[1] 14.92537
VarGermRate(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.0007176543
SEGermRate(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.004235724
GermRateRecip(germ.counts = y, intervals = int,
               method = "coolbear", partial = FALSE)

[1] 0.1674877
GermRateRecip(germ.counts = y, intervals = int,
               method = "farooq", partial = FALSE)

[1] 0.1683168

```

```

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-----
GermSpeed(germ.counts = x, intervals = int)

GermSpeed(), GermSpeedAccumulated(), GermSpeedCorrected()

[1] 6.138925

GermSpeedAccumulated(germ.counts = x, intervals = int)

[1] 34.61567

GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                    method = "normal")

[1] 0.1534731

GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                    method = "accumulated")

[1] 0.8653917

# From partial germination counts (with percentages instead of counts)
#-----
GermSpeed(germ.counts = x, intervals = int,
           percent = TRUE, total.seeds = 50)

[1] 12.27785

GermSpeedAccumulated(germ.counts = x, intervals = int,
                     percent = TRUE, total.seeds = 50)

[1] 69.23134

# From cumulative germination counts
#-----
GermSpeed(germ.counts = y, intervals = int, partial = FALSE)

[1] 6.138925

GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE)

[1] 34.61567

GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "normal")

[1] 0.1534731

GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "accumulated")

[1] 0.8653917

# From cumulative germination counts (with percentages instead of counts)
#-----

```

```
GermSpeed(germ.counts = y, intervals = int, partial = FALSE,
           percent = TRUE, total.seeds = 50)
```

```
[1] 12.27785
```

```
GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE,
                      percent = TRUE, total.seeds = 50)
```

```
[1] 69.23134
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----
```

```
WeightGermPercent(germ.counts = x, total.seeds = 50, intervals = int)
```

```
WeightGermPercent()
```

```
[1] 47.42857
```

```
# From cumulative germination counts
```

```
#-----
```

```
WeightGermPercent(germ.counts = y, total.seeds = 50, intervals = int,
                  partial = FALSE)
```

```
[1] 47.42857
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----
```

```
MeanGermPercent(germ.counts = x, total.seeds = 50, intervals = int)
```

```
MeanGermPercent(), MeanGermNumber()
```

```
[1] 5.714286
```

```
MeanGermNumber(germ.counts = x, intervals = int)
```

```
[1] 2.857143
```

```
# From cumulative germination counts
```

```
#-----
```

```
MeanGermPercent(germ.counts = y, total.seeds = 50, intervals = int, partial = FALSE)
```

```
[1] 5.714286
```

```
MeanGermNumber(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 2.857143
```

```
# From number of germinated seeds
#-----
MeanGermPercent(germinated.seeds = 40, total.seeds = 50, intervals = int)
```

```
[1] 5.714286
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
```

```
# From partial germination counts
#-----
# Without max specified
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50)
```

```
TimsonsIndex(), GermRateGeorge()
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              modification = "none")
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              modification = "labouriau")
```

```
[1] 8.3
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              modification = "khanungar")
```

```
[1] 47.42857
```

```
GermRateGeorge(germ.counts = x, intervals = int)
```

```
[1] 332
```

```
# With max specified
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50, max = 10)
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              max = 10, modification = "none")
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              max = 10, modification = "labouriau")
```

```
[1] 4.410256
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
              max = 10, modification = "khanungar")
```

```
[1] 24.57143
```

```
GermRateGeorge(germ.counts = x, intervals = int, max = 10)
```

```
[1] 172
```

```
GermRateGeorge(germ.counts = x, intervals = int, max = 14)
```

```
[1] 332
```

```
# From cumulative germination counts
```

```
#-----
```

```
# Without max specified
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50)
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              modification = "none")
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              modification = "labouriau")
```

```
[1] 8.3
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              modification = "khanungar")
```

```
[1] 47.42857
```

```
GermRateGeorge(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 332
```

```
# With max specified
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50, max = 10)
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              max = 10, modification = "none")
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              max = 10, modification = "labouriau")
```

```
[1] 4.410256
```

```
TimsonsIndex(germ.counts = y, intervals = int, partial = FALSE,  
              total.seeds = 50,  
              max = 10, modification = "khanungar")
```

```
[1] 24.57143
```

```
GermRateGeorge(germ.counts = y, intervals = int, partial = FALSE,  
              max = 10)
```

```
[1] 172
```

```
GermRateGeorge(germ.counts = y, intervals = int, partial = FALSE,
               max = 14)
```

```
[1] 332
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----
GermIndex(germ.counts = x, intervals = int, total.seeds = 50)
```

```
GermIndex()
```

```
[1] 5.84
```

```
GermIndex(germ.counts = x, intervals = int, total.seeds = 50,
          modification = "none")
```

```
[1] 5.84
```

```
GermIndex(germ.counts = x, intervals = int, total.seeds = 50,
          modification = "santanaranal")
```

```
[1] 7.3
```

```
# From cumulative germination counts
```

```
#-----
GermIndex(germ.counts = y, intervals = int, partial = FALSE,
          total.seeds = 50)
```

```
[1] 5.84
```

```
GermIndex(germ.counts = y, intervals = int, partial = FALSE,
          total.seeds = 50,
          modification = "none")
```

```
[1] 5.84
```

```
GermIndex(germ.counts = y, intervals = int, partial = FALSE,
          total.seeds = 50,
          modification = "santanaranal")
```

```
[1] 7.3
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
```

```
# From partial germination counts
```

```
#-----
EmergenceRateIndex(germ.counts = x, intervals = int, total.seeds = 50)
```

```
EmergenceRateIndex()
```

[1] 292

```
EmergenceRateIndex(germ.counts = x, intervals = int, total.seeds = 50,
  method = "shmueligoldberg")
```

[1] 292

```
EmergenceRateIndex(germ.counts = x, intervals = int, total.seeds = 50,
  method = "sgsantanaranal")
```

[1] 7.3

```
EmergenceRateIndex(germ.counts = x, intervals = int, total.seeds = 50,
  method = "bilbrowanjura")
```

[1] 5.970149

```
EmergenceRateIndex(germ.counts = x, intervals = int, total.seeds = 50,
  method = "fakorede")
```

[1] 8.375

```
# From cumulative germination counts
#-----
EmergenceRateIndex(germ.counts = y, intervals = int, total.seeds = 50,
  partial = FALSE)
```

[1] 292

```
EmergenceRateIndex(germ.counts = y, intervals = int, total.seeds = 50,
  partial = FALSE,
  method = "shmueligoldberg")
```

[1] 292

```
EmergenceRateIndex(germ.counts = y, intervals = int, total.seeds = 50,
  partial = FALSE,
  method = "sgsantanaranal")
```

[1] 7.3

```
EmergenceRateIndex(germ.counts = y, intervals = int, total.seeds = 50,
  partial = FALSE,
  method = "bilbrowanjura")
```

[1] 5.970149

```
EmergenceRateIndex(germ.counts = y, intervals = int, total.seeds = 50,
  partial = FALSE,
  method = "fakorede")
```

[1] 8.375

```
x <- c(0, 0, 34, 40, 21, 10, 4, 5, 3, 5, 8, 7, 7, 6, 6, 4, 0, 2, 0, 2)
y <- c(0, 0, 34, 74, 95, 105, 109, 114, 117, 122, 130, 137, 144, 150,
  156, 160, 160, 162, 162, 164)
int <- 1:length(x)
total.seeds = 200
```

```
# From partial germination counts
```



```
#-----
PeakValue(germ.counts = x, intervals = int, total.seeds = 200)
```

```
PeakValue(), GermValue()
```

```
[1] 9.5
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
           method = "czabator")
```

```
$`Germination Value`
```

```
[1] 38.95
```

```
[[2]]
```

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

```
DGS
```

```
3 5.666667
4 9.250000
5 9.500000
6 8.750000
7 7.785714
8 7.125000
9 6.500000
10 6.100000
11 5.909091
12 5.708333
13 5.538462
14 5.357143
15 5.200000
16 5.000000
17 4.705882
18 4.500000
19 4.263158
20 4.100000
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
           method = "dp", k = 10)
```

```
$`Germination Value`
```

```
[1] 53.36595
```

```
[[2]]
```

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

	DGS	SumDGSbyN	GV
3	5.666667	5.666667	9.633333
4	9.250000	7.458333	27.595833
5	9.500000	8.138889	38.659722
6	8.750000	8.291667	43.531250
7	7.785714	8.190476	44.638095
8	7.125000	8.012897	45.673512
9	6.500000	7.796769	45.611097
10	6.100000	7.584673	46.266503
11	5.909091	7.398497	48.090230
12	5.708333	7.229481	49.521942
13	5.538462	7.075752	50.945411
14	5.357143	6.932534	51.994006
15	5.200000	6.799262	53.034246
16	5.000000	6.670744	53.365948
17	4.705882	6.539753	52.318022
18	4.500000	6.412268	51.939373
19	4.263158	6.285850	50.915385
20	4.100000	6.164414	50.548194

```
$testend
```

```
[1] 16
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
           method = "czabator", from.onset = FALSE)
```

```
$`Germination Value`
```

```
[1] 38.95
```

```
[[2]]
```

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
1	0	1	0	0.0

2	0	2	0	0.0
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

DGS

1	0.000000
2	0.000000
3	5.666667
4	9.250000
5	9.500000
6	8.750000
7	7.785714
8	7.125000
9	6.500000
10	6.100000
11	5.909091
12	5.708333
13	5.538462
14	5.357143
15	5.200000
16	5.000000
17	4.705882
18	4.500000
19	4.263158
20	4.100000

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
           method = "dp", k = 10, from.onset = FALSE)
```

```
$`Germination Value`
[1] 46.6952
```

```
[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
1           0          1                   0                0.0
2           0          2                   0                0.0
3          34          3                   34               17.0
4          40          4                   74               37.0
5          21          5                   95               47.5
6          10          6                  105               52.5
```

7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

	DGS	SumDGSbyN	GV
1	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000
3	5.666667	1.888889	3.211111
4	9.250000	3.729167	13.797917
5	9.500000	4.883333	23.195833
6	8.750000	5.527778	29.020833
7	7.785714	5.850340	31.884354
8	7.125000	6.009673	34.255134
9	6.500000	6.064153	35.475298
10	6.100000	6.067738	37.013202
11	5.909091	6.053316	39.346552
12	5.708333	6.024567	41.268285
13	5.538462	5.987174	43.107655
14	5.357143	5.942172	44.566291
15	5.200000	5.892694	45.963013
16	5.000000	5.836901	46.695205
17	4.705882	5.770370	46.162961
18	4.500000	5.699794	46.168331
19	4.263158	5.624182	45.555871
20	4.100000	5.547972	45.493374

```
$testend
```

```
[1] 16
```

```
# From cumulative germination counts
```

```
#-----
```

```
PeakValue(germ.counts = y, interval = int, total.seeds = 200,
           partial = FALSE)
```

```
[1] 9.5
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
           partial = FALSE, method = "czabator")
```

```
$`Germination Value`
```

```
[1] 38.95
```

```
[[2]]
```

```
  germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
3           34         3                   34                   17.0
```

4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

DGS

3	5.666667
4	9.250000
5	9.500000
6	8.750000
7	7.785714
8	7.125000
9	6.500000
10	6.100000
11	5.909091
12	5.708333
13	5.538462
14	5.357143
15	5.200000
16	5.000000
17	4.705882
18	4.500000
19	4.263158
20	4.100000

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
           partial = FALSE, method = "dp", k = 10)
```

```
$`Germination Value`
```

```
[1] 53.36595
```

```
[[2]]
```

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5

13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

	DGS	SumDGSbyN	GV
3	5.666667	5.666667	9.633333
4	9.250000	7.458333	27.595833
5	9.500000	8.138889	38.659722
6	8.750000	8.291667	43.531250
7	7.785714	8.190476	44.638095
8	7.125000	8.012897	45.673512
9	6.500000	7.796769	45.611097
10	6.100000	7.584673	46.266503
11	5.909091	7.398497	48.090230
12	5.708333	7.229481	49.521942
13	5.538462	7.075752	50.945411
14	5.357143	6.932534	51.994006
15	5.200000	6.799262	53.034246
16	5.000000	6.670744	53.365948
17	4.705882	6.539753	52.318022
18	4.500000	6.412268	51.939373
19	4.263158	6.285850	50.915385
20	4.100000	6.164414	50.548194

```
$testend
```

```
[1] 16
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
           partial = FALSE, method = "czabator", from.onset = FALSE)
```

```
$`Germination Value`
```

```
[1] 38.95
```

```
[[2]]
```

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
1	0	1	0	0.0
2	0	2	0	0.0
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0

17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

DGS

1	0.000000
2	0.000000
3	5.666667
4	9.250000
5	9.500000
6	8.750000
7	7.785714
8	7.125000
9	6.500000
10	6.100000
11	5.909091
12	5.708333
13	5.538462
14	5.357143
15	5.200000
16	5.000000
17	4.705882
18	4.500000
19	4.263158
20	4.100000

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
           partial = FALSE, method = "dp", k = 10, from.onset = FALSE)
```

\$`Germination Value`

[1] 46.6952

[[2]]

	germ.counts	intervals	Cumulative.germ.counts	Cumulative.germ.percent
1	0	1	0	0.0
2	0	2	0	0.0
3	34	3	34	17.0
4	40	4	74	37.0
5	21	5	95	47.5
6	10	6	105	52.5
7	4	7	109	54.5
8	5	8	114	57.0
9	3	9	117	58.5
10	5	10	122	61.0
11	8	11	130	65.0
12	7	12	137	68.5
13	7	13	144	72.0
14	6	14	150	75.0
15	6	15	156	78.0
16	4	16	160	80.0
17	0	17	160	80.0
18	2	18	162	81.0
19	0	19	162	81.0
20	2	20	164	82.0

DGS SumDGSbyN GV

```

1  0.000000  0.000000  0.000000
2  0.000000  0.000000  0.000000
3  5.666667  1.888889  3.211111
4  9.250000  3.729167 13.797917
5  9.500000  4.883333 23.195833
6  8.750000  5.527778 29.020833
7  7.785714  5.850340 31.884354
8  7.125000  6.009673 34.255134
9  6.500000  6.064153 35.475298
10 6.100000  6.067738 37.013202
11 5.909091  6.053316 39.346552
12 5.708333  6.024567 41.268285
13 5.538462  5.987174 43.107655
14 5.357143  5.942172 44.566291
15 5.200000  5.892694 45.963013
16 5.000000  5.836901 46.695205
17 4.705882  5.770370 46.162961
18 4.500000  5.699794 46.168331
19 4.263158  5.624182 45.555871
20 4.100000  5.547972 45.493374

```

```
$testend
```

```
[1] 16
```

```

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

```

```
# From partial germination counts
```

```
#-----
CUGerm(germ.counts = x, intervals = int)
```

```
CUGerm()
```

```
[1] 0.7092199
```

```
# From cumulative germination counts
```

```
#-----
CUGerm(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.7092199
```

```

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

```

```
# From partial germination counts
```

```
#-----
GermSynchrony(germ.counts = x, intervals = int)
```

```
GermSynchrony(), GermUncertainty()
```

```
[1] 0.2666667
```



```
GermUncertainty(germ.counts = x, intervals = int)
```

```
[1] 2.062987
```

```
# From cumulative germination counts
```

```
#-----
```

```
GermSynchrony(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.2666667
```

```
GermUncertainty(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 2.062987
```

Non-linear regression analysis

Several mathematical functions have been used to fit the cumulative germination count data and describe the germination process by non-linear regression analysis. They include functions such as Richard's, Weibull, logistic, log-logistic, gaussian, four-parameter hill function etc. Currently `germinationmetrics` implements the four-parameter hill function to fit the count data and computed various associated metrics.

Four-parameter hill function

The four-parameter hill function defined as follows (El-Kassaby et al., 2008).

$$f(x) = y = y_0 + \frac{ax^b}{x^b + c^b}$$

Where, y is the cumulative germination percentage at time x , y_0 is the intercept on the y axis, a is the asymptote, b is a mathematical parameter controlling the shape and steepness of the germination curve and c is the “half-maximal activation level”.

this function can also be reparameterized by substituting b with e^β to constraint b to positive values only.

$$y = y_0 + \frac{ax^{e^\beta}}{c^{e^\beta} + x^{e^\beta}}$$

Where, $b = e^\beta$ and $\beta = \log_e(b)$.

The details of various parameters that are computed from this function are given in Table 4.

Table 4 Germination parameters estimated from the four-parameter hill function.

Germination parameters	Details	Unit	Measures
y intercept (y_0)	The intercept on the y axis.		
Asymptote (a)	It is the maximum cumulative germination percentage, which is equivalent to germination capacity.	%	Germination capacity
Shape and steepness (b)	Mathematical parameter controlling the shape and steepness of the germination curve. The larger the b , the steeper the rise toward the asymptote a , and the shorter the time between germination onset and maximum germination.		Germination rate
Half-maximal activation level (c)	Time required for 50% of viable seeds to germinate.	time	Germination time

Germination parameters	Details	Unit	Measures
<i>lag</i>	It is the time at germination onset and is computed by solving four-parameter hill function after setting y to 0 as follows. $lag = b\sqrt{\frac{-y_0c^b}{a+y_0}}$	time	Germination time
D_{lag-50}	The duration between the time at germination onset (<i>lag</i>) and that at 50% germination (c).	time	Germination time
$t_{50_{total}}$	Time required for 50% of total seeds to germinate.	time	Germination time
$t_{50_{germinated}}$	Time required for 50% of viable/germinated seeds to germinate	time	Germination time
$t_{x_{total}}$	Time required for $x\%$ of total seeds to germinate.	time	Germination time
$t_{x_{germinated}}$	Time required for $x\%$ of viable/germinated seeds to germinate	time	Germination time
Uniformity ($U_{t_{max}-t_{min}}$)	It is the time interval between the percentages of viable seeds specified in the arguments umin and umin to germinate.	time	Germination time
Time at maximum germination rate (<i>TMGR</i>)	The partial derivative of the four-parameter hill function gives the instantaneous rate of germination (s) as follows. $s = \frac{\partial y}{\partial x} = \frac{abc^b x^{b-1}}{(c^b + x^b)^2}$ From this function for instantaneous rate of germination, <i>TMGR</i> can be estimated as follows. $TMGR = b\sqrt{\frac{c^b(b-1)}{b+1}}$ It represents the point in time when the instantaneous rate of germination starts to decline.	time	Germination time
Area under the curve (<i>AUC</i>)	It is obtained by integration of the fitted curve between time 0 and time specified in the argument tmax .		Mixed
<i>MGT</i>	Calculated by integration of the fitted curve and proper normalisation.	time	Germination time
<i>Skewness</i>	It is computed as follows. $\frac{MGT}{t_{50_{germinated}}}$		

Examples

```

x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
total.seeds = 50

# From partial germination counts
#-----
FourPHFfit(germ.counts = x, intervals = int, total.seeds = 50, tmax = 20)

```

FourPHFfit()

```

$data
  gp csgp intervals
1  0    0         1
2  0    0         2
3  0    0         3
4  0    0         4
5  8    8         5
6 34   42         6
7 20   62         7
8 14   76         8
9  2   78         9
10 0   78        10
11 2   80        11
12 0   80        12
13 0   80        13
14 0   80        14

$Parameters
  term estimate std.error statistic    p.value
1  bta 2.290709 0.05602634  40.88628 2.965932e-14
2    c 6.034954 0.03872162 155.85488 3.270089e-21

$Fit
  sigma isConv    finTol   logLik    AIC    BIC deviance df.residual
1 1.61522  TRUE 7.105427e-14 -25.49868 56.99736 58.91453 31.30723         12
  nobs
1   14

$a
[1] 80

$b
[1] 9.881937

$c
[1] 6.034954

$y0
[1] 0

$lag
[1] 0

```

```

$Dlag50
[1] 6.034954

$t50.total
[1] 6.355121

$txp.total
      10      60
4.956264 6.744598

$t50.Germinated
[1] 6.034954

$txp.Germinated
      10      60
4.831807 6.287724

$Uniformity
      90      10 uniformity
7.537690 4.831807 2.705882

$TMGR
[1] 5.912194

$AUC
[1] 1108.976

$MGT
[1] 6.632252

$Skewness
[1] 1.098973

$msg
[1] "#1. success "

$isConv
[1] TRUE

$model
Nonlinear regression model
  model: csgp ~ FourPHF_fixa_fixy0(x = intervals, a = max(csgp), bta,      c)
  data: data
  bta      c
2.291 6.035
residual sum-of-squares: 31.31

Algorithm: multifit/levenberg-marquardt, (scaling: levenberg, solver: qr)

Number of iterations to convergence: 9
Achieved convergence tolerance: 7.105e-14

attr(,"class")

```

```
[1] "FourPHFfit" "list"
# From cumulative germination counts
#-----
FourPHFfit(germ.counts = y, intervals = int, total.seeds = 50, tmax = 20,
           partial = FALSE)

$data
  gp csgp intervals
1  0    0         1
2  0    0         2
3  0    0         3
4  0    0         4
5  8    8         5
6 34   42         6
7 20   62         7
8 14   76         8
9  2   78         9
10 0   78        10
11 2   80        11
12 0   80        12
13 0   80        13
14 0   80        14

$Parameters
  term estimate std.error statistic      p.value
1  bta 2.290709 0.05602634  40.88628 2.965932e-14
2    c 6.034954 0.03872162 155.85488 3.270089e-21

$Fit
  sigma isConv      finTol    logLik      AIC      BIC deviance df.residual
1 1.61522  TRUE 7.105427e-14 -25.49868 56.99736 58.91453 31.30723          12
  nobs
1   14

$a
[1] 80

$b
[1] 9.881937

$c
[1] 6.034954

$y0
[1] 0

$lag
[1] 0

$Dlag50
[1] 6.034954

$t50.total
[1] 6.355121
```

```

$txp.total
      10      60
4.956264 6.744598

$t50.Germinated
[1] 6.034954

$txp.Germinated
      10      60
4.831807 6.287724

$Uniformity
      90      10 uniformity
7.537690 4.831807 2.705882

$TMGR
[1] 5.912194

$AUC
[1] 1108.976

$MGT
[1] 6.632252

$Skewness
[1] 1.098973

$msg
[1] "#1. success "

$isConv
[1] TRUE

$model
Nonlinear regression model
  model: csgp ~ FourPHF_fixa_fixy0(x = intervals, a = max(csgp), bta,      c)
  data: data
  bta      c
2.291 6.035
residual sum-of-squares: 31.31

Algorithm: multifit/levenberg-marquardt, (scaling: levenberg, solver: qr)

Number of iterations to convergence: 9
Achieved convergence tolerance: 7.105e-14

attr("class")
[1] "FourPHFfit" "list"
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
total.seeds = 50

```

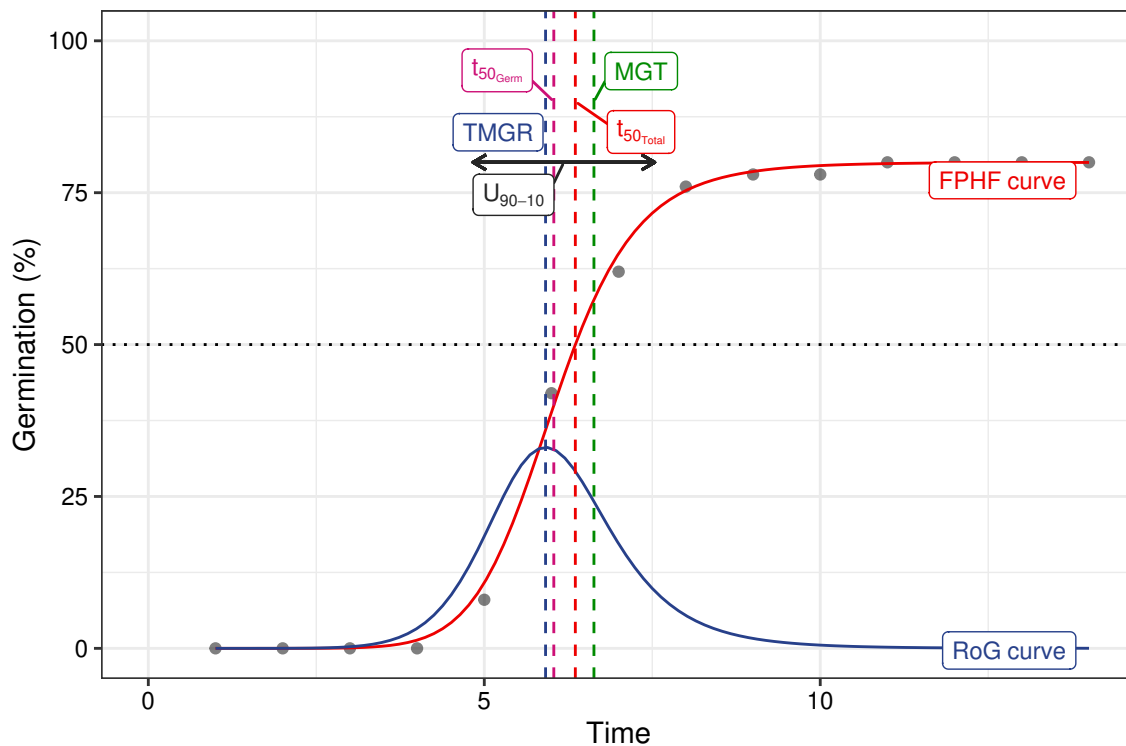
```
# From partial germination counts
#-----
fit1 <- FourPHFfit(germ.counts = x, intervals = int,
                  total.seeds = 50, tmax = 20)

# From cumulative germination counts
#-----
fit2 <- FourPHFfit(germ.counts = y, intervals = int,
                  total.seeds = 50, tmax = 20, partial = FALSE)

# Default plots
plot(fit1)
```

Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2))`, : All aesthetics have length 1, but the data has 14 rows.
i Please consider using ``annotate()`` or provide this layer with data containing a single row.

Warning in `geom_segment(aes(x = UfmMax, xend = UfmMin, y = ypos2, yend = ypos2))`, : All aesthetics have length 1, but the data has 14 rows.
i Please consider using ``annotate()`` or provide this layer with data containing a single row.

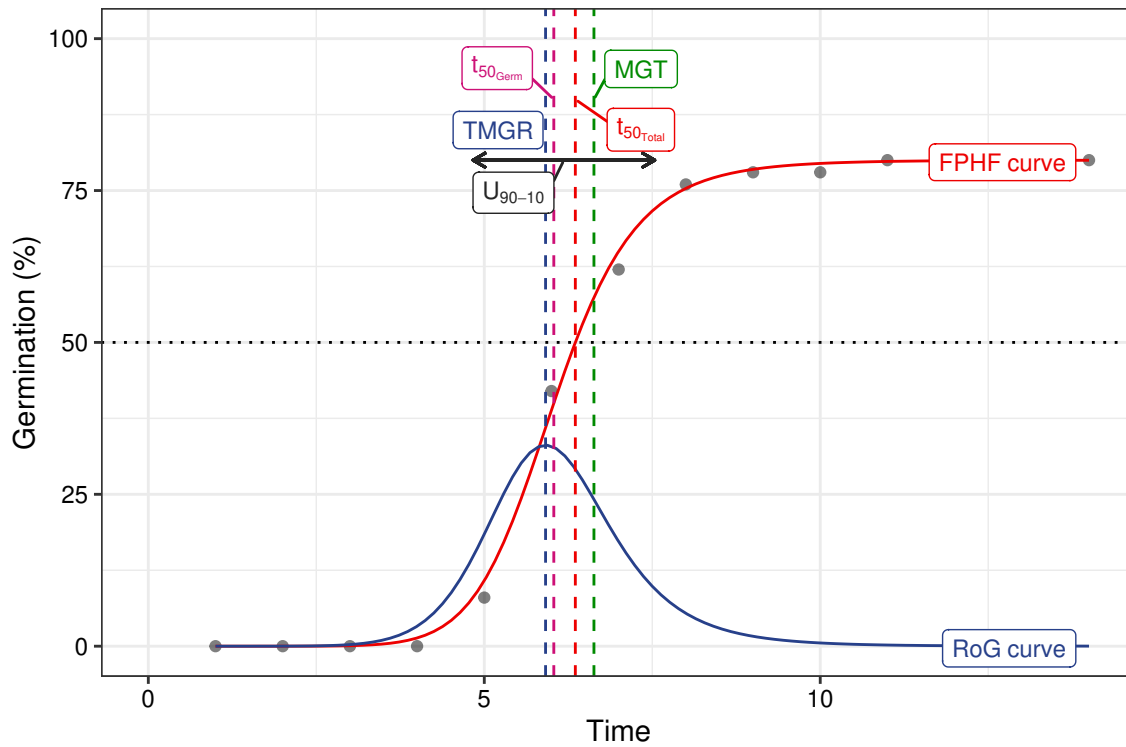


```
plot(fit2)
```

Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2))`, : All aesthetics have length 1, but the data has 14 rows.
i Please consider using ``annotate()`` or provide this layer with data containing a single row.

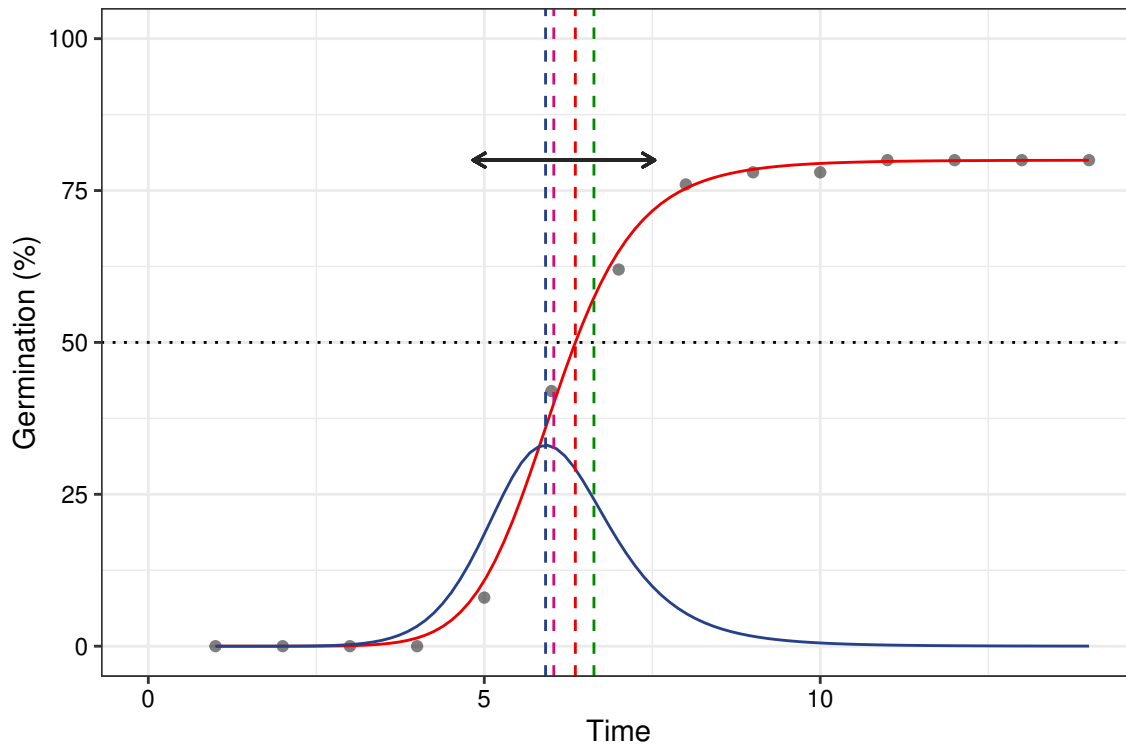
All aesthetics have length 1, but the data has 14 rows.

i Please consider using ``annotate()`` or provide this layer with data containing a single row.



```
# No labels
plot(fit1, plotlabels = FALSE)
```

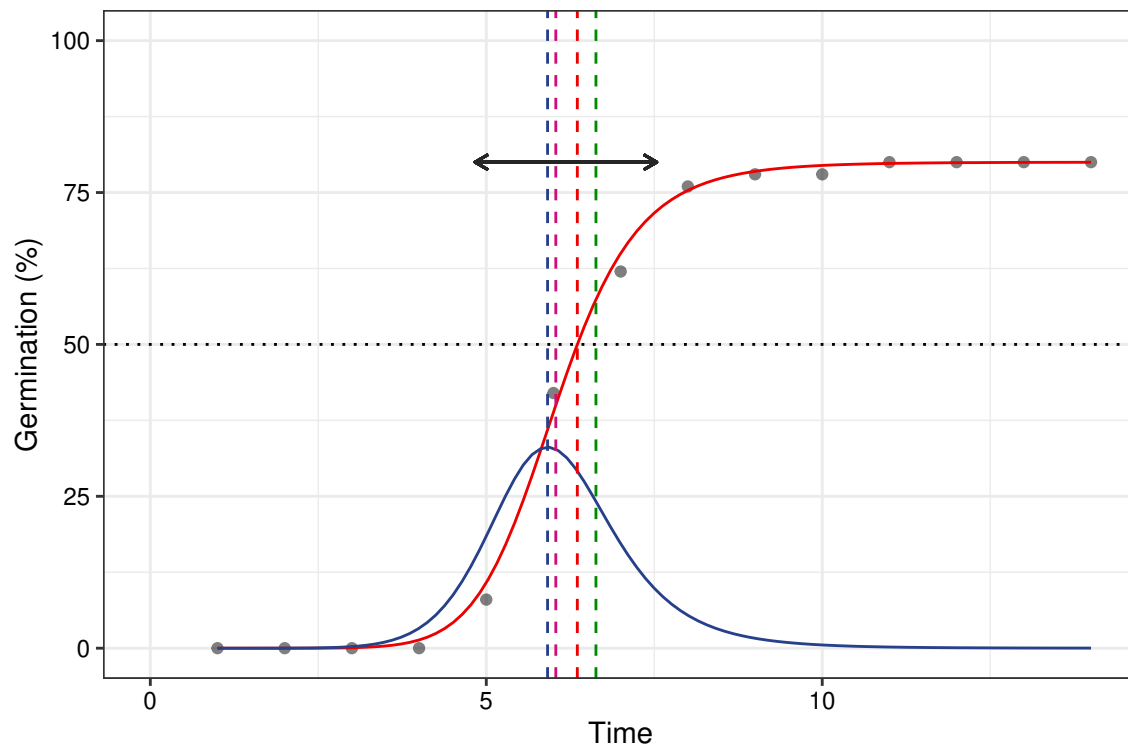
Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2), : All aesthetics have length 1, but the data has 14 rows.`
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.
 All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.



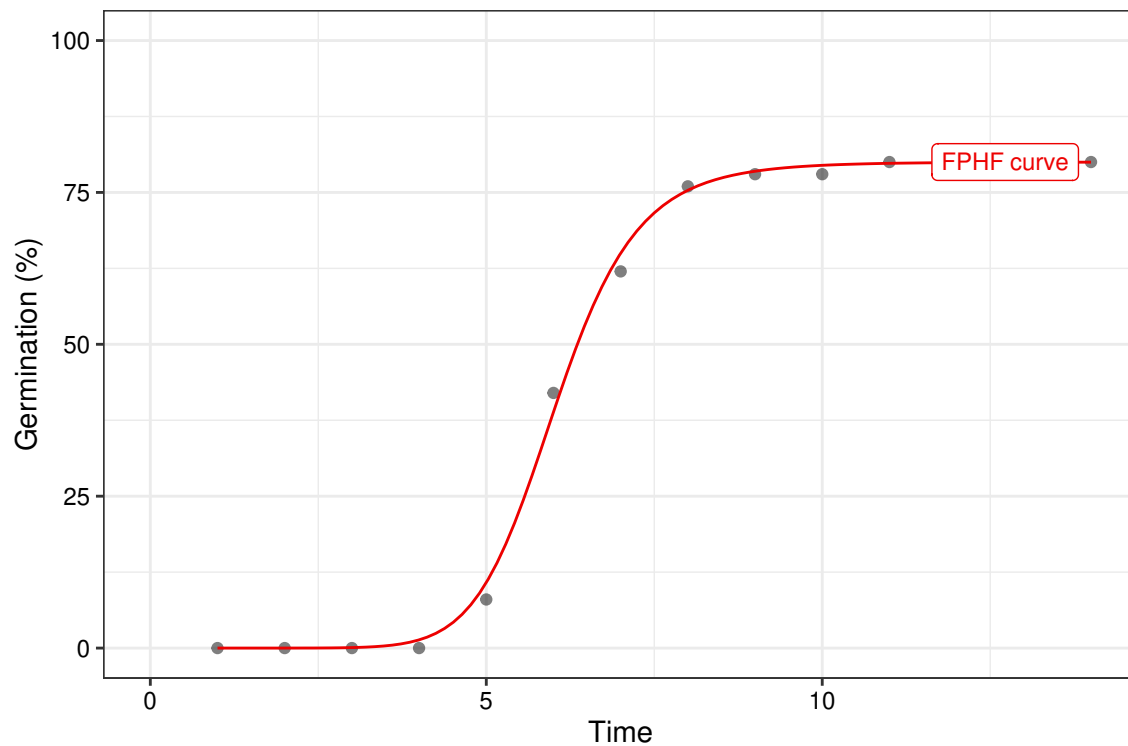
```
plot(fit2, plotlabels = FALSE)
```

Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2),` : All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.

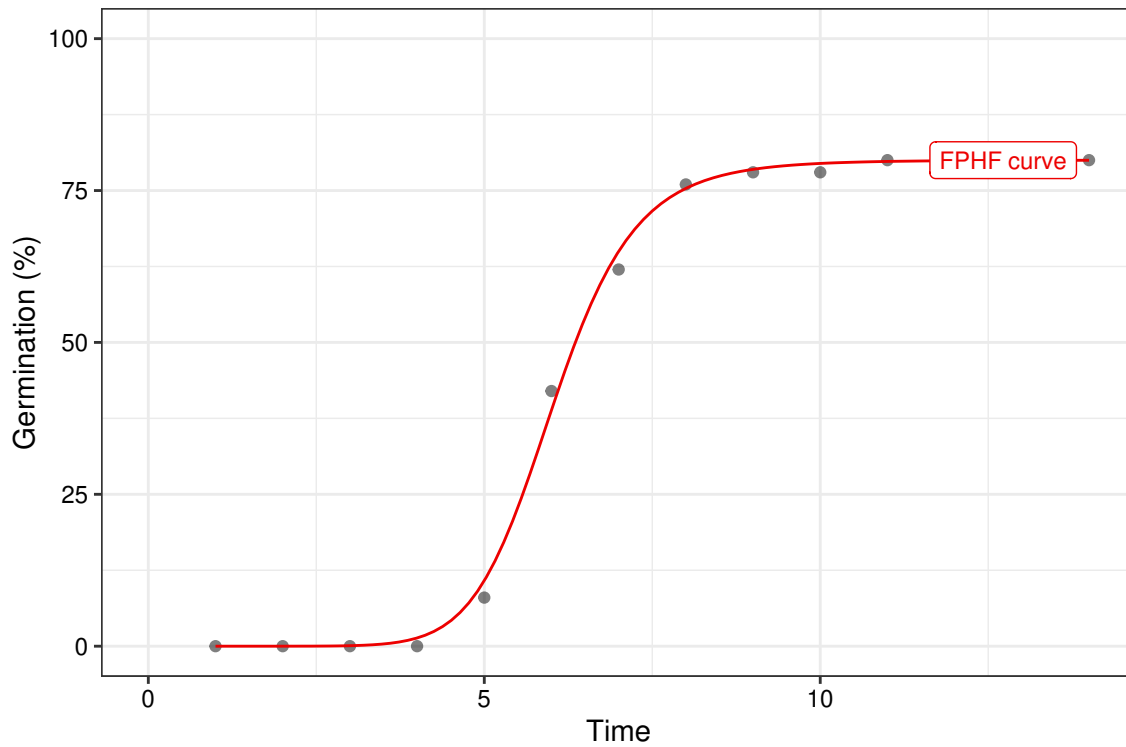
All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.



```
# Only the FPHF curve
plot(fit1, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```



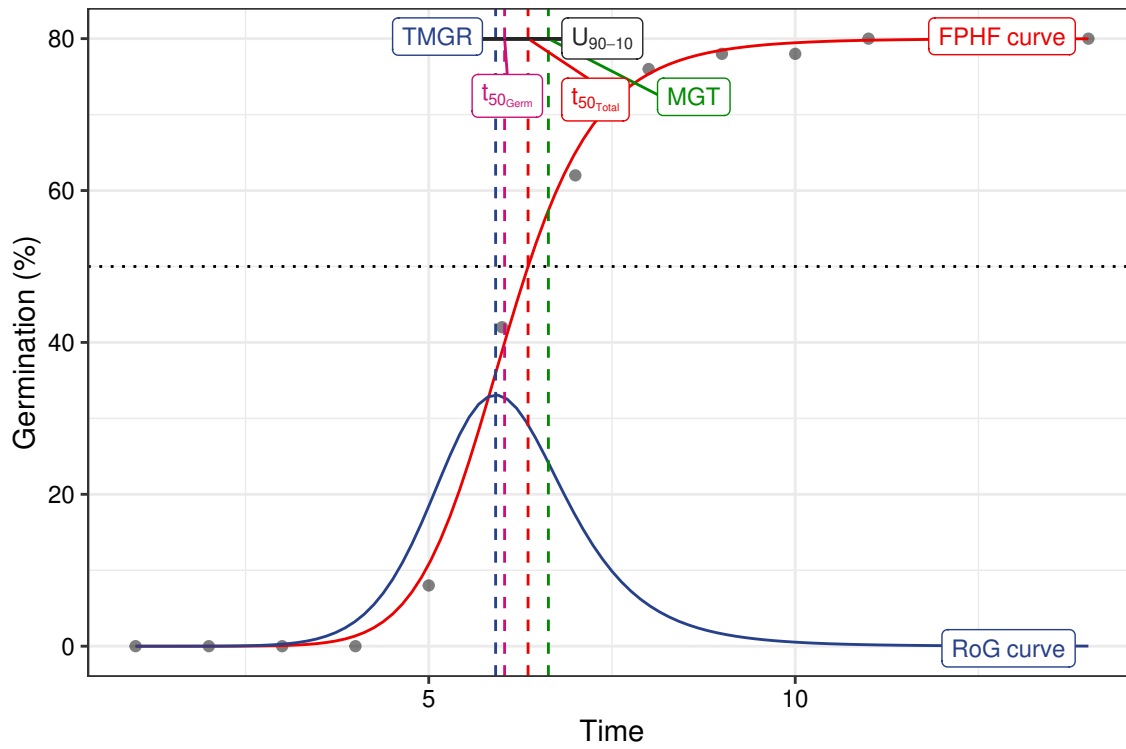
```
plot(fit2, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```



```
# Without y axis limits adjustment
plot(fit1, limits = FALSE)
```

Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2))`, : All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.

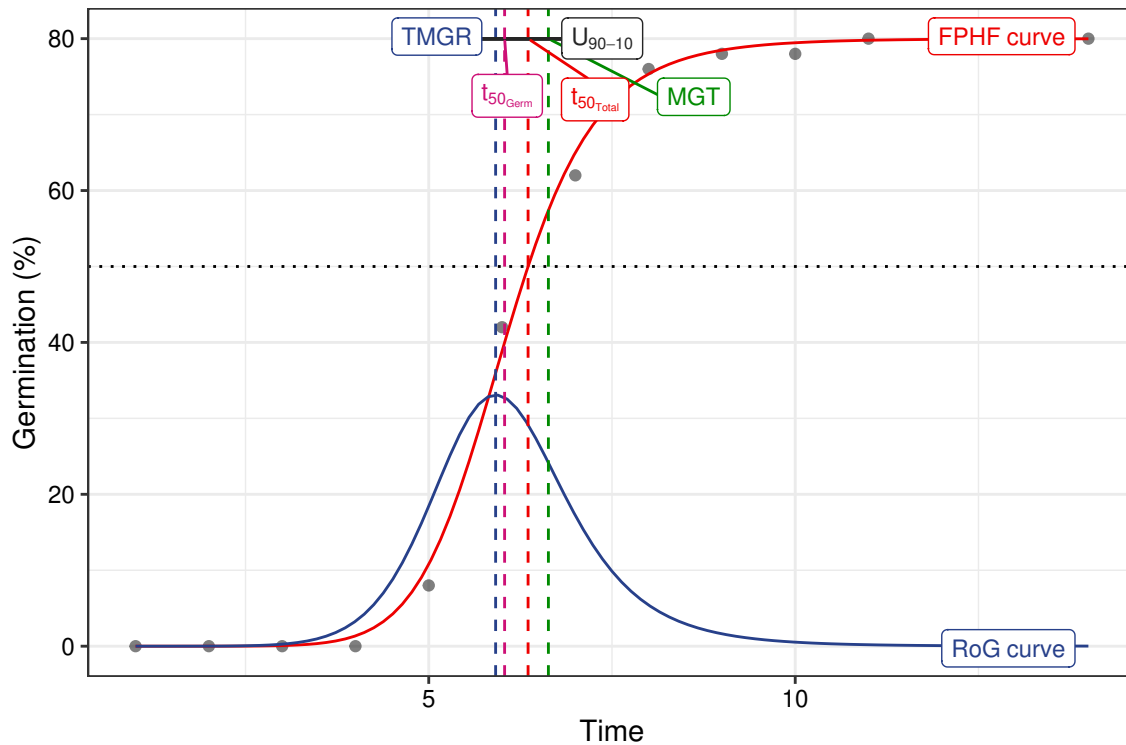
All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.



```
plot(fit2, limits = FALSE)
```

Warning in `geom_segment(aes(x = UfmMin, xend = UfmMax, y = ypos2, yend = ypos2))`: All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.

All aesthetics have length 1, but the data has 14 rows.
 i Please consider using ``annotate()`` or provide this layer with data containing a single row.



Wrapper functions

Wrapper functions `germination.indices()` and `FourPHFfit.bulk()` are available in the package for computing results for multiple samples in batch from a data frame of germination counts recorded at specific time intervals.

`germination.indices()` This wrapper function can be used to compute several germination indices simultaneously for multiple samples in batch.

```
data(gcdata)

counts.per.intervals <- c("Day01", "Day02", "Day03", "Day04", "Day05",
                          "Day06", "Day07", "Day08", "Day09", "Day10",
                          "Day11", "Day12", "Day13", "Day14")
germination.indices(gcdata, total.seeds.col = "Total Seeds",
                   counts.intervals.cols = counts.per.intervals,
                   intervals = 1:14, partial = TRUE, max.int = 5)
```

	Genotype	Rep	Day01	Day02	Day03	Day04	Day05	Day06	Day07	Day08	Day09	Day10
1	G1	1	0	0	0	0	4	17	10	7	1	0
2	G2	1	0	0	0	1	3	15	13	6	2	1
3	G3	1	0	0	0	2	3	18	9	8	2	1
4	G4	1	0	0	0	0	4	19	12	6	2	1
5	G5	1	0	0	0	0	5	20	12	8	1	0
6	G1	2	0	0	0	0	3	21	11	7	1	1
7	G2	2	0	0	0	0	4	18	11	7	1	0
8	G3	2	0	0	0	1	3	14	12	6	2	1
9	G4	2	0	0	0	1	3	19	10	8	1	1
10	G5	2	0	0	0	0	4	18	13	6	2	1
11	G1	3	0	0	0	0	5	21	11	8	1	0

12	G2	3	0	0	0	0	3	20	10	7	1	1
13	G3	3	0	0	0	0	4	19	12	8	1	1
14	G4	3	0	0	0	0	3	21	11	6	1	0
15	G5	3	0	0	0	0	4	17	10	8	1	1

	Day11	Day12	Day13	Day14	Total	Seeds	GermPercent	PeakGermPercent
1	1	0	0	0		50	80.00000	34.00000
2	0	1	0	0		51	82.35294	29.41176
3	1	1	0	0		48	93.75000	37.50000
4	1	1	0	0		51	90.19608	37.25490
5	0	1	1	0		50	96.00000	40.00000
6	1	1	0	0		49	93.87755	42.85714
7	1	0	0	0		48	87.50000	37.50000
8	0	1	0	0		47	85.10638	29.78723
9	1	1	0	0		52	86.53846	36.53846
10	0	1	0	0		50	90.00000	36.00000
11	0	1	1	0		51	94.11765	41.17647
12	1	1	0	0		51	86.27451	39.21569
13	0	1	1	0		49	95.91837	38.77551
14	1	1	0	0		48	91.66667	43.75000
15	1	0	0	0		48	87.50000	35.41667

	FirstGermTime	LastGermTime	PeakGermTime	TimeSpreadGerm	t50_Coolbear
1		5	11	6	5.970588
2		4	12	6	6.192308
3		4	12	6	6.333333
4		5	12	6	6.041667
5		5	13	6	5.975000
6		5	12	6	5.976190
7		5	11	6	5.972222
8		4	12	6	6.208333
9		4	12	6	6.310345
10		5	12	6	6.076923
11		5	13	6	5.928571
12		5	12	6	5.975000
13		5	13	6	6.083333
14		5	12	6	5.928571
15		5	11	6	6.050000

	t50_Farooq	MeanGermTime	VarGermTime	SEGermTime	CVGermTime	MeanGermRate
1	5.941176	6.700000	1.446154	0.1901416	0.1794868	0.1492537
2	6.153846	6.857143	2.027875	0.2197333	0.2076717	0.1458333
3	5.972222	6.866667	2.572727	0.2391061	0.2335882	0.1456311
4	6.225806	6.891304	2.187923	0.2180907	0.2146419	0.1451104
5	5.950000	6.812500	2.368351	0.2221275	0.2259002	0.1467890
6	5.952381	6.869565	2.071498	0.2122088	0.2095140	0.1455696
7	5.944444	6.690476	1.389663	0.1818989	0.1761967	0.1494662
8	6.166667	6.875000	2.112179	0.2297923	0.2113940	0.1454545
9	5.973684	6.866667	2.300000	0.2260777	0.2208604	0.1456311
10	6.038462	6.822222	1.831313	0.2017321	0.1983606	0.1465798
11	5.904762	6.791667	2.381206	0.2227295	0.2272072	0.1472393
12	5.950000	6.886364	2.149577	0.2210295	0.2129053	0.1452145
13	6.041667	6.936170	2.539315	0.2324392	0.2297410	0.1441718
14	5.904762	6.772727	1.900634	0.2078370	0.2035568	0.1476510
15	6.259259	6.809524	1.670151	0.1994129	0.1897847	0.1468531

	VarGermRate	SEGermRate	CVG	GermRateRecip	Coolbear
1	0.0007176543	0.004235724	14.92537		0.1674877

2	0.0009172090	0.004673148	14.58333	0.1614907
3	0.0011572039	0.005071059	14.56311	0.1578947
4	0.0009701218	0.004592342	14.51104	0.1655172
5	0.0010995627	0.004786184	14.67890	0.1673640
6	0.0009301809	0.004496813	14.55696	0.1673307
7	0.0006935558	0.004063648	14.94662	0.1674419
8	0.0009454531	0.004861721	14.54545	0.1610738
9	0.0010345321	0.004794747	14.56311	0.1584699
10	0.0008453940	0.004334343	14.65798	0.1645570
11	0.0011191581	0.004828643	14.72393	0.1686747
12	0.0009558577	0.004660905	14.52145	0.1673640
13	0.0010970785	0.004831366	14.41718	0.1643836
14	0.0009033254	0.004531018	14.76510	0.1686747
15	0.0007767634	0.004300508	14.68531	0.1652893

	GermRateRecip_Farooq	GermSpeed_Count	GermSpeed_Percent
1	0.1683168	6.138925	12.27785
2	0.1625000	6.362698	12.47588
3	0.1674419	6.882179	14.33787
4	0.1606218	6.927417	13.58317
5	0.1680672	7.318987	14.63797
6	0.1680000	6.931782	14.14649
7	0.1682243	6.448449	13.43427
8	0.1621622	6.053175	12.87909
9	0.1674009	6.830592	13.13575
10	0.1656051	6.812698	13.62540
11	0.1693548	7.342796	14.39764
12	0.1680672	6.622258	12.98482
13	0.1655172	7.052320	14.39249
14	0.1693548	6.706782	13.97246
15	0.1597633	6.363925	13.25818

	GermSpeedAccumulated_Count	GermSpeedAccumulated_Percent
1	34.61567	69.23134
2	35.54058	69.68741
3	38.29725	79.78594
4	38.68453	75.85202
5	41.00786	82.01571
6	38.77620	79.13509
7	36.38546	75.80304
8	33.77079	71.85275
9	38.11511	73.29829
10	38.19527	76.39054
11	41.17452	80.73436
12	37.00640	72.56158
13	39.29399	80.19182
14	37.69490	78.53103
15	35.69697	74.36868

	GermSpeedCorrected_Normal	GermSpeedCorrected_Accumulated	WeightGermPercent
1	0.1534731	0.8653917	47.42857
2	0.1514928	0.8462043	47.89916
3	0.1529373	0.8510501	54.46429
4	0.1505960	0.8409680	52.24090
5	0.1524789	0.8543303	56.14286
6	0.1506909	0.8429608	54.51895
7	0.1535345	0.8663205	51.93452

8	0.1513294	0.8442698	49.39210
9	0.1517909	0.8470024	50.27473
10	0.1513933	0.8487837	52.57143
11	0.1529749	0.8578026	55.18207
12	0.1505059	0.8410547	50.00000
13	0.1500494	0.8360424	55.24781
14	0.1524269	0.8567022	53.86905
15	0.1515220	0.8499278	51.19048

	MeanGermPercent	MeanGermNumber	TimsonsIndex	TimsonsIndex_Labouriau
1	5.714286	2.857143	8.000000	1.00
2	5.882353	3.000000	9.803922	1.25
3	6.696429	3.214286	14.583333	1.40
4	6.442577	3.285714	7.843137	1.00
5	6.857143	3.428571	10.000000	1.00
6	6.705539	3.285714	6.122449	1.00
7	6.250000	3.000000	8.333333	1.00
8	6.079027	2.857143	10.638298	1.25
9	6.181319	3.214286	9.615385	1.25
10	6.428571	3.214286	8.000000	1.00
11	6.722689	3.428571	9.803922	1.00
12	6.162465	3.142857	5.882353	1.00
13	6.851312	3.357143	8.163265	1.00
14	6.547619	3.142857	6.250000	1.00
15	6.250000	3.000000	8.333333	1.00

	TimsonsIndex_KhanUngar	GermRateGeorge	GermIndex	GermIndex_mod
1	0.5714286	4	5.840000	7.300000
2	0.7002801	5	5.882353	7.142857
3	1.0416667	7	6.687500	7.133333
4	0.5602241	4	6.411765	7.108696
5	0.7142857	5	6.900000	7.187500
6	0.4373178	3	6.693878	7.130435
7	0.5952381	4	6.395833	7.309524
8	0.7598784	5	6.063830	7.125000
9	0.6868132	5	6.173077	7.133333
10	0.5714286	4	6.460000	7.177778
11	0.7002801	5	6.784314	7.208333
12	0.4201681	3	6.137255	7.113636
13	0.5830904	4	6.775510	7.063830
14	0.4464286	3	6.625000	7.227273
15	0.5952381	4	6.291667	7.190476

	EmergenceRateIndex_SG	EmergenceRateIndex_SG_mod
1	292	7.300000
2	300	7.142857
3	321	7.133333
4	327	7.108696
5	345	7.187500
6	328	7.130435
7	307	7.309524
8	285	7.125000
9	321	7.133333
10	323	7.177778
11	346	7.208333
12	313	7.113636
13	332	7.063830

14	318	7.227273		
15	302	7.190476		
	EmergenceRateIndex_BilbroWanjura	EmergenceRateIndex_Fakorede	PeakValue	
1	5.970149	8.375000	9.500000	
2	6.125000	8.326531	9.313725	
3	6.553398	7.324444	10.416667	
4	6.675079	7.640359	10.049020	
5	7.045872	7.096354	11.250000	
6	6.696203	7.317580	10.714286	
7	6.277580	7.646259	10.416667	
8	5.818182	8.078125	9.574468	
9	6.553398	7.934815	9.855769	
10	6.596091	7.580247	10.250000	
11	7.067485	7.216146	11.029412	
12	6.389439	7.981921	9.803922	
13	6.776074	7.231326	10.969388	
14	6.496644	7.388430	10.677083	
15	6.167832	7.782313	10.156250	
	GermValue_Czabator	GermValue_DP	GermValue_Czabator_mod	GermValue_DP_mod
1	54.28571	57.93890	54.28571	39.56076
2	54.78662	52.58713	54.78662	40.99260
3	69.75446	68.62289	69.75446	53.42809
4	64.74158	70.43331	64.74158	48.86825
5	77.14286	80.16914	77.14286	56.23935
6	71.84506	76.51983	71.84506	53.06435
7	65.10417	69.41325	65.10417	47.37690
8	58.20345	56.00669	58.20345	43.67948
9	60.92165	58.13477	60.92165	45.30801
10	65.89286	70.91875	65.89286	49.10820
11	74.14731	77.39782	74.14731	54.27520
12	60.41632	64.44988	60.41632	44.71582
13	75.15470	78.16335	75.15470	54.94192
14	69.90947	74.40140	69.90947	51.41913
15	63.47656	67.62031	63.47656	46.48043
	CUGerm	GermSynchrony	GermUncertainty	
1	0.7092199	0.2666667	2.062987	
2	0.5051546	0.2346109	2.321514	
3	0.3975265	0.2242424	2.462012	
4	0.4672113	0.2502415	2.279215	
5	0.4312184	0.2606383	2.146051	
6	0.4934701	0.2792271	2.160545	
7	0.7371500	0.2729384	2.040796	
8	0.4855842	0.2256410	2.357249	
9	0.4446640	0.2494949	2.321080	
10	0.5584666	0.2555556	2.187983	
11	0.4288905	0.2686170	2.128670	
12	0.4760266	0.2737844	2.185245	
13	0.4023679	0.2506938	2.241181	
14	0.5383760	0.2991543	2.037680	
15	0.6133519	0.2497096	2.185028	

FourPHFfit.bulk() This wrapper function can be used to fit the four-parameter hill function for multiple samples in batch.

```
data(gcdata)

counts.per.intervals <- c("Day01", "Day02", "Day03", "Day04", "Day05",
                          "Day06", "Day07", "Day08", "Day09", "Day10",
                          "Day11", "Day12", "Day13", "Day14")

FourPHFfit.bulk(gcdata, total.seeds.col = "Total Seeds",
                counts.intervals.cols = counts.per.intervals,
                intervals = 1:14, partial = TRUE,
                fix.y0 = TRUE, fix.a = TRUE, xp = c(10, 60),
                tmax = 20, tries = 3, umax = 90, umin = 10)
```

	Genotype	Rep	Day01	Day02	Day03	Day04	Day05	Day06	Day07	Day08	Day09	Day10
1	G1	1	0	0	0	0	4	17	10	7	1	0
2	G2	1	0	0	0	1	3	15	13	6	2	1
3	G3	1	0	0	0	2	3	18	9	8	2	1
4	G4	1	0	0	0	0	4	19	12	6	2	1
5	G5	1	0	0	0	0	5	20	12	8	1	0
6	G1	2	0	0	0	0	3	21	11	7	1	1
7	G2	2	0	0	0	0	4	18	11	7	1	0
8	G3	2	0	0	0	1	3	14	12	6	2	1
9	G4	2	0	0	0	1	3	19	10	8	1	1
10	G5	2	0	0	0	0	4	18	13	6	2	1
11	G1	3	0	0	0	0	5	21	11	8	1	0
12	G2	3	0	0	0	0	3	20	10	7	1	1
13	G3	3	0	0	0	0	4	19	12	8	1	1
14	G4	3	0	0	0	0	3	21	11	6	1	0
15	G5	3	0	0	0	0	4	17	10	8	1	1

	Day11	Day12	Day13	Day14	Total	Seeds	a	b	c	y0	lag
1	1	0	0	0		50	80.00000	9.881937	6.034954	0	0
2	0	1	0	0		51	82.35294	9.227666	6.175193	0	0
3	1	1	0	0		48	93.75000	7.793051	6.138110	0	0
4	1	1	0	0		51	90.19608	8.925655	6.125173	0	0
5	0	1	1	0		50	96.00000	9.419181	6.049642	0	0
6	1	1	0	0		49	93.87755	9.450149	6.097415	0	0
7	1	0	0	0		48	87.50000	10.172459	6.029851	0	0
8	0	1	0	0		47	85.10638	8.940696	6.189774	0	0
9	1	1	0	0		52	86.53846	8.617391	6.125122	0	0
10	0	1	0	0		50	90.00000	9.608844	6.109504	0	0
11	0	1	1	0		51	94.11765	9.400212	6.018760	0	0
12	1	1	0	0		51	86.27451	9.162526	6.108452	0	0
13	0	1	1	0		49	95.91837	8.995210	6.149012	0	0
14	1	1	0	0		48	91.66667	10.391845	6.015910	0	0
15	1	0	0	0		48	87.50000	9.136744	6.121579	0	0

	Dlag50	t50.total	t10.total	t60.total	t50.Germinated	t10.Germinated
1	6.034954	6.355121	4.956264	6.744598	6.034954	4.831807
2	6.175193	6.473490	4.983236	6.872603	6.175193	4.866755
3	6.138110	6.244191	4.673022	6.608438	6.138110	4.630062
4	6.125173	6.276794	4.850875	6.614968	6.125173	4.788597
5	6.049642	6.103433	4.814125	6.386789	6.049642	4.790946
6	6.097415	6.182279	4.868632	6.477599	6.097415	4.832471
7	6.029851	6.202812	4.930422	6.510495	6.029851	4.858476
8	6.189774	6.439510	4.940057	6.823299	6.189774	4.841105
9	6.125122	6.352172	4.836658	6.733276	6.125122	4.746573

10	6.109504	6.253043	4.920629	6.566506	6.109504	4.860681
11	6.018760	6.099435	4.798627	6.391291	6.018760	4.764246
12	6.108452	6.326184	4.893596	6.684526	6.108452	4.806013
13	6.149012	6.207501	4.841308	6.509954	6.149012	4.816393
14	6.015910	6.122389	4.915140	6.397491	6.015910	4.869398
15	6.121579	6.317392	4.892502	6.667247	6.121579	4.813083
	t60.Germinated	Uniformity_90	Uniformity_10	Uniformity	TMGR	AUC
1	6.287724	7.537690	4.831807	2.705882	5.912194	1108.976
2	6.452582	7.835407	4.866755	2.968652	6.031282	1128.559
3	6.465924	8.137342	4.630062	3.507280	5.938180	1283.693
4	6.409838	7.834810	4.788597	3.046213	5.972686	1239.887
5	6.315746	7.639028	4.790946	2.848083	5.914289	1328.328
6	6.364722	7.693469	4.832471	2.860997	5.961879	1294.463
7	6.275050	7.483643	4.858476	2.625166	5.914057	1213.908
8	6.476945	7.914163	4.841105	3.073058	6.036192	1164.346
9	6.420208	7.904041	4.746573	3.157468	5.961631	1188.793
10	6.372823	7.679177	4.860681	2.818496	5.978115	1240.227
11	6.284051	7.603611	4.764246	2.839365	5.883557	1305.200
12	6.384836	7.763854	4.806013	2.957841	5.964080	1188.021
13	6.432524	7.850345	4.816393	3.033952	5.998270	1316.407
14	6.255276	7.432372	4.869398	2.562974	5.905180	1273.385
15	6.399357	7.785806	4.813083	2.972723	5.976087	1203.664
	MGT	Skewness	msg	sigma	finTol	logLik
1	6.632252	1.098973	#1. success	1.615220	7.105427e-14	-25.49868
2	6.784407	1.098655	#1. success	1.115372	2.309264e-14	-20.31471
3	6.772742	1.103392	#1. success	2.432704	9.947598e-14	-31.23213
4	6.739666	1.100323	#1. success	2.396582	5.684342e-14	-31.02269
5	6.654981	1.100062	#1. success	2.399662	1.094236e-12	-31.04067
6	6.702473	1.099232	#1. success	3.034962	1.563194e-13	-34.32887
7	6.622417	1.098272	#1. success	1.663019	1.421085e-13	-25.90697
8	6.804000	1.099232	#1. success	1.120704	4.327205e-12	-20.38149
9	6.745241	1.101242	#1. success	2.429960	7.958079e-13	-31.21633
10	6.711900	1.098600	#1. success	1.686656	8.142820e-12	-26.10456
11	6.624248	1.100600	#1. success	2.628113	1.989520e-13	-32.31381
12	6.718639	1.099892	#1. success	2.878146	1.151079e-12	-33.58613
13	6.762274	1.099733	#1. success	2.604588	2.984279e-13	-32.18793
14	6.604967	1.097916	#1. success	2.764756	9.805490e-13	-33.02342
15	6.732266	1.099760	#1. success	1.954008	8.739676e-13	-28.16444
	BIC	deviance	df.residual	nobs		
1	58.91453	31.30723	12	14		
2	48.54660	14.92865	12	14		
3	70.38143	71.01658	12	14		
4	69.96256	68.92324	12	14		
5	69.99852	69.10052	12	14		
6	76.57491	110.53195	12	14		
7	59.73112	33.18760	12	14		
8	48.68015	15.07174	12	14		
9	70.34984	70.85647	12	14		
10	60.12629	34.13771	12	14		
11	72.54479	82.88372	12	14		
12	75.08944	99.40469	12	14		
13	72.29303	81.40654	12	14		
14	73.96401	91.72652	12	14		
15	64.24606	45.81777	12	14		

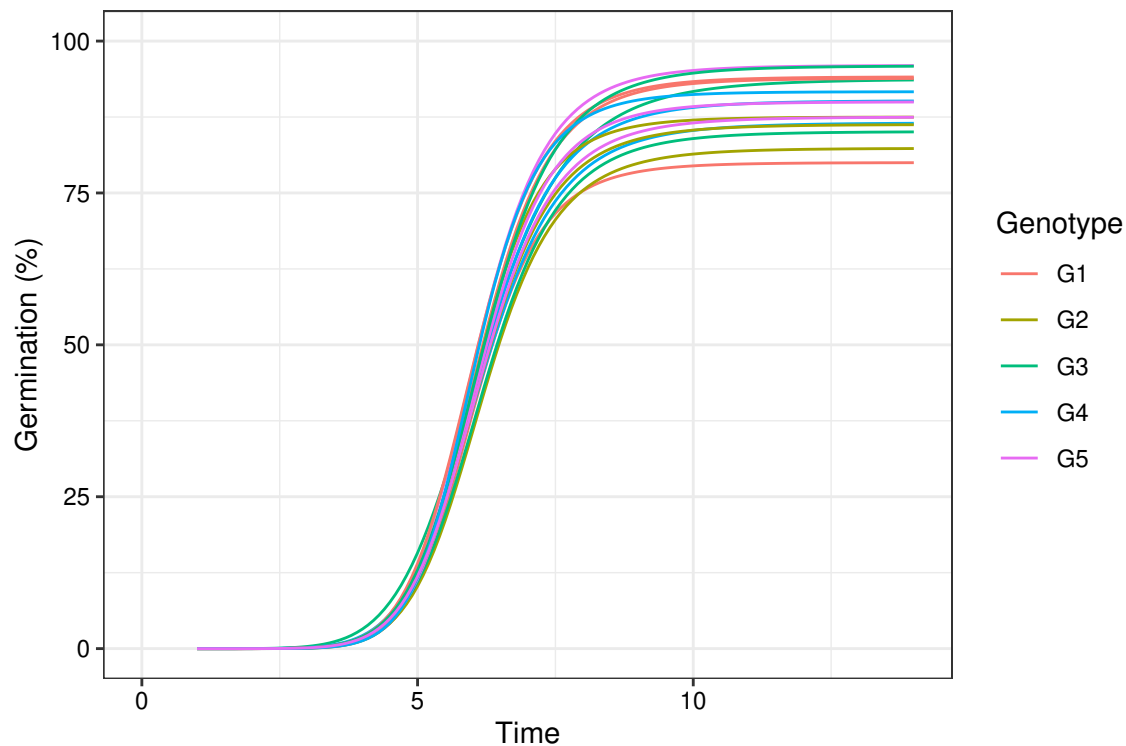
Multiple fitted curves generated in batch can also be plotted.

```
data(gcdata)

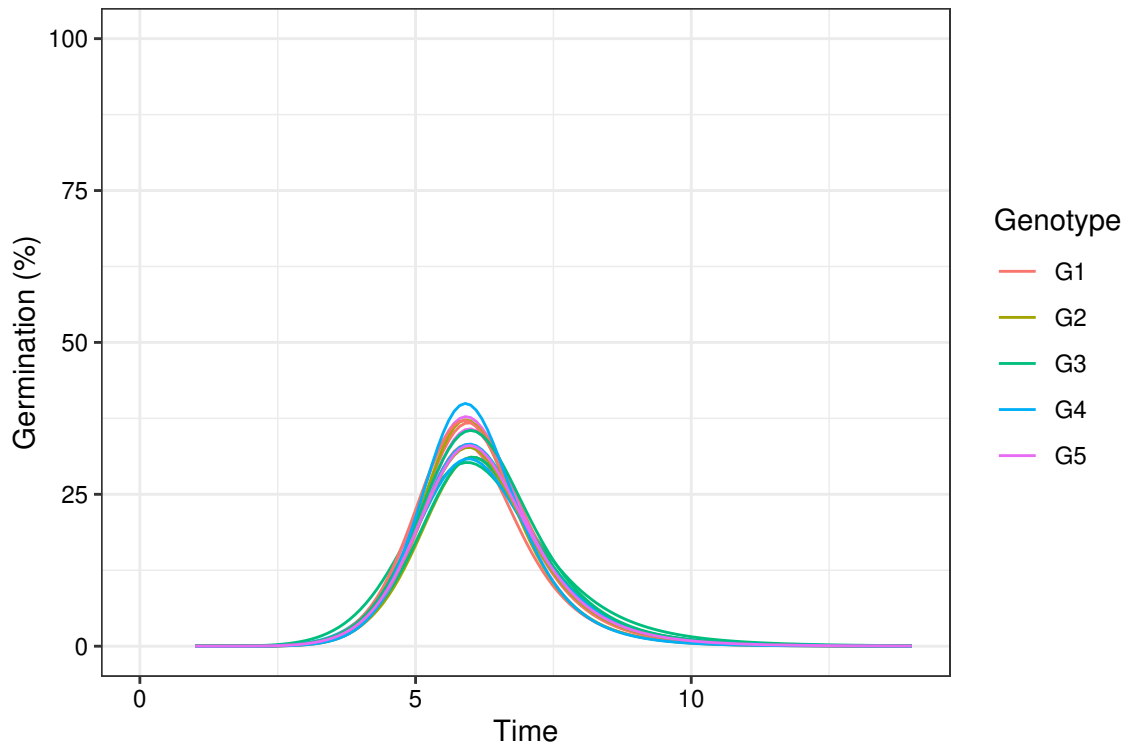
counts.per.intervals <- c("Day01", "Day02", "Day03", "Day04", "Day05",
                          "Day06", "Day07", "Day08", "Day09", "Day10",
                          "Day11", "Day12", "Day13", "Day14")

fits <- FourPHFfit.bulk(gcdata, total.seeds.col = "Total Seeds",
                       counts.intervals.cols = counts.per.intervals,
                       intervals = 1:14, partial = TRUE,
                       fix.y0 = TRUE, fix.a = TRUE, xp = c(10, 60),
                       tmax = 20, tries = 3, umax = 90, umin = 10)

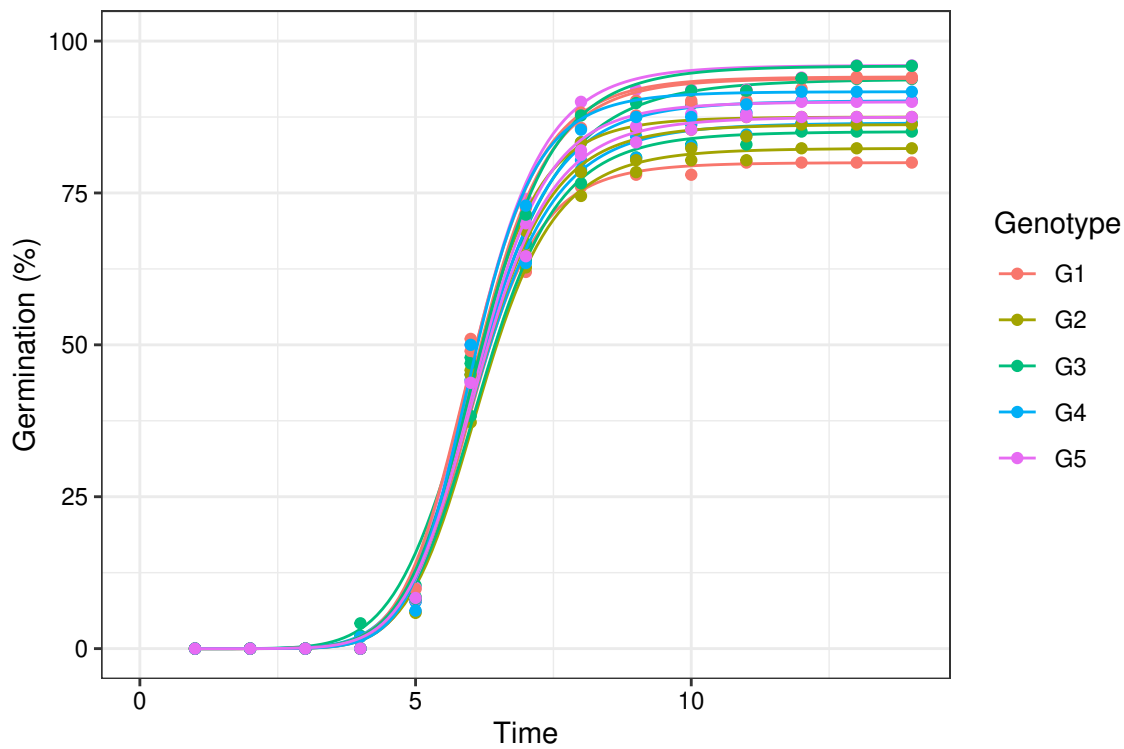
# Plot FPHF curves
plot(fits, group.col = "Genotype")
```



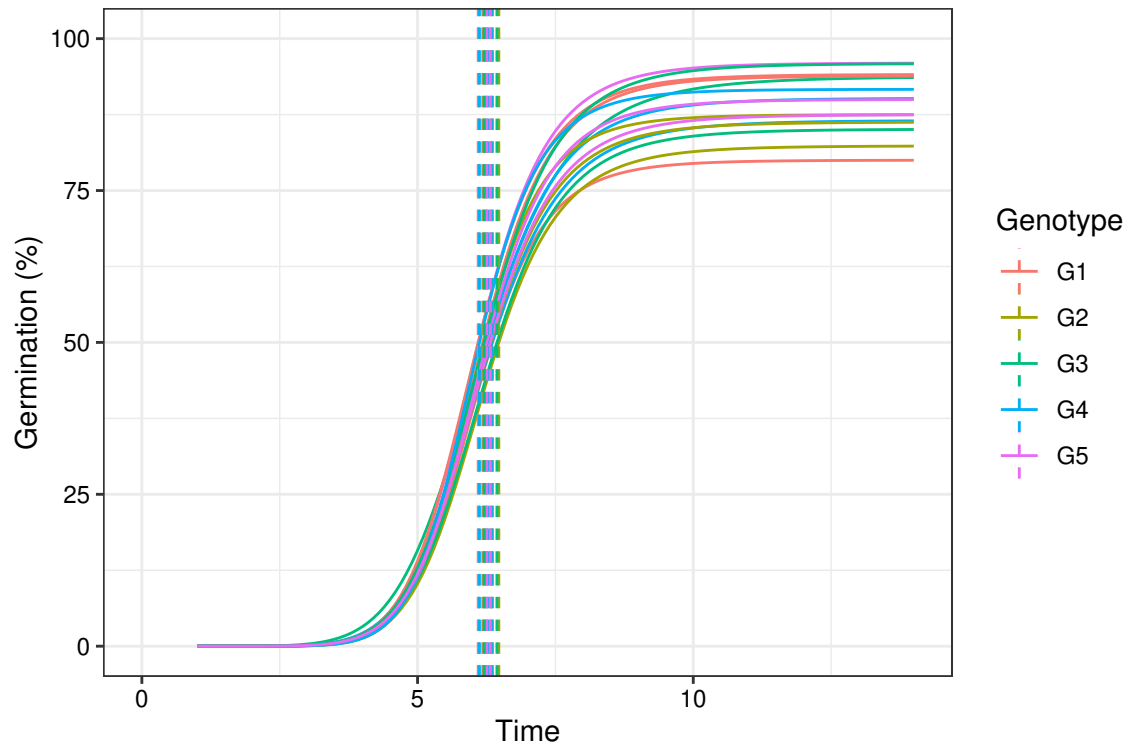
```
# Plot ROG curves
plot(fits, rog = TRUE, group.col = "Genotype")
```



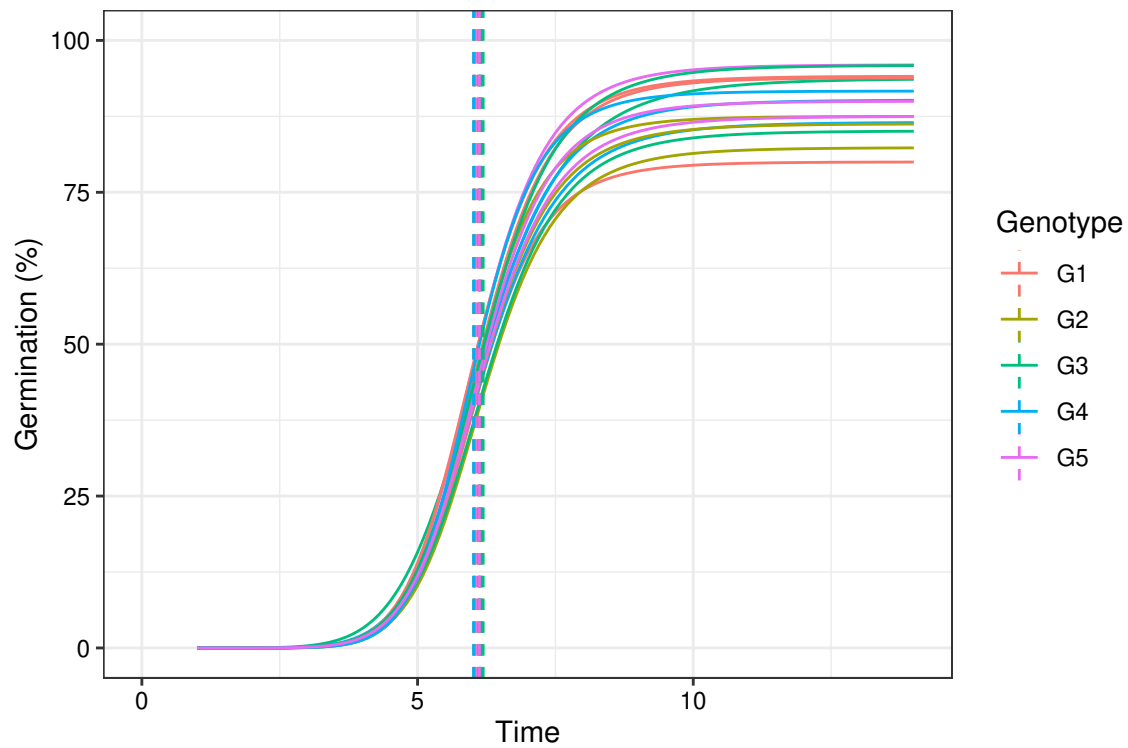
```
# Plot FPHF curves with points
plot(fits, group.col = "Genotype", show.points = TRUE)
```



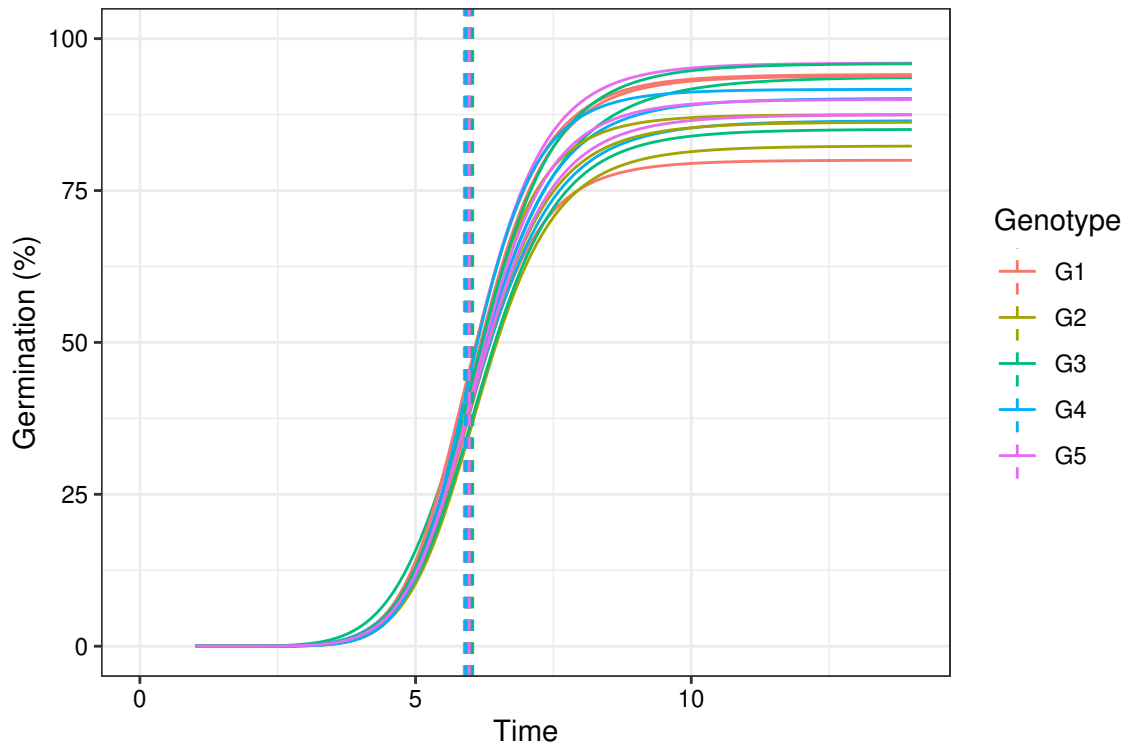
```
# Plot FPHF curves with annotations
plot(fits, group.col = "Genotype", annotate = "t50.total")
```



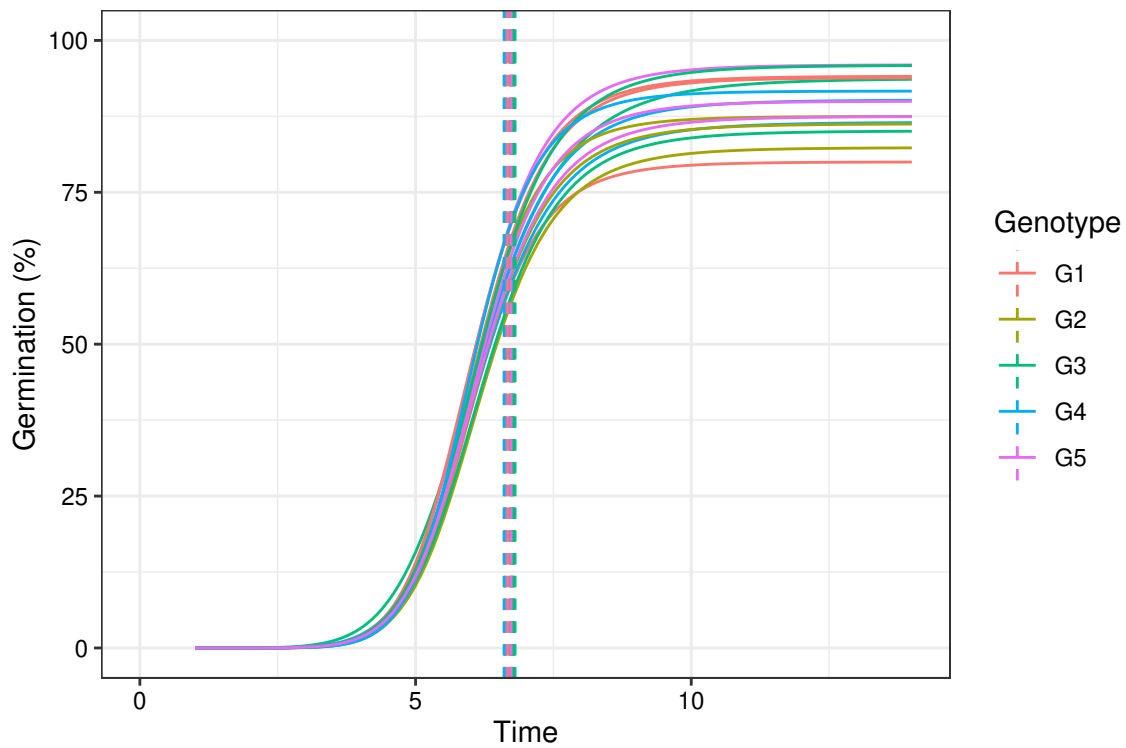
```
plot(fits, group.col = "Genotype", annotate = "t50.germ")
```



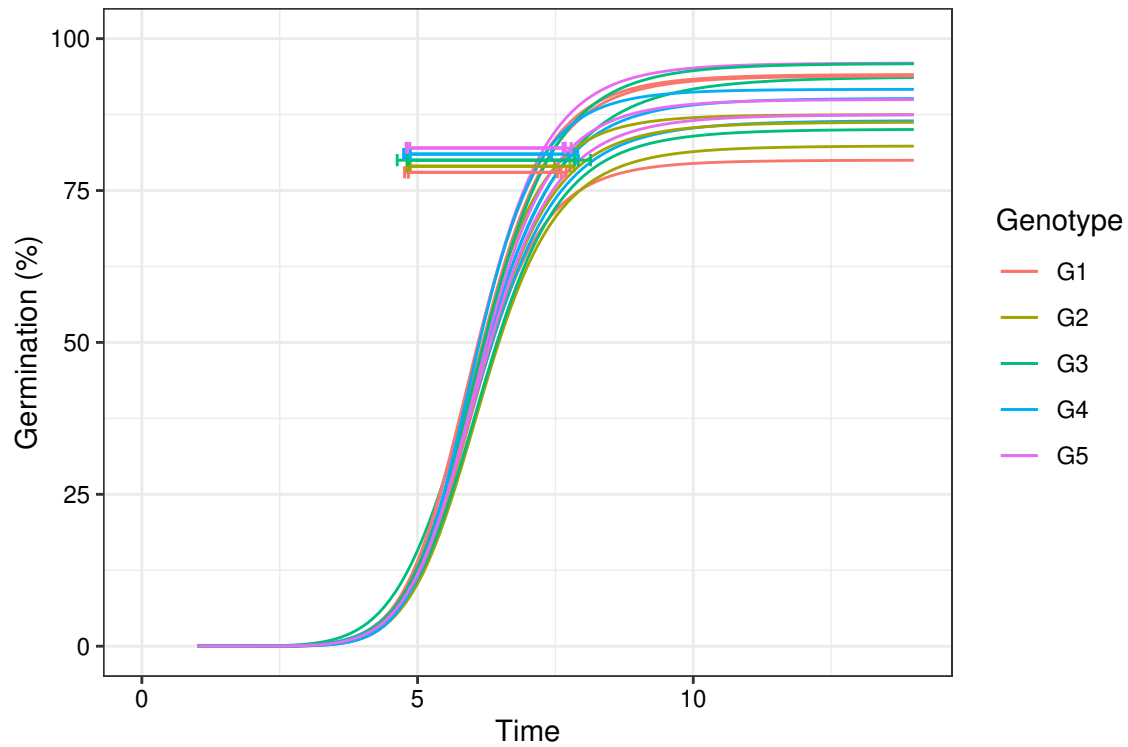
```
plot(fits, group.col = "Genotype", annotate = "tmgr")
```



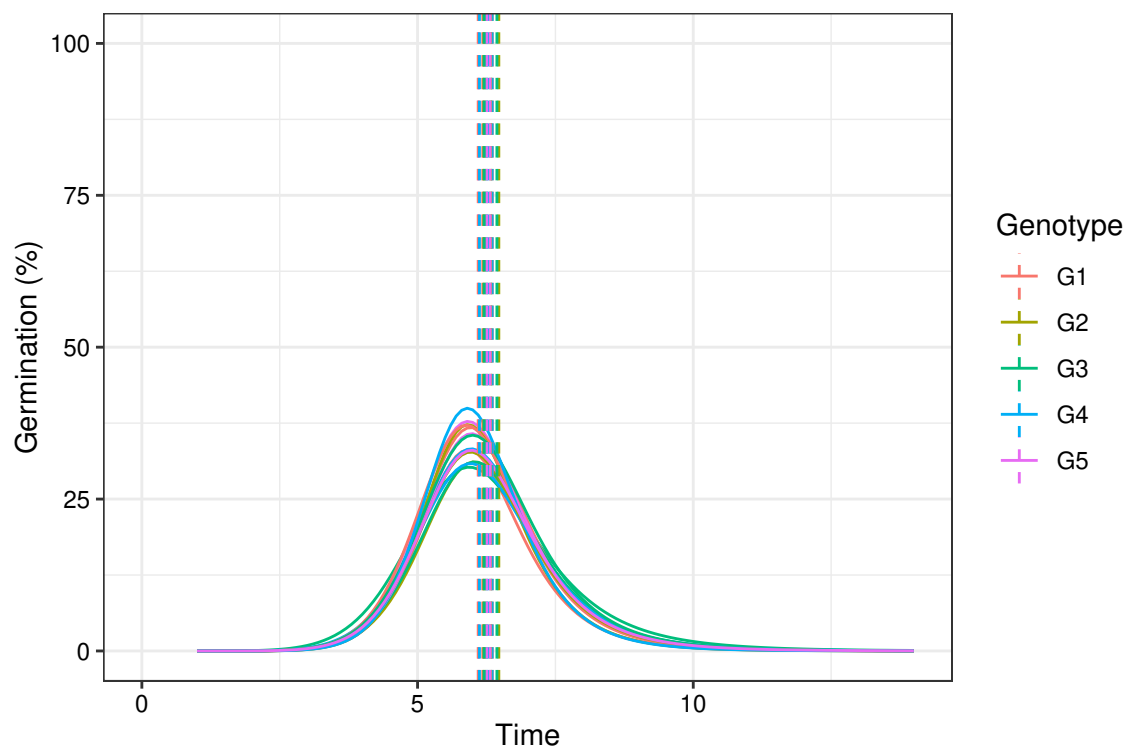
```
plot(fits, group.col = "Genotype", annotate = "mgt")
```



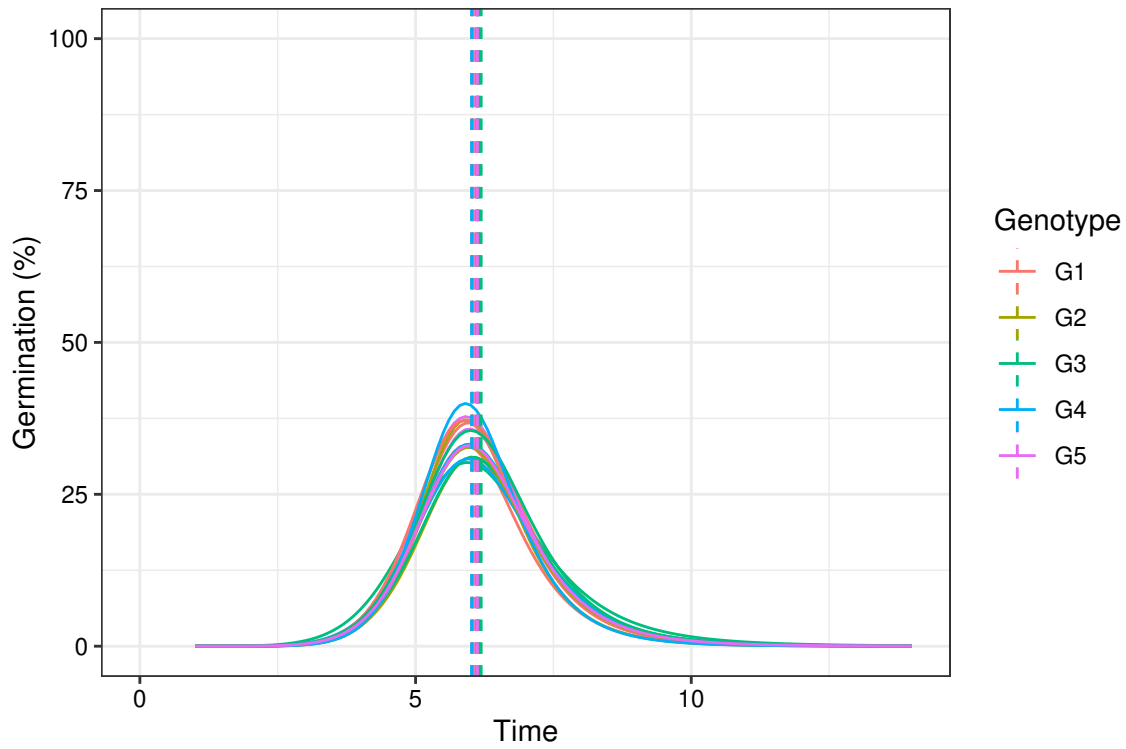
```
plot(fits, group.col = "Genotype", annotate = "uniformity")
```



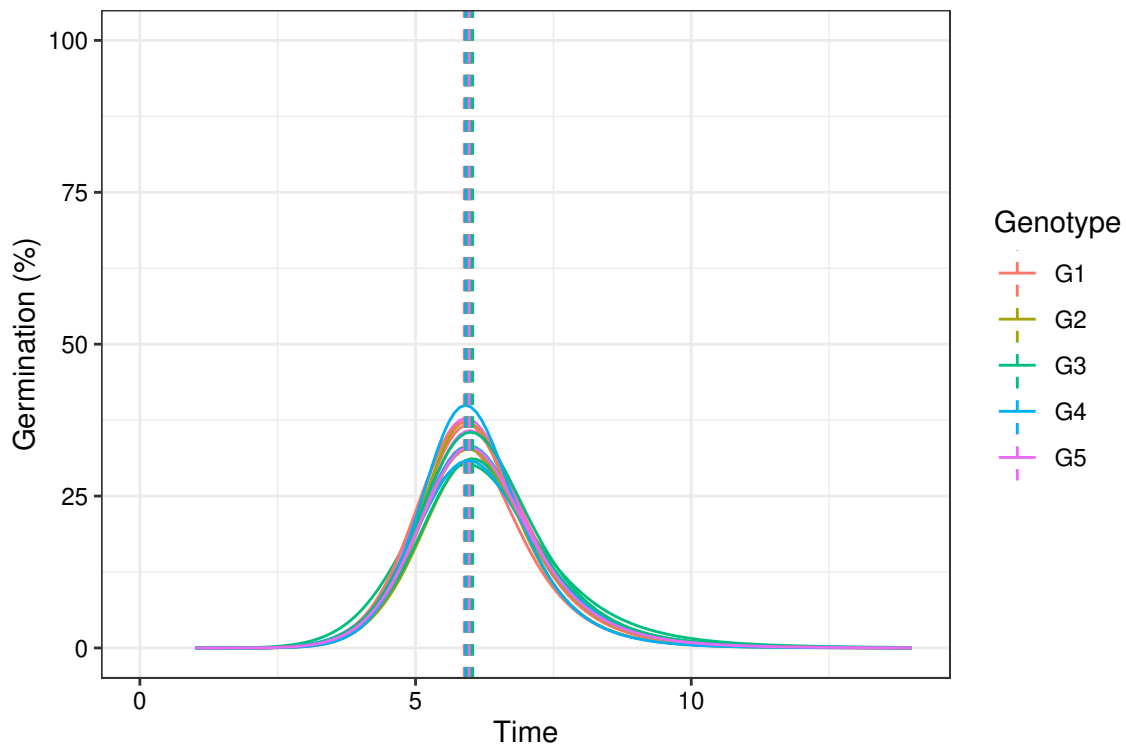
```
# Plot ROG curves with annotations
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "t50.total")
```



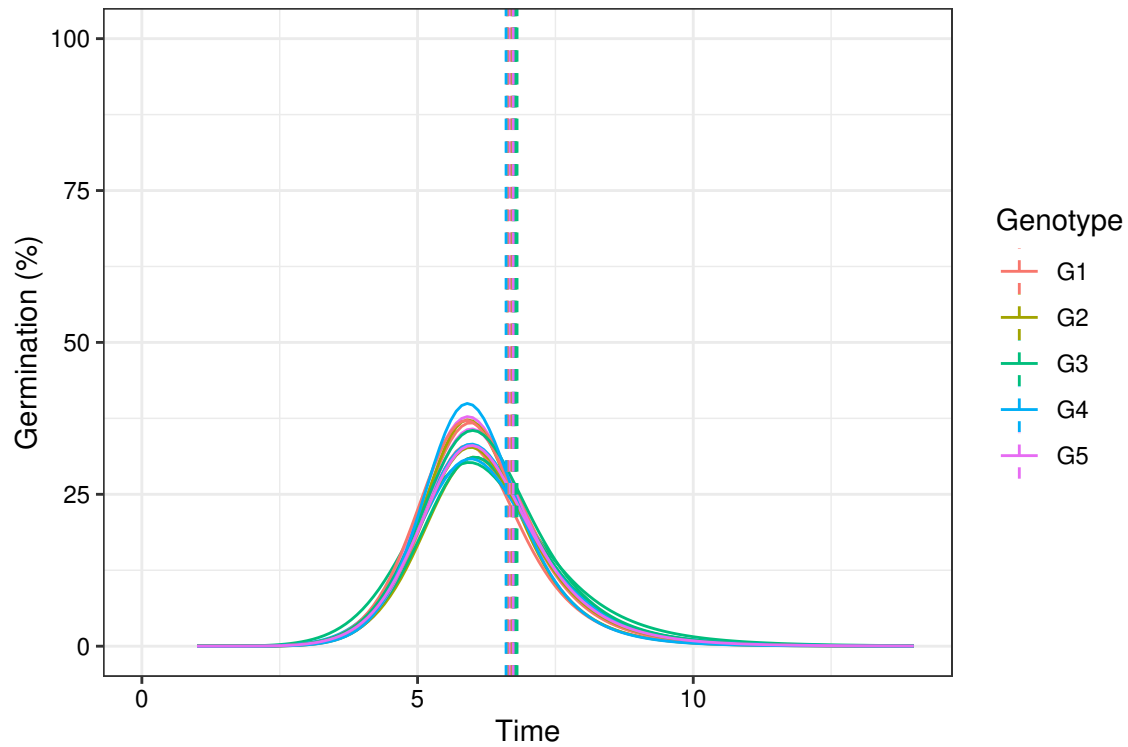
```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "t50.germ")
```

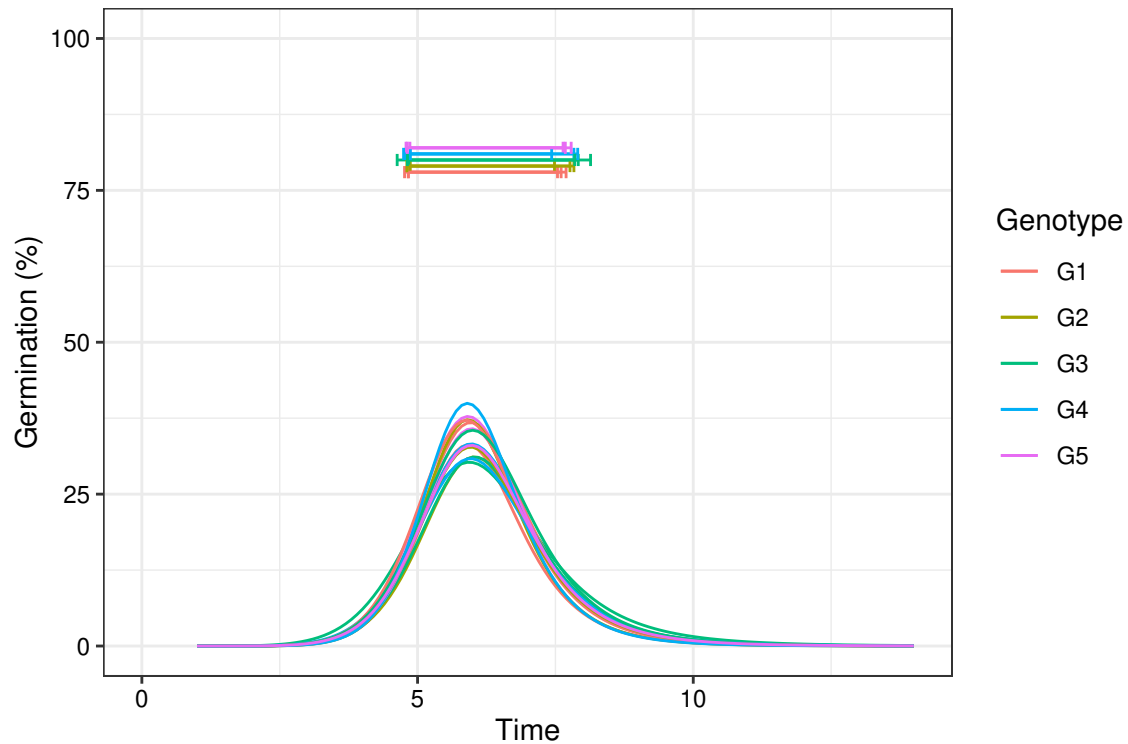
```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "tmgr")
```



```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "mgt")
```



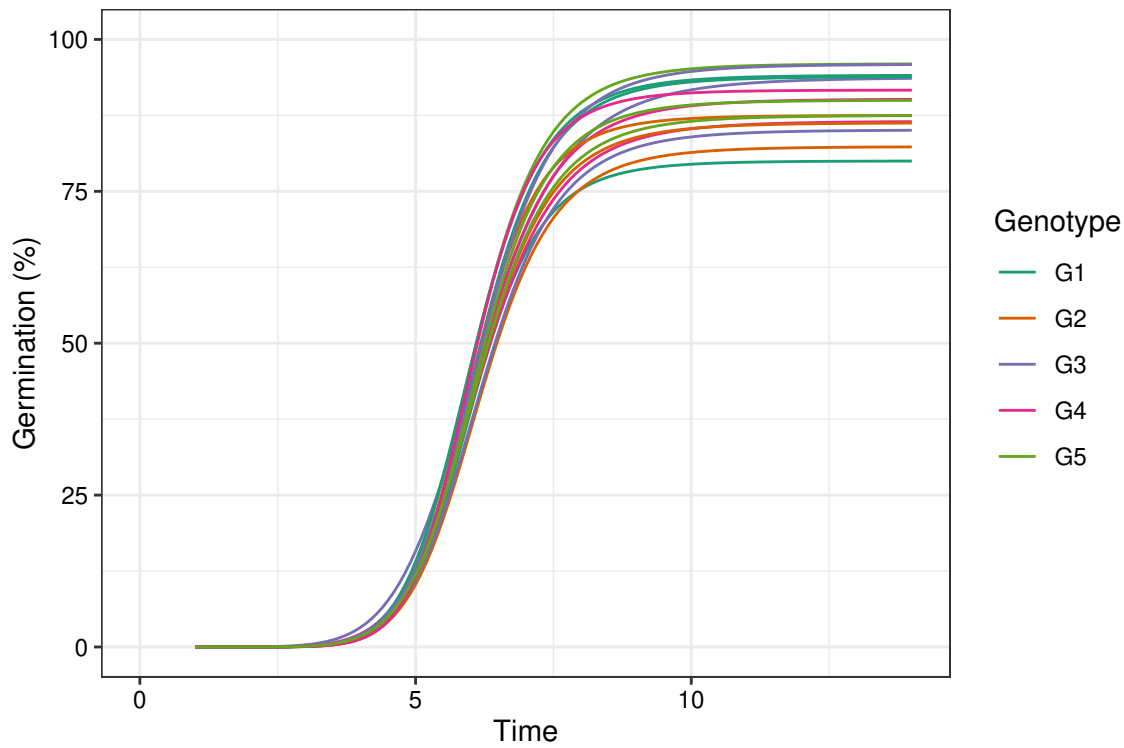
```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "uniformity")
```



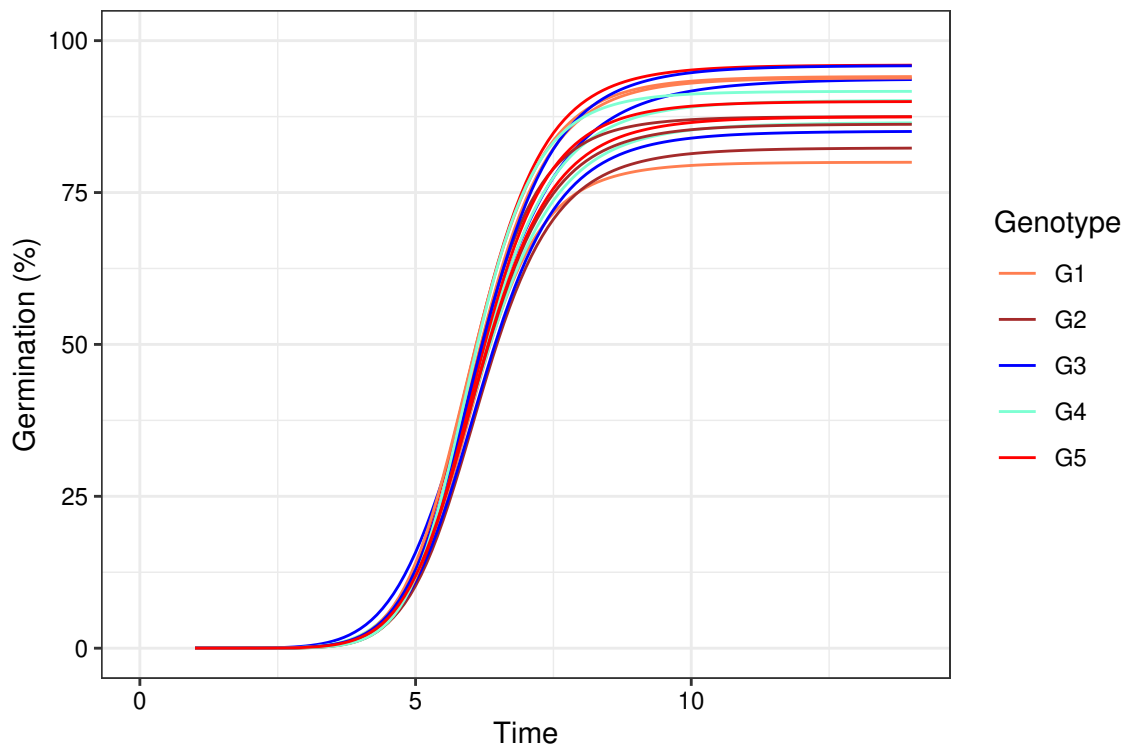
```
# Change colour of curves using ggplot2 options
library(ggplot2)
curvesplot <- plot(fits, group.col = "Genotype")

# 'Dark2' palette from RColorBrewer
```

```
curvesplot + scale_colour_brewer(palette = "Dark2")
```



```
# Manual colours
curvesplot +
  scale_colour_manual(values = c("Coral", "Brown", "Blue",
    "Aquamarine", "Red"))
```



Citing *germinationmetrics*

To cite the R package '*germinationmetrics*' in publications use:

Aravind, J., Vimala Devi, S., Radhamani, J., Jacob, S. R., and Kalyani Srinivasan (2025). *germinationmetrics: Seed Germination Indices and Curve Fitting*. R package version 0.1.9, <https://github.com/aravind-j/germinationmetrics> <https://cran.r-project.org/package=germinationmetrics>.

A BibTeX entry for LaTeX users is

```
@Manual{,
  title = {germinationmetrics: Seed Germination Indices and Curve Fitting},
  author = {J. Aravind and S. {Vimala Devi} and J. Radhamani and Sherry Rachel Jacob and {Kalyani Srinivasan}},
  note = {R package version 0.1.9 https://aravind-j.github.io/germinationmetrics/ https://CRAN.R-project.org/package=germinationmetrics},
  year = {2025},
}
```

This free and open-source software implements academic research by the authors and co-workers. If you use it, please support the project by citing the package.

Session Info

```
sessionInfo()
```

```
R Under development (unstable) (2025-12-09 r89129 ucrt)
Platform: x86_64-w64-mingw32/x64
Running under: Windows 11 x64 (build 26200)
```

```
Matrix products: default
LAPACK version 3.12.1
```

```
locale:
[1] LC_COLLATE=C LC_CTYPE=English_India.utf8
[3] LC_MONETARY=English_India.utf8 LC_NUMERIC=C
[5] LC_TIME=English_India.utf8
```

```
time zone: Asia/Calcutta
tzcode source: internal
```

```
attached base packages:
[1] stats      graphics  grDevices  utils      datasets  methods    base
```

```
other attached packages:
[1] germinationmetrics_0.1.9 ggplot2_4.0.1
```

```
loaded via a namespace (and not attached):
[1] generics_0.1.4      tidyr_1.3.1          bitops_1.0-9         stringi_1.8.7
[5] lattice_0.22-7      digest_0.6.39        magrittr_2.0.4       evaluate_1.0.5
[9] grid_4.6.0          RColorBrewer_1.1-3   fastmap_1.2.0        plyr_1.8.9
[13] Matrix_1.7-4        ggrepel_0.9.6        backports_1.5.0      tinytex_0.58
[17] httr_1.4.7          purrr_1.2.0          pander_0.6.6         scales_1.4.0
```

[21] XML_3.99-0.20	Rdpack_2.6.4	cli_3.6.5	rlang_1.1.6
[25] rbibutils_2.4	withr_3.0.2	yaml_2.3.12	tools_4.6.0
[29] reshape2_1.4.5	dplyr_1.1.4	mathjaxr_2.0-0	broom_1.0.11
[33] curl_7.0.0	vctrs_0.6.5	R6_2.6.1	stats4_4.6.0
[37] lifecycle_1.0.4	gsnlsls_1.4.2	stringr_1.6.0	pkgconfig_2.0.3
[41] pillar_1.11.1	gtable_0.3.6	data.table_1.17.8	glue_1.8.0
[45] Rcpp_1.1.0.8.1	xfun_0.54	tibble_3.3.0	tidyselect_1.2.1
[49] rstudioapi_0.17.1	knitr_1.50	dichromat_2.0-0.1	farver_2.1.2
[53] htmltools_0.5.9	labeling_0.4.3	rmarkdown_2.30	compiler_4.6.0
[57] S7_0.2.1	RCurl_1.98-1.17		

References

- Allan, R. E., Vogel, O. A., and Peterson, C. J. (1962). Seedling emergence rate of fall-sown wheat and its association with plant height and coleoptile length. *Agronomy Journal* 54, 347. doi:10.2134/agronj1962.00021962005400040022x.
- Al-Mudaris, M. A. (1998). Notes on various parameters recording the speed of seed germination. *Der Tropenlandwirt - Journal of Agriculture in the Tropics and Subtropics* 99, 147–154. Available at: <https://www.jarts.info/index.php/tropenlandwirt/article/download/1495/671>.
- AOSA (1983). *Seed Vigor Testing Handbook*. Ithaca, NY, USA: Association of Official Seed Analysts.
- Baskin, C. C., and Baskin, J. M. (1998). *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. San Diego: Academic Press.
- Bewley, J. D., and Black, M. (1994). *Seeds: Physiology of Development and Germination*. New York, USA: Plenum Publishing Corporation Available at: <https://link.springer.com/book/10.1007/978-1-4899-1002-8>.
- Bilbro, J. D., and Wanjura, D. F. (1982). Soil crusts and cotton emergence relationships. *Transactions of the ASAE* 25, 1484–1487. doi:10.13031/2013.33750.
- Bonner, F. T. (1967). Ideal sowing depth for sweetgum seed. *Tree Planters' Notes* 18, 1–1. Available at: <https://rngr.net/publications/tpn/18-1/pdf.2005-05-13.4925080024/>.
- Bouton, J. H., Dudeck, A. E., and Smith, R. L. (1976). Germination in freshly harvested seed of centipedegrass. *Agronomy Journal* 68, 991. doi:10.2134/agronj1976.00021962006800060040x.
- Bradbeer, J. W. (1988). *Seed Dormancy and Germination*. Glasgow; London: Blackie Available at: <https://link.springer.com/book/10.1007/978-1-4684-7747-4> [Accessed January 15, 2018].
- Brown, R. F., and Mayer, D. G. (1988). Representing cumulative germination. 1. A critical analysis of single-value germination indices. *Annals of Botany* 61, 117–125. doi:10.1093/oxfordjournals.aob.a087534.
- Chaudhary, T. N., and Ghildyal, B. P. (1970). Effect of temperature associated with levels of bulk density on rice seedling emergence. *Plant and Soil* 33, 87–90. doi:10.1007/bf01378199.
- Chopra, U. K., and Chaudhary, T. N. (1980). Effect of soil temperature alteration by soil covers on seedling emergence of wheat (*Triticum aestivum* L.) sown on two dates. *Plant and Soil* 57, 125–129. doi:10.1007/bf02139648.
- Coolbear, P., Francis, A., and Grierson, D. (1984). The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. *Journal of Experimental Botany* 35, 1609–1617. doi:10.1093/jxb/35.11.1609.

- Czabator, F. J. (1962). Germination value: An index combining speed and completeness of pine seed germination. *Forest Science* 8, 386–396. doi:10.1093/forestscience/8.4.386.
- Djavanshir, K., and Pourbeik, H. (1976). Germination value-A new formula. *Silvae Genetica* 25, 79–83. Available at: https://www.thuenen.de/media/institute/fg/PDF/Silvae_Genetica/1976/Vol._25_Heft_2/25_2_79.pdf.
- Edmond, J. B., and Drapala, W. J. (1958). The effects of temperature, sand and soil, and acetone on germination of okra seed. *Proceedings of the American Society for Horticultural Science* 71, 428–434.
- Edwards, T. I. (1932). Temperature relations of seed germination. *The Quarterly Review of Biology* 7, 428–443. doi:10.1086/394417.
- El-Kassaby, Y. A., Moss, I., Kolotelo, D., and Stoehr, M. (2008). Seed germination: Mathematical representation and parameters extraction. *Forest Science* 54, 220–227. doi:10.1093/forestscience/54.2.220.
- Ellis, R. H., and Roberts, E. H. (1980). Improved equations for the prediction of seed longevity. *Annals of Botany* 45, 13–30. doi:10.1093/oxfordjournals.aob.a085797.
- Erbach, D. C. (1982). Tillage for continuous corn and corn-soybean rotation. *Transactions of the ASAE* 25, 906–911. doi:10.13031/2013.33638.
- Evetts, L. L., and Burnside, O. C. (1972). Germination and seedling development of common milkweed and other species. *Weed Science* 20, 371–378. doi:10.1017/S004317450003589x.
- Fakorede, M. A. B., and Agbana, S. B. (1983). Heterotic effects and association of seedling vigour with mature characteristics and grain yield in some tropical maize cultivars. *Maydica* 28, 327–338.
- Fakorede, M. A. B., and Ayoola, A. O. (1980). Relation between seedling vigor and selection for yield improvement in maize. *Maydica* 25, 135–147.
- Fakorede, M. A. B., and Ojo, D. K. (1981). Variability for seedling vigour in maize. *Experimental Agriculture* 17, 195–201. doi:10.1017/s0014479700011455.
- Farooq, M., Basra, S. M. A., Ahmad, N., and Hafeez, K. (2005). Thermal hardening: A new seed vigor enhancement tool in rice. *Journal of Integrative Plant Biology* 47, 187–193. doi:10.1111/J.1744-7909.2005.00031.x.
- George, D. W. (1961). Influence of germination temperature on the expression of post-harvest dormancy in wheat. in *Crop Science Abstracts; Western Society of Crop Science Annual Meeting, 1961* (Western Society of Crop Science), 15.
- Goloff, A. A., and Bazzaz, F. A. (1975). A germination model for natural seed populations. *Journal of Theoretical Biology* 52, 259–283. doi:10.1016/0022-5193(75)90001-6.
- Gomes, F. P. (1960). *Curso De Estatística Experimental*. Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo Available at: <https://books.google.de/books?id=ZckqGwAACAAJ>.
- Goodchild, N. A., and Walker, M. G. (1971). A method of measuring seed germination in physiological studies. *Annals of Botany* 35, 615–621. doi:10.1093/oxfordjournals.aob.a084504.
- Gordon, A. G. (1969). Some observations on the germination energy tests for cereals. *Proceedings of the Association of Official Seed Analysts* 59, 58–72. Available at: <https://www.jstor.org/stable/23432357> [Accessed December 11, 2018].

- Gordon, A. G. (1971). The germination resistance test - A new test for measuring germination quality of cereals. *Canadian Journal of Plant Science* 51, 181–183. doi:10.4141/cjps71-036.
- Grose, R. J., and Zimmer, W. J. (1958). Some laboratory germination responses of the seeds of river red gum, *Eucalyptus camaldulensis* Dehn. Syn. *Eucalyptus rostrata* Schlecht. *Australian Journal of Botany* 6, 129. doi:10.1071/bt9580129.
- Haugland, E., and Brandsaeter, L. O. (1996). Experiments on bioassay sensitivity in the study of allelopathy. *Journal of Chemical Ecology* 22, 1845–1859. doi:10.1007/BF02028508.
- Heydecker, W. (1972). *Seed Ecology. Proceedings of the Nineteenth Easter School in Agricultural Science, University of Nottingham, 1972*. University Park, USA: Pennsylvania State University Press.
- Hsu, F. H., and Nelson, C. J. (1986). Planting date effects on seedling development of perennial warm-season forage grasses. I. Field emergence. *Agronomy Journal* 78, 33–38. doi:10.2134/agronj1986.00021962007800010008x.
- ISTA (2015). “Chapter 5: The germination test,” in *International Rules for Seed Testing. International Seed Testing Association, Zurich, Switzerland*. (International Seed Testing Association), i-5-56. Available at: <https://doi.org/10.15258/istarules.2015.05>.
- Kader, M. A. (2005). A comparison of seed germination calculation formulae and the associated interpretation of resulting data. *Journal and Proceedings of the Royal Society of New South Wales* 138, 65–75. doi:10.5962/p.361564.
- Kendrick, R. E., and Frankland, B. (1969). Photocontrol of germination in *Amaranthus caudatus*. *Planta* 85, 326–339. doi:10.1007/bf00381281.
- Khamassi, K., Harbaoui, K., Jaime, A. T. da S., and Jeddi, F. B. (2013). Optimal germination temperature assessed by indices and models in field bean (*Vicia faba* L. Var. *Minor*). *Agriculturae Conspectus Scientificus* 78, 131–136. Available at: <https://hrcak.srce.hr/104663>.
- Khan, M. A., and Ungar, I. A. (1984). The effect of salinity and temperature on the germination of polymorphic seeds and growth of *Atriplex triangularis* Willd. *American Journal of Botany* 71, 481–489. doi:10.2307/2443323.
- Khandakar, A. L., and Bradbeer, J. W. (1983). *Jute seed quality*. Bangladesh Agricultural Research Council, Dhaka.
- Kotowski, F. (1926). Temperature relations to germination of vegetable seeds. *Proceedings of the American Society for Horticultural Science* 23, 176–184.
- Labouriau, L. G. (1983a). *A Germinação Das Sementes*. Organização dos Estados Americanos. Programa Regional de Desenvolvimento Científico e Tecnológico. Série de Biologia. Monografia 24.
- Labouriau, L. G. (1983b). Uma nova linha de pesquisa na fisiologia da germinação das sementes. in *Anais do XXXIV Congresso Nacional de Botânica. SBB, Porto Alegre* (Sociedade Botânica do Brasil), 11–50.
- Labouriau, L. G., and Valadares, M. E. B. (1976). On the germination of seeds of *Calotropis procera* (Ait.) Ait. f. *Anais da Academia Brasileira de Ciências* 48.
- Lyon, J. L., and Coffelt, R. J. (1966). Rapid method for determining numerical indexes for time-course curves. *Nature* 211, 330–330. doi:10.1038/211330a0.
- Maguire, J. D. (1962). Speed of germination - Aid in selection and evaluation for seedling emergence and

- vigor. *Crop Science* 2, 176–177. doi:10.2135/cropsci1962.0011183x000200020033x.
- Melville, A. H., Galletta, G. J., Draper, A. D., and Ng, T. J. (1980). Seed germination and early seedling vigor in progenies of inbred strawberry selections. *HortScience* 15, 749–750.
- Mock, J. J., and Eberhart, S. A. (1972). Cold tolerance in adapted maize populations. *Crop Science* 12, 466–469. doi:10.2135/cropsci1972.0011183x001200040021x.
- Negm, F. B., and Smith, O. E. (1978). Effects of ethylene and carbon dioxide on the germination of osmotically inhibited lettuce seed. *Plant Physiology* 62, 473–476. doi:10.1104/pp.62.4.473.
- Nichols, M. A., and Heydecker, W. (1968). Two approaches to the study of germination data. *Proceedings of the International Seed Testing Association* 33, 531–540.
- Primack, R. B. (1985). Longevity of individual flowers. *Annual Review of Ecology and Systematics* 16, 15–37. doi:10.1146/annurev.es.16.110185.000311.
- Quintanilla, L. G., Pajarón, S., Pangua, E., and Amigo, J. (2000). Effect of temperature on germination in northernmost populations of *Culcita macrocarpa* and *Woodwardia radicans*. *Plant Biology* 2, 612–617. doi:10.1055/s-2000-16638.
- Ranal, M. A. (1999). Effects of temperature on spore germination in some fern species from semideciduous mesophytic forest. *American Fern Journal* 89, 149. doi:10.2307/1547349.
- Ranal, M. A., and Santana, D. G. de (2006). How and why to measure the germination process? *Brazilian Journal of Botany* 29, 1–11. doi:10.1590/s0100-84042006000100002.
- Reddy, L. V. (1978). Effect of temperature on seed dormancy and alpha-amylase activity during kernel maturation and germination in wheat (*Triticum aestivum* L.) cultivars. Available at: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/1j92gb854.
- Reddy, L. V., Metzger, R. J., and Ching, T. M. (1985). Effect of temperature on seed dormancy of wheat. *Crop Science* 25, 455. doi:10.2135/cropsci1985.0011183X002500030007x.
- Roh, M., Bentz, J.-A., Wang, P., Li, E., and Koshioka, M. (2004). Maturity and temperature stratification affect the germination of *Styrax japonicus* seeds. *The Journal of Horticultural Science and Biotechnology* 79, 645–651. doi:10.1080/14620316.2004.11511820.
- Santana, D. G. de, and Ranal, M. A. (2004). *Análise Da Germinação: Um Enfoque Estatístico*. Brasília: Universidade de Brasília.
- Schrader, J. A., and Graves, W. R. (2000). Seed germination and seedling growth of *Alnus maritima* from its three disjunct populations. *Journal of the American Society for Horticultural Science* 125, 128–134. doi:10.21273/JASHS.125.1.128.
- Scott, S. J., Jones, R. A., and Williams, W. A. (1984). Review of data analysis methods for seed germination. *Crop Science* 24, 1192–1199. doi:10.2135/cropsci1984.0011183x002400060043x.
- Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal* 27, 379–423. doi:10.1002/j.1538-7305.1948.tb01338.x.
- Shmueli, M., and Goldberg, D. (1971). Emergence, early growth, and salinity of five vegetable crops germinated by sprinkle and trickle irrigation in an arid zone. *HortScience* 6, 563–565.

- Smith, P. G., and Millet, A. H. (1964). Germinating and sprouting responses of the tomato at low temperatures. *Proceedings of the American Society for Horticultural Science* 84, 480–484.
- Throneberry, G. O., and Smith, F. G. (1955). Relation of respiratory and enzymatic activity to corn seed viability. *Plant Physiology* 30, 337–343. doi:10.1104/pp.30.4.337.
- Timson, J. (1965). New method of recording germination data. *Nature* 207, 216. doi:10.1038/207216a0.
- Tucker, H., and Wright, L. N. (1965). Estimating rapidity of germination. *Crop Science* 5, 398–399. doi:10.2135/cropsci1965.0011183X000500050006x.
- Vallance, K. (1950). Studies on the germination of the seeds of *Striga hermonthica* I. The influence of moisture-treatment, stimulant-dilution, and after-ripening on germination. *Annals of Botany* 14, 347–363. doi:10.1093/oxfordjournals.aob.a083251.
- Wardle, D. A., Ahmed, M., and Nicholson, K. S. (1991). Allelopathic influence of nodding thistle (*Carduus nutans* L.) seeds on germination and radicle growth of pasture plants. *New Zealand Journal of Agricultural Research* 34, 185–191. doi:10.1080/00288233.1991.10423358.
- Went, F. W. (1957). *The experimental control of plant growth*. Chronica Botanica Co., Waltham, Mass., USA; The Ronald Press Co., New York, USA.