

# The `germinationmetrics` Package: A Brief Introduction

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## 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)
```

## Version History

The current version of the package is 0.1.5. 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

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.

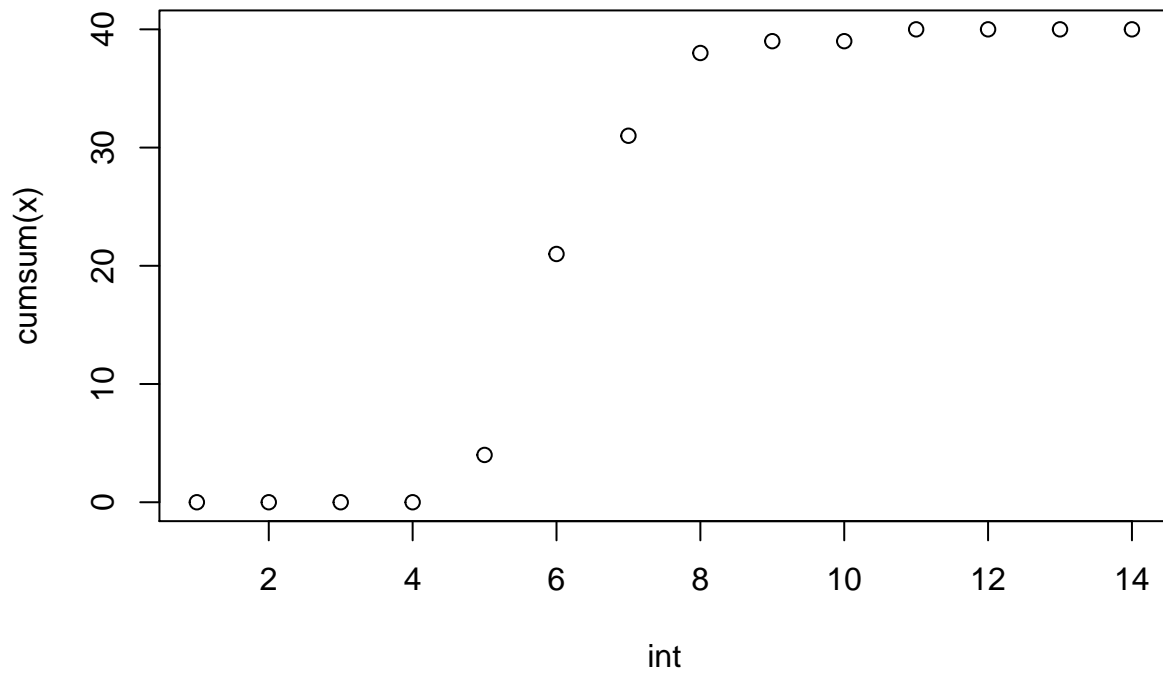
intervals	counts	cumulative.counts
1	0	0
2	0	0
3	0	0
4	0	0
5	4	4
6	17	21
7	10	31
8	7	38
9	1	39
10	0	39
11	1	40
12	0	40
13	0	40
14	0	40

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 ( $GP$ )	<b>GermPercent</b>	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	<a href="#">ISTA (2015)</a>
Time for the first germination or Germination time lag ( $t_0$ )	<b>FirstGermTime</b>	It is the time for first germination to occur (e.g. First day of germination)	time	Germination time	<a href="#">Edwards (1932)</a> ; <a href="#">Czabator (1962)</a> ; <a href="#">Goloff and Bazzaz (1975)</a> ; <a href="#">Labouriau (1983a)</a> ; <a href="#">Ranal (1999)</a> ; <a href="#">Quintanilla et al. (2000)</a>
Time for the last germination ( $t_g$ )	<b>LastGermTime</b>	It is the time for last germination to occur (e.g. Last day of germination)	time	Germination time	<a href="#">Edwards (1932)</a>
Time spread of germination or Germination distribution	<b>TimeSpreadGerm</b>	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	<a href="#">Al-Mudaris (1998)</a> ; <a href="#">Schrader and Graves (2000)</a> ; <a href="#">Kader (2005)</a>
Peak period of germination or Modal time of germination	<b>PeakGermTime</b>	It is the time in which highest frequency of germinated seeds are observed and need not be unique.	time	Germination time	<a href="#">Ranal and Santana (2006)</a>
Median germination time ( $t_{50}$ ) (Coolbear)	<b>t50</b>	It is the time to reach 50% of final/maximum germination. With argument <code>method</code> specified as " <code>coolbear</code> ", it is computed as follows. $t_{50} = T_i + \frac{(\frac{N+1}{2} - N_i)(T_j - T_i)}{N_j - N_i}$ 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 $N_i < \frac{N+1}{2} < N_j$ .	time	Germination time	<a href="#">Coolbear et al. (1984)</a>
Median germination time ( $t_{50}$ ) (Farooq)	<b>t50</b>	With argument <code>method</code> specified as " <code>farooq</code> ", it is computed as follows. $t_{50} = T_i + \frac{(\frac{N}{2} - N_i)(T_j - T_i)}{N_j - N_i}$ 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 $N_i < \frac{N}{2} < N_j$ .	time	Germination time	<a href="#">Farooq et al. (2005)</a>

Germination index	Function	Details	Unit	Measures	Reference
Mean germination time or Mean length of incubation time ( $\bar{T}$ ) or Germination resistance ( $GR$ ) or Sprouting index ( $SI$ ) or Emergence index ( $EI$ )	<b>MeanGermTime</b>	<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, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> is the total number of time intervals.</p> <p>It is the inverse of mean germination rate (<math>\bar{V}</math>).</p> $\bar{T} = \frac{1}{\bar{V}}$	time	Germination time	<a href="#">Edmond and Drapala (1958)</a> ; <a href="#">Czabator (1962)</a> ; <a href="#">Smith and Millet (1964)</a> ; <a href="#">Gordon (1969)</a> ; <a href="#">Gordon (1971)</a> ; <a href="#">Mock and Eberhart (1972)</a> ; <a href="#">Ellis and Roberts (1980)</a> <a href="#">Labouriau (1983a)</a> ; <a href="#">Ranal and Santana (2006)</a>
Variance of germination time ( $s_T^2$ )	<b>VarGermTime</b>	<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, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> is the total number of time intervals.</p>	time	Germination time	<a href="#">Labouriau (1983a)</a> ; <a href="#">Ranal and Santana (2006)</a>
Standard error of germination time ( $s_{\bar{T}}$ )	<b>SEGermTime</b>	<p>It signifies the accuracy of the calculation of the mean germination time.</p> <p>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, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval) and <math>k</math> is the total number of time intervals.</p>	time	Germination time	<a href="#">Labouriau (1983a)</a> ; <a href="#">Ranal and Santana (2006)</a>

Germination index	Function	Details	Unit	Measures	Reference
Mean germination rate ( $\bar{V}$ )	<b>MeanGermRate</b>	<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, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> is the total number of time intervals.</p> <p>It is the inverse of mean germination time (<math>\bar{T}</math>).</p> $\bar{V} = \frac{1}{\bar{T}}$	time <sup>-1</sup>	Germination rate	<a href="#">Labouriau and Valadares (1976)</a> ; <a href="#">Labouriau (1983b)</a> ; <a href="#">Ranal and Santana (2006)</a>
Coefficient of velocity of germination ( $CVG$ ) or Coefficient of rate of germination ( $CRG$ ) or Kotowski's coefficient of velocity	<b>CVG</b>	<p>It is estimated according to the following formula.</p> $CVG = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k N_i T_i} \times 100$ $CVG = \bar{V} \times 100$ <p>Where, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> is the total number of time intervals.</p>	% day <sup>-1</sup>	Germination rate	<a href="#">Kotowski (1926)</a> , <a href="#">Nichols and Heydecker (1968)</a> ; <a href="#">Bewley and Black (1994)</a> ; <a href="#">Labouriau (1983b)</a> ; <a href="#">Scott et al. (1984)</a>
Variance of germination rate ( $s_V^2$ )	<b>VarGermRate</b>	<p>It is calculated according to the following formula.</p> $s_V^2 = \bar{V}^4 \times s_T^2$ <p>Where, <math>s_T^2</math> is the variance of germination time.</p>	time <sup>-2</sup>	Germination rate	<a href="#">Labouriau (1983b)</a> ; <a href="#">Ranal and Santana (2006)</a>
Standard error of germination rate ( $s_{\bar{V}}$ )	<b>SEGermRate</b>	<p>It is estimated according to the following formula.</p> $s_{\bar{V}} = \sqrt{\frac{s_V^2}{\sum_{i=1}^k N_i}}$ <p>Where, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> is the total number of time intervals.</p>	time <sup>-1</sup>	Germination rate	<a href="#">Labouriau (1983b)</a> ; <a href="#">Ranal and Santana (2006)</a>
Germination rate as the reciprocal of the median time ( $v_{50}$ )	<b>GermRateRecip</b>	<p>It is the reciprocal of the median germination time (<math>t_{50}</math>).</p> $v_{50} = \frac{1}{t_{50}}$	time <sup>-1</sup>	Germination rate	<a href="#">Went (1957)</a> ; <a href="#">Labouriau (1983b)</a> ; <a href="#">Ranal and Santana (2006)</a>

Germination index	Function	Details	Unit	Measures	Reference
Speed of germination 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)	<b>GermSpeed</b>	<p>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.</p> $S = \sum_{i=1}^k \frac{N_i}{T_i}$ <p>Where, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>k</math> 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 <sup>-1</sup>	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)
Speed of accumulated germination	<b>GermSpeedAccumulated</b>	<p>It is the rate of germination in terms of the accumulated/cumulative total number of seeds that germinate in a time interval. It is estimated as follows.</p> $S_{accumulated} = \sum_{i=1}^k \frac{\sum_{j=1}^i N_j}{T_i}$ <p>Where, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>\sum_{j=1}^i N_j</math> is the cumulative/accumulated number of seeds germinated in the <math>i</math>th interval, and <math>k</math> 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 <sup>-1</sup>	Mixed	Bradbeer (1988); Wardle et al. (1991); Haugland and Brandsaeter (1996); Santana and Ranal (2004)
Corrected germination rate index	<b>GermSpeedCorrected</b>	<p>It is computed as follows.</p> $S_{corrected} = \frac{S}{FGP}$ <p>Where, <math>FGP</math> is the final germination percentage or germinability.</p>	time <sup>-1</sup>	Mixed	Evetts and Burnside (1972)
Weighted germination percentage ( $WGP$ )	<b>WeightGermPercent</b>	<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, <math>N_i</math> is the number of seeds that germinated in the time interval <math>i</math> (not cumulative, but partial count), <math>N</math> is the total number of seeds tested, and <math>k</math> is the total number of time intervals.</p>		Mixed	Reddy et al. (1985); Reddy (1978)

Germination index	Function	Details	Unit	Measures	Reference
Mean germination percentage per unit time ( $GP$ )	<b>MeanGermPercent</b>	<p>It is estimated as follows.</p> $\overline{GP} = \frac{GP}{T_k}$ <p>Where, <math>GP</math> is the final germination percentage, <math>T_k</math> is the time at the <math>k</math>th time interval, and <math>k</math> is the total number of time intervals required for final germination.</p>		Mixed	<a href="#">Czabator (1962)</a>
Number of seeds germinated per unit time $\overline{N}$	<b>MeanGermNumber</b>	<p>It is estimated as follows.</p> $\overline{N} = \frac{N_g}{T_k}$ <p>Where, <math>N_g</math> is the number of germinated seeds at the end of the germination test, <math>T_k</math> is the time at the <math>k</math>th time interval, and <math>k</math> is the total number of time intervals required for final germination.</p>		Mixed	<a href="#">Khamassi et al. (2013)</a>
Timson's index [ $\sum 10$ (Ten summation), $\sum 5$ or $\sum 20$ ] or Germination energy index ( $GEI$ )	<b>TimsonsIndex</b>	<p>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 (<math>G_i</math>) as follows.</p> $\Sigma k = \sum_{i=1}^k G_i$ <p>Where, <math>G_i</math> is the cumulative germination percentage in time interval <math>i</math>, and <math>k</math> is the total number of time intervals. It also estimated in terms of partial germination percentage as follows.</p> $\Sigma k = \sum_{i=1}^k g_i(k-j)$ <p>Where, <math>g_i</math> is the germination (not cumulative, but partial germination) in time interval <math>i</math> (<math>i</math> varying from 0 to <math>k</math>), <math>k</math> is the total number of time intervals, and <math>j = i - 1</math>.</p>		Mixed	<a href="#">Grose and Zimmer (1958)</a> ; <a href="#">Timson (1965)</a> ; <a href="#">Lyon and Coffelt (1966)</a> ; <a href="#">Chaudhary and Ghildyal (1970)</a> ; <a href="#">Negm and Smith (1978)</a> ; <a href="#">Brown and Mayer (1988)</a> ; <a href="#">Baskin and Baskin (1998)</a> ; <a href="#">Goodchild and Walker (1971)</a>
Modified Timson's index ( $\Sigma k_{mod}$ ) (Labouriau)	<b>TimsonsIndex</b>	<p>It is estimated as Timson's index <math>\Sigma k</math> divided by the sum of partial germination percentages.</p> $\Sigma k_{mod} = \frac{\Sigma k}{\sum_{i=1}^k g_i}$		Mixed	<a href="#">Ranal and Santana (2006)</a>
Modified Timson's index ( $\Sigma k_{mod}$ ) (Khan and Unger)	<b>TimsonsIndex</b>	<p>It is estimated as Timson's index (<math>\Sigma k</math>) divided by the total time period of germination (<math>T_k</math>).</p> $\Sigma k_{mod} = \frac{\Sigma k}{T_k}$		Mixed	<a href="#">Khan and Ungar (1984)</a>



Germination index	Function	Details	Unit	Measures	Reference
George's index ( <i>GR</i> )	<b>GermRateGeorge</b>	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.		Mixed	<a href="#">George (1961)</a> ; <a href="#">Tucker and Wright (1965)</a> ; <a href="#">Nichols and Heydecker (1968)</a>
Germination Index ( <i>GI</i> ) (Melville)	<b>GermIndex</b>	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.		Mixed	<a href="#">Melville et al. (1980)</a>
Germination Index ( <i>GI<sub>mod</sub></i> ) (Melville; Santana and Ranal)	<b>GermIndex</b>	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.		Mixed	<a href="#">Melville et al. (1980)</a> ; <a href="#">Santana and Ranal (2004)</a> ; <a href="#">Ranal and Santana (2006)</a>
Emergence Rate Index ( <i>ERI</i> ) or Germination Rate Index (Shmueli and Goldberg)	<b>EmergenceRateIndex</b>	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.		Mixed	<a href="#">Shmueli and Goldberg (1971)</a>

Germination index	Function	Details	Unit	Measures	Reference
Modified Emergence Rate Index ( $ERI_{mod}$ ) or Modified Germination Rate Index (Shmueli and Goldberg; Santana and Ranal)	<b>EmergenceRateIndex</b>	<p>It is estimated by dividing Emergence rate index (<math>ERI</math>) 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, <math>N_g</math> is the total number of germinated seeds at the end of the test, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), <math>i_0</math> is the time interval when emergence/germination started, and <math>k</math> is the total number of time intervals.</p>		Mixed	<a href="#">Shmueli and Goldberg (1971)</a> ; <a href="#">Santana and Ranal (2004)</a> ; <a href="#">Ranal and Santana (2006)</a>
Emergence Rate Index ( $ERI$ ) or Germination Rate Index (Bilbro & Wanjura)	<b>EmergenceRateIndex</b>	<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, <math>N_g</math> is the total number of germinated seeds at the end of the test, <math>N_i</math> is the number of seeds germinated in the <math>i</math>th time interval (not the accumulated number, but the number corresponding to the <math>i</math>th interval), and <math>\bar{T}</math> is the mean germination time or mean emergence time.</p>		Mixed	<a href="#">Bilbro and Wanjura (1982)</a>
Emergence Rate Index ( $ERI$ ) or Germination Rate Index (Fakorede)	<b>EmergenceRateIndex</b>	<p>It is estimated as follows.</p> $ERI = \frac{\bar{T}}{FGP/100}$ <p>Where, <math>\bar{T}</math> is the Mean germination time and <math>FGP</math> is the final germination time.</p>		Mixed	<a href="#">Fakorede and Ayoola (1980)</a> ; <a href="#">Fakorede and Ojo (1981)</a> ; <a href="#">Fakorede and Agbana (1983)</a>
Peak value( $PV$ ) (Czabator) or Emergence Energy ( $EE$ )	<b>PeakValue</b>	<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, <math>T_i</math> is the time from the start of the experiment to the <math>i</math>th interval, <math>G_i</math> is the cumulative germination percentage in the <math>i</math>th time interval, and <math>k</math> is the total number of time intervals.</p>	% time <sup>-1</sup>	Mixed	<a href="#">Czabator (1962)</a> ; <a href="#">Bonner (1967)</a>

Germination index	Function	Details	Unit	Measures	Reference
Germination value ( <i>GV</i> ) (Czabator)	<b>GermValue</b>	<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 (<math>\overline{GP}</math>). <i>GV</i> value can be modified (<math>GV_{mod}</math>), to consider the entire duration from the beginning of the test instead of just from the onset of germination.</p>		Mixed	<a href="#">Czabator (1962)</a> ; <a href="#">Brown and Mayer (1988)</a>
Germination value ( <i>GV</i> ) (Diavanshir and Pourbiek)	<b>GermValue</b>	<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 (<math>\frac{\sum DGS}{N}</math>). 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 (<math>GV_{mod}</math>), to consider the entire duration from the beginning of the test instead of just from the onset of germination.</p>		Mixed	<a href="#">Djavanshir and Pourbeik (1976)</a> ; <a href="#">Brown and Mayer (1988)</a>
Coefficient of uniformity of germination ( <i>CUG</i> )	<b>CUGerm</b>	<p>It is computed as follows.</p> $CUG = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k (\bar{T} - T_i)^2 N_i}$ <p>Where, <math>\bar{T}</math> is the the mean germination time, <math>T_i</math> is the time from the start of the experiment to the <i>i</i>th interval (day for the example), <math>N_i</math> 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>		Germination uniformity	<a href="#">Heydecker (1972)</a> ; <a href="#">Bewley and Black (1994)</a>
Coefficient of variation of the germination time ( $CV_T$ )	<b>CVGermTime</b>	<p>It is estimated as follows.</p> $CV_T = \sqrt{\frac{s_T^2}{\bar{T}}}$ <p>Where, <math>s_T^2</math> is the variance of germination time and <math>\bar{T}</math> is the mean germination time.</p>		Germination uniformity	<a href="#">Gomes (1960)</a> ; <a href="#">Ranal and Santana (2006)</a>

Germination index	Function	Details	Unit	Measures	Reference
Synchronization index ( $\bar{E}$ ) or Uncertainty of the germination process ( $U$ ) or informational entropy ( $H$ )	<b>GermUncertainty</b>	<p>It is estimated as follows.</p> $\bar{E} = - \sum_{i=1}^k f_i \log_2 f_i$ <p>Where, <math>f_i</math> is the relative frequency of germination (<math>f_i = \frac{N_i}{\sum_{i=1}^k N_i}</math>), <math>N_i</math> is the number of seeds germinated on the <math>i</math>th time interval, and <math>k</math> is the total number of time intervals.</p>	bit	Germination synchrony	<a href="#">Shannon (1948)</a> ; <a href="#">Labouriau and Valadares (1976)</a> ; <a href="#">Labouriau (1983b)</a>
Synchrony of germination ( $Z$ index)	<b>GermSynchrony</b>	<p>It is computed as follows.</p> $Z = \frac{\sum_{i=1}^k C_{N_i,2}}{C_{\Sigma N_i,2}}$ <p>Where, <math>C_{N_i,2}</math> is the partial combination of the two germinated seeds from among <math>N_i</math>, the number of seeds germinated on the <math>i</math>th time interval (estimated as <math>C_{N_i,2} = \frac{N_i(N_i-1)}{2}</math>), and <math>C_{\Sigma N_i,2}</math> 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>		Germination synchrony	<a href="#">Primack (1985)</a> ; <a href="#">Ranal and Santana (2006)</a>

## 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)
```

```
# From partial germination counts
GermPercent(germ.counts = x, total.seeds = 50)
```

```
GermPercent()
```

```
[1] 80
```

```
# From cumulative germination counts
GermPercent(germ.counts = y, total.seeds = 50, partial = FALSE)
```

```
[1] 80
```

```
# 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, 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] 19.04012
SEGermTime(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.2394781
CVGermTime(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.6512685

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] 0.009448666
SEGermRate(germ.counts = y, intervals = int, partial = FALSE)

[1] 0.005334776
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] 0.07673656
GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                  method = "accumulated")

[1] 0.4326958

# 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] 0.07673656
```

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

```
[1] 0.4326958
```

```
# 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
```

```
#-----
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] 0.07673656
```

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

```
[1] 0.4326958
```

```
# 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] 0.07673656
```

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

```
[1] 0.4326958
```

```
# 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)
```

```
EmergenceRateIndex()
```

```
[1] 292
```

```
EmergenceRateIndex(germ.counts = x, intervals = int,
                  method = "melville")
```

```
[1] 292
```

```
EmergenceRateIndex(germ.counts = x, intervals = int,
                  method = "melvillesantanaranal")
```

```
[1] 7.3
```

```
EmergenceRateIndex(germ.counts = x, intervals = int,
                  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, partial = FALSE,)
```

```
[1] 292
```

```
EmergenceRateIndex(germ.counts = y, intervals = int, partial = FALSE,
                  method = "melville")
```

[1] 292

```
EmergenceRateIndex(germ.counts = y, intervals = int, partial = FALSE,
                    method = "melvillesantanaranal")
```

[1] 7.3

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

[1] 5.970149

```
EmergenceRateIndex(germ.counts = y, intervals = int, partial = FALSE,
                    total.seeds = 50, 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	DGS
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	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	DGS
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	4.100000

	SumDGSbyN	GV
3	5.666667	9.633333
4	7.458333	27.595833
5	8.138889	38.659722
6	8.291667	43.531250
7	8.190476	44.638095
8	8.012897	45.673512
9	7.796769	45.611097
10	7.584673	46.266503
11	7.398497	48.090230
12	7.229481	49.521942
13	7.075752	50.945411
14	6.932534	51.994006
15	6.799262	53.034246
16	6.670744	53.365948
17	6.539753	52.318022
18	6.412268	51.939373
19	6.285850	50.915385
20	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    DGS
1           0         1                   0                0.0 0.000000
2           0         2                   0                0.0 0.000000
3          34         3                  34               17.0 5.666667
4          40         4                  74               37.0 9.250000
5          21         5                  95               47.5 9.500000
6          10         6                 105               52.5 8.750000
7           4         7                 109               54.5 7.785714
8           5         8                 114               57.0 7.125000
9           3         9                 117               58.5 6.500000
10          5        10                 122               61.0 6.100000
11          8        11                 130               65.0 5.909091
12          7        12                 137               68.5 5.708333
13          7        13                 144               72.0 5.538462
14          6        14                 150               75.0 5.357143
15          6        15                 156               78.0 5.200000
16          4        16                 160               80.0 5.000000
17          0        17                 160               80.0 4.705882
18          2        18                 162               81.0 4.500000
19          0        19                 162               81.0 4.263158
20          2        20                 164               82.0 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    DGS
1           0         1                   0                0.0 0.000000
2           0         2                   0                0.0 0.000000
3          34         3                  34               17.0 5.666667
4          40         4                  74               37.0 9.250000
5          21         5                  95               47.5 9.500000
6          10         6                 105               52.5 8.750000
7           4         7                 109               54.5 7.785714
8           5         8                 114               57.0 7.125000
9           3         9                 117               58.5 6.500000
10          5        10                 122               61.0 6.100000
11          8        11                 130               65.0 5.909091
12          7        12                 137               68.5 5.708333
13          7        13                 144               72.0 5.538462
14          6        14                 150               75.0 5.357143
15          6        15                 156               78.0 5.200000
16          4        16                 160               80.0 5.000000
17          0        17                 160               80.0 4.705882
18          2        18                 162               81.0 4.500000
19          0        19                 162               81.0 4.263158
20          2        20                 164               82.0 4.100000

  SumDGSbyN    GV
1 0.000000 0.000000
2 0.000000 0.000000
```

```

3  1.888889  3.211111
4  3.729167 13.797917
5  4.883333 23.195833
6  5.527778 29.020833
7  5.850340 31.884354
8  6.009673 34.255134
9  6.064153 35.475298
10 6.067738 37.013202
11 6.053316 39.346552
12 6.024567 41.268285
13 5.987174 43.107655
14 5.942172 44.566291
15 5.892694 45.963013
16 5.836901 46.695205
17 5.770370 46.162961
18 5.699794 46.168331
19 5.624182 45.555871
20 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	DGS
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	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	DGS
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	4.100000

	SumDGSbyN	GV
3	5.666667	9.633333
4	7.458333	27.595833
5	8.138889	38.659722
6	8.291667	43.531250
7	8.190476	44.638095
8	8.012897	45.673512
9	7.796769	45.611097
10	7.584673	46.266503
11	7.398497	48.090230
12	7.229481	49.521942
13	7.075752	50.945411
14	6.932534	51.994006
15	6.799262	53.034246
16	6.670744	53.365948
17	6.539753	52.318022
18	6.412268	51.939373
19	6.285850	50.915385
20	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	DGS
1	0	1	0	0.0	0.000000
2	0	2	0	0.0	0.000000
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	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	DGS
1	0	1	0	0.0	0.000000
2	0	2	0	0.0	0.000000
3	34	3	34	17.0	5.666667
4	40	4	74	37.0	9.250000
5	21	5	95	47.5	9.500000
6	10	6	105	52.5	8.750000
7	4	7	109	54.5	7.785714
8	5	8	114	57.0	7.125000
9	3	9	117	58.5	6.500000
10	5	10	122	61.0	6.100000
11	8	11	130	65.0	5.909091
12	7	12	137	68.5	5.708333
13	7	13	144	72.0	5.538462
14	6	14	150	75.0	5.357143
15	6	15	156	78.0	5.200000
16	4	16	160	80.0	5.000000
17	0	17	160	80.0	4.705882
18	2	18	162	81.0	4.500000
19	0	19	162	81.0	4.263158
20	2	20	164	82.0	4.100000

	SumDGSbyN	GV
1	0.000000	0.000000
2	0.000000	0.000000

```

3  1.888889  3.211111
4  3.729167 13.797917
5  4.883333 23.195833
6  5.527778 29.020833
7  5.850340 31.884354
8  6.009673 34.255134
9  6.064153 35.475298
10 6.067738 37.013202
11 6.053316 39.346552
12 6.024567 41.268285
13 5.987174 43.107655
14 5.942172 44.566291
15 5.892694 45.963013
16 5.836901 46.695205
17 5.770370 46.162961
18 5.699794 46.168331
19 5.624182 45.555871
20 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] 0.05267935

```

```

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.”

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
$lag$	It is the time at germination onset and is computed by solving four-parameter hill function after setting $y$ to 0 as follows.	time	Germination time
$lag = b \sqrt{\frac{-y_0 c^b}{a + y_0}}$			
$D_{lag-50}$	The duration between the time at germination onset ( $lag$ ) and that at 50% germination ( $c$ ).	time	Germination time

Germination parameters	Details	Unit	Measures
$t_{50_{total}}$	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 <b>umin</b> and <b>umax</b> to germinate.	time	Germination time
Time at maximum germination rate ( $TMGR$ )	<p>The partial derivative of the four-parameter hill function gives the instantaneous rate of germination (<math>s</math>) as follows.</p> $s = \frac{\partial y}{\partial x} = \frac{abc^b x^{b-1}}{(c^b + x^b)^2}$ <p>From this function for instantaneous rate of germination, <math>TMGR</math> can be estimated as follows.</p> $TMGR = b \sqrt{\frac{c^b(b-1)}{b+1}}$ <p>It represents the point in time when the instantaneous rate of germination starts to decline.</p>	time	Germination time
Area under the curve ( $AUC$ )	It is obtained by integration of the fitted curve between time 0 and time specified in the argument <b>tmax</b> .		Mixed
$MGT$	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      a 80.000000 1.24158595  64.43372 1.973240e-14
2      b  9.881947 0.70779379  13.96162 6.952322e-08
3      c  6.034954 0.04952654 121.85294 3.399385e-17
4     y0  0.000000 0.91607007   0.00000 1.000000e+00

```

`$Fit`

```

      sigma isConv      finTol    logLik      AIC      BIC deviance df.residual
1 1.769385  TRUE 1.490116e-08 -25.49868 60.99736 64.19265 31.30723          10
      nobs
1     14

```

`$a`

```
[1] 80
```

`$b`

```
[1] 9.881947
```

`$c`

```
[1] 6.034954
```

`$y0`

```
[1] 0
```

`$lag`

```
[1] 0
```

`$Dlag50`

```
[1] 6.034954
```

`$t50.total`

```
[1] 6.355122
```

`$txp.total`

```

      10      60
4.956266 6.744598

```



```

$t50.Germinated
[1] 6.034954

$txp.Germinated
      10      60
4.831809 6.287724

$Uniformity
      90      10 uniformity
7.537688 4.831809 2.705880

$TMGR
[1] 5.912195

$AUC
[1] 1108.975

$MGT
[1] 6.632252

$Skewness
[1] 1.098973

$msg
[1] "#1. Relative error in the sum of squares is at most `ftol'. "

$isConv
[1] TRUE

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      a 80.000000 1.2415867  64.43368 1.973252e-14
2      b  9.881927 0.7077918  13.96163 6.952270e-08
3      c  6.034953 0.0495266 121.85275 3.399437e-17
4     y0  0.000000 0.9160705   0.00000 1.000000e+00

$Fit
      sigma isConv      finTol    logLik      AIC      BIC deviance df.residual
1 1.769385  TRUE 1.490116e-08 -25.49868 60.99736 64.19265 31.30723          10
  nobs
1   14

$a
[1] 80

$b
[1] 9.881927

$c
[1] 6.034953

$y0
[1] 0

$lag
[1] 0

$Dlag50
[1] 6.034953

$t50.total
[1] 6.355121

$txp.total
      10      60
4.956263 6.744599

$t50.Germinated
[1] 6.034953

$txp.Germinated
      10      60
4.831806 6.287723

$Uniformity
      90      10 uniformity
7.537691 4.831806 2.705885

$TMGR
[1] 5.912194

$AUC
[1] 1108.976

```

```
$MGT
[1] 6.632252

$Skewness
[1] 1.098973

$msg
[1] "#1. Relative error in the sum of squares is at most `ftol'. "

$isConv
[1] TRUE

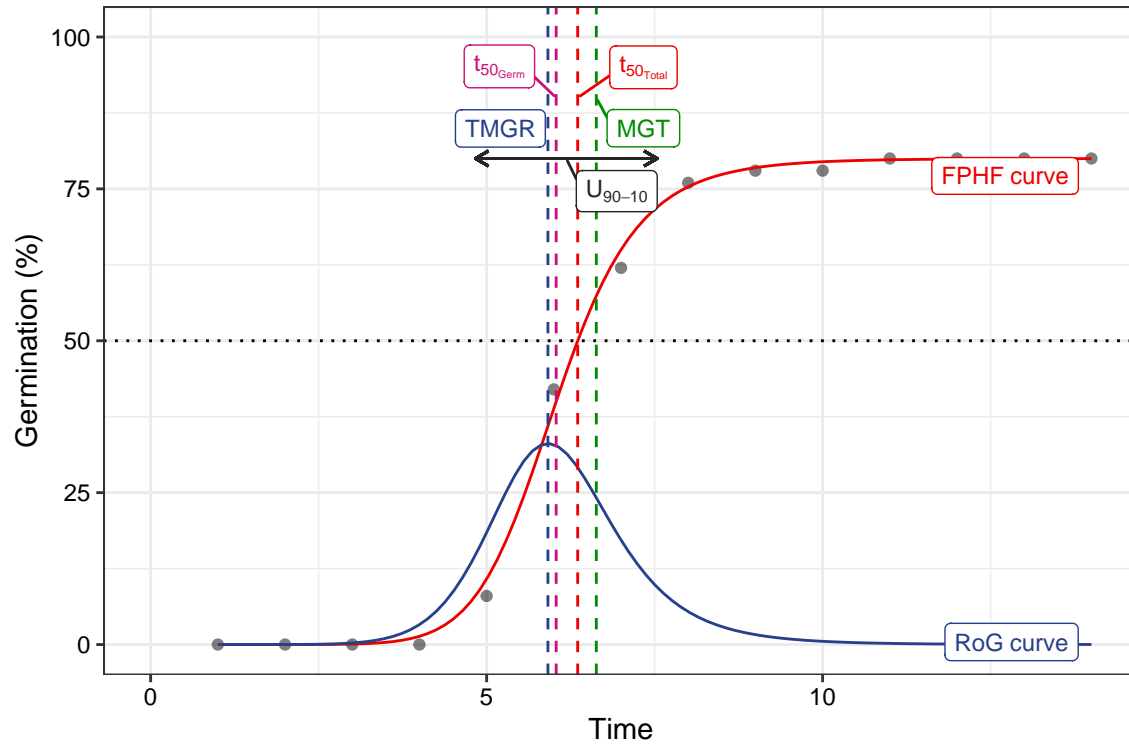
attr("class")
[1] "FourPHFfit" "list"

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

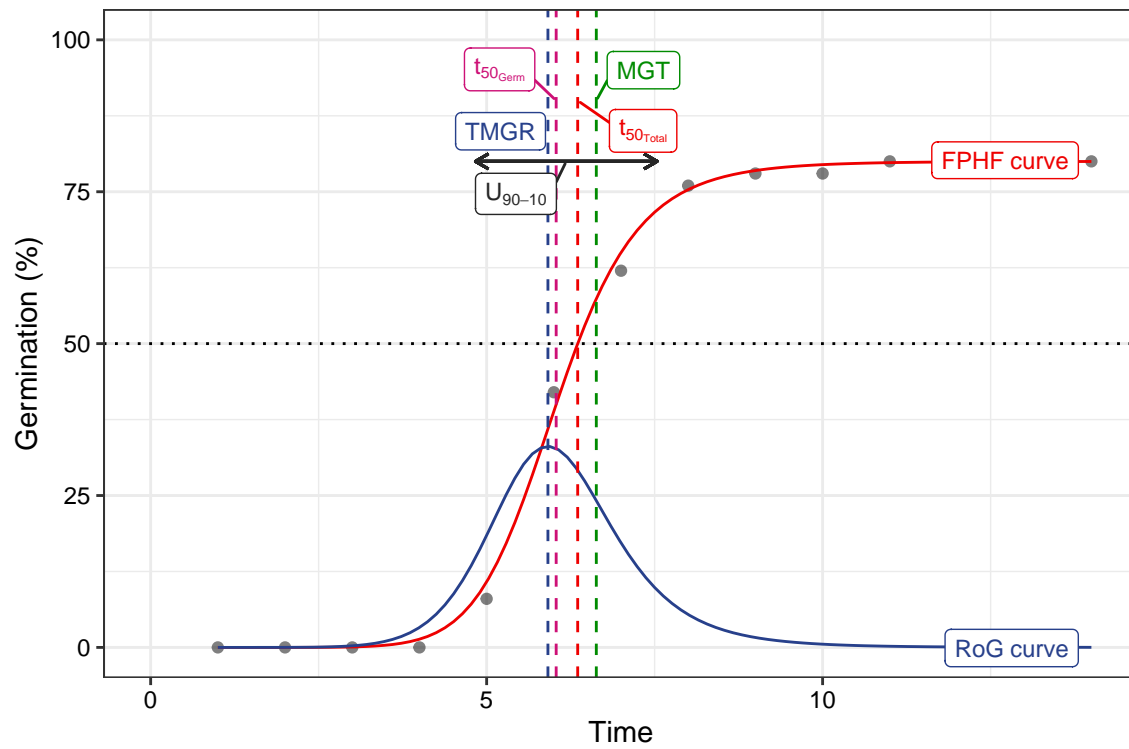
# From partial germination counts
#-----
fit1 <- FourPHFfit(germ.counts = x, intervals = int,
                  total.seeds = 50, tmax = 20)

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

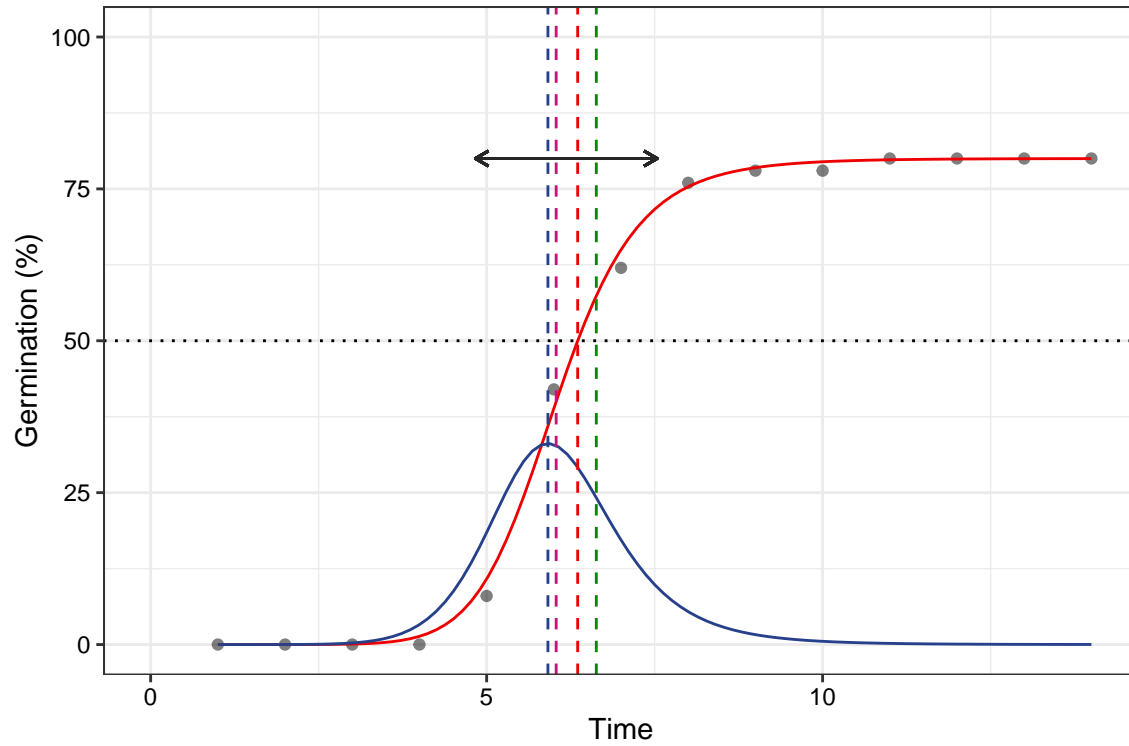
# Default plots
plot(fit1)
```



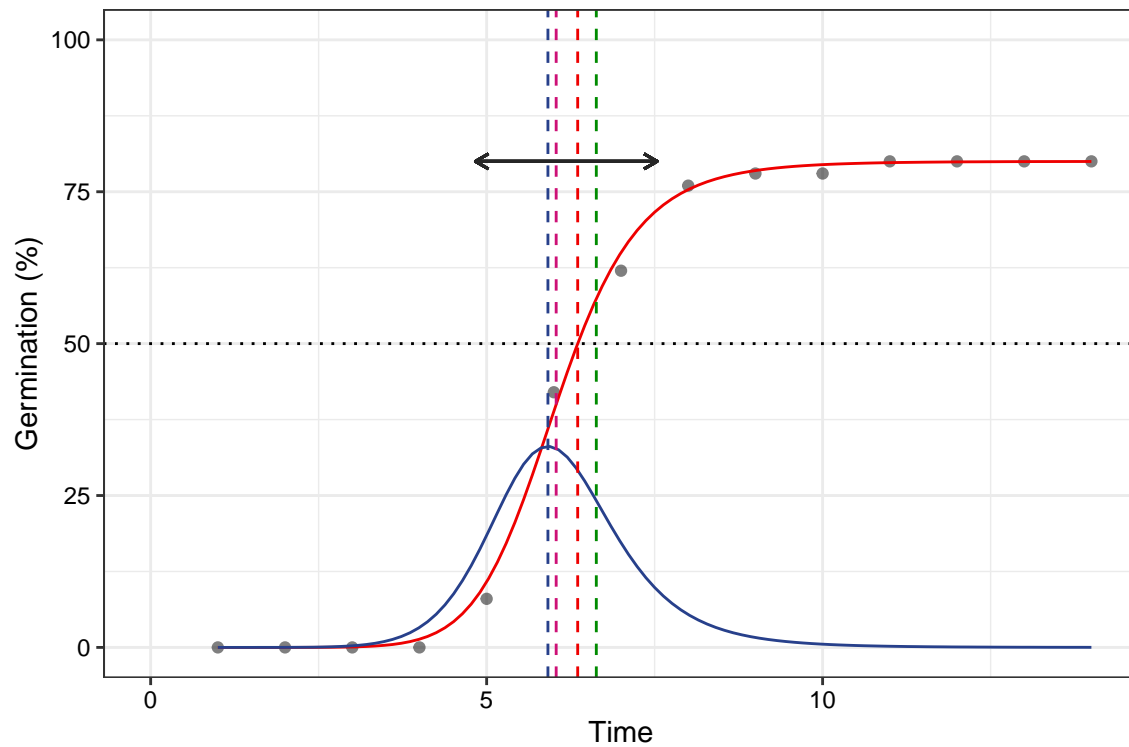
```
plot(fit2)
```



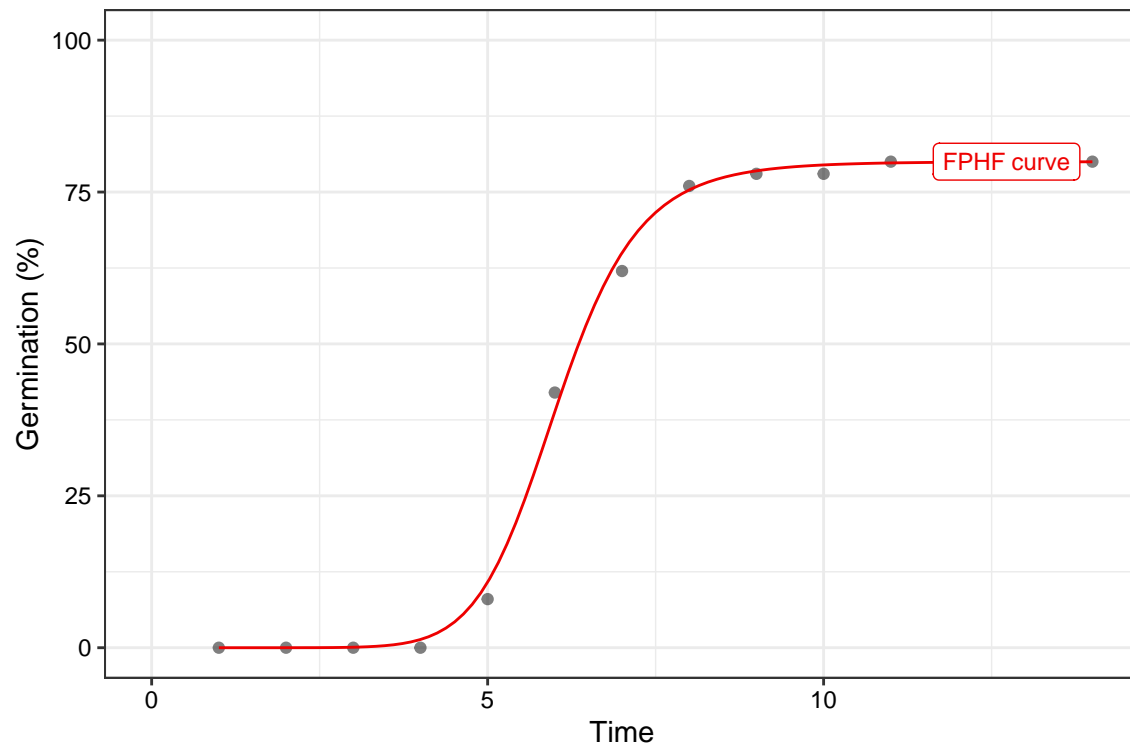
```
# No labels
plot(fit1, plotlabels = FALSE)
```



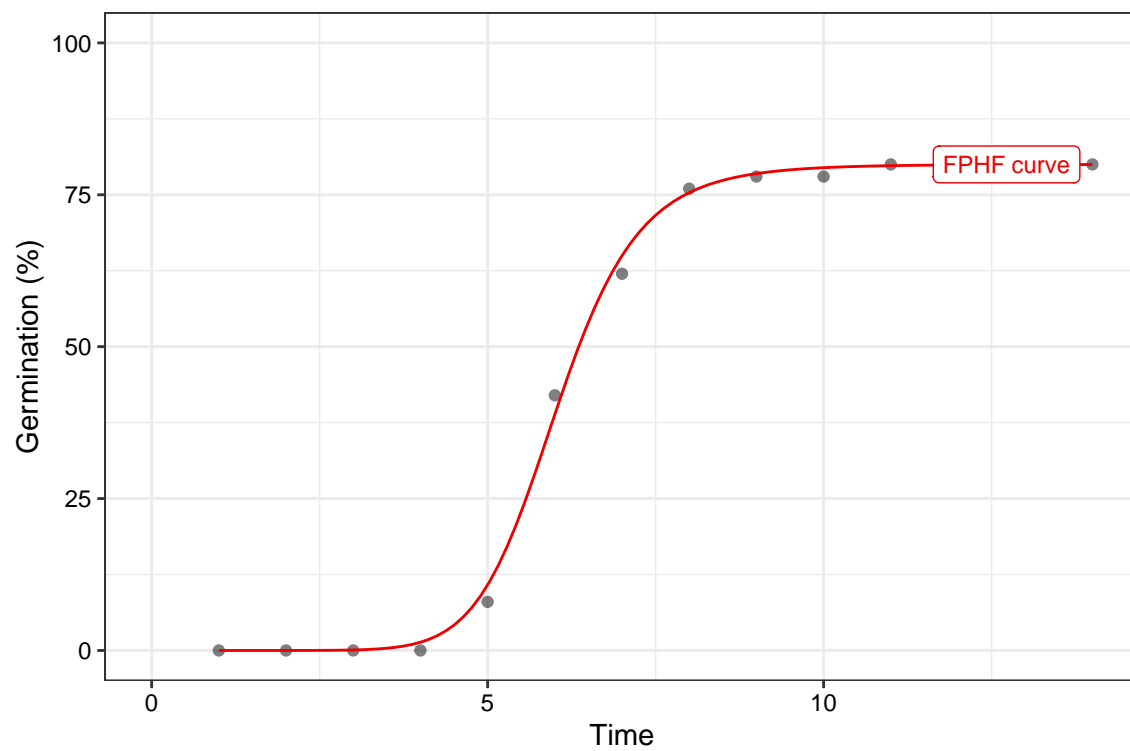
```
plot(fit2, plotlabels = FALSE)
```



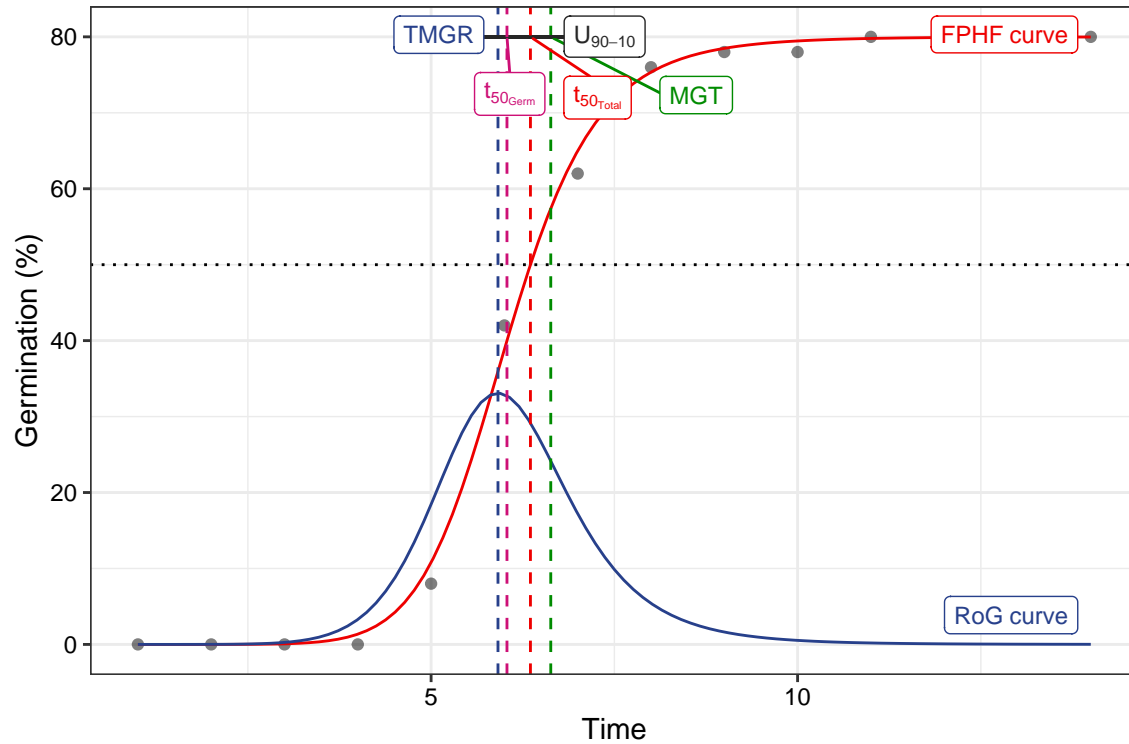
```
# Only the FPGHF curve
plot(fit1, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```



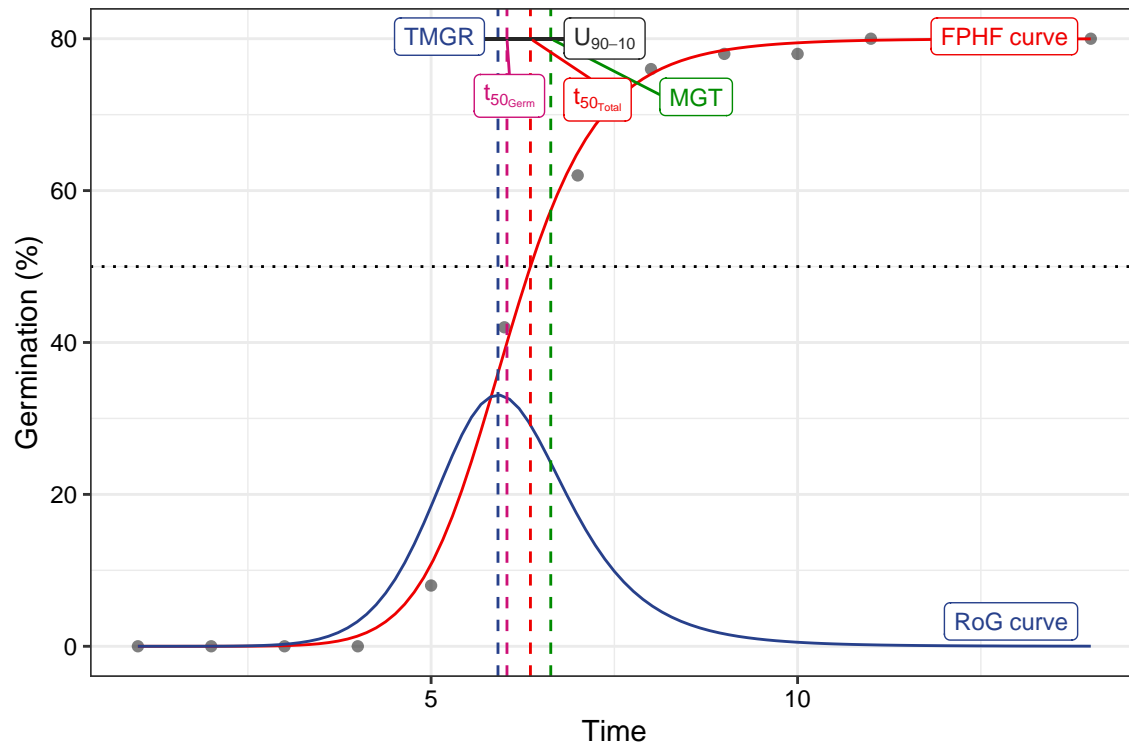
```
plot(fit2, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,  
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```



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



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



## 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	Day11
1	G1	1	0	0	0	0	4	17	10	7	1	0	1
2	G2	1	0	0	0	1	3	15	13	6	2	1	0
3	G3	1	0	0	0	2	3	18	9	8	2	1	1
4	G4	1	0	0	0	0	4	19	12	6	2	1	1
5	G5	1	0	0	0	0	5	20	12	8	1	0	0
6	G1	2	0	0	0	0	3	21	11	7	1	1	1
7	G2	2	0	0	0	0	4	18	11	7	1	0	1
8	G3	2	0	0	0	1	3	14	12	6	2	1	0
9	G4	2	0	0	0	1	3	19	10	8	1	1	1
10	G5	2	0	0	0	0	4	18	13	6	2	1	0
11	G1	3	0	0	0	0	5	21	11	8	1	0	0
12	G2	3	0	0	0	0	3	20	10	7	1	1	1
13	G3	3	0	0	0	0	4	19	12	8	1	1	0
14	G4	3	0	0	0	0	3	21	11	6	1	0	1
15	G5	3	0	0	0	0	4	17	10	8	1	1	1
	Day12	Day13	Day14	Total	Seeds	GermPercent	FirstGermTime	LastGermTime					
1	0	0	0		50	80.00000		5		11			
2	1	0	0		51	82.35294		4		12			
3	1	0	0		48	93.75000		4		12			
4	1	0	0		51	90.19608		5		12			
5	1	1	0		50	96.00000		5		13			
6	1	0	0		49	93.87755		5		12			
7	0	0	0		48	87.50000		5		11			
8	1	0	0		47	85.10638		4		12			
9	1	0	0		52	86.53846		4		12			
10	1	0	0		50	90.00000		5		12			
11	1	1	0		51	94.11765		5		13			
12	1	0	0		51	86.27451		5		12			
13	1	1	0		49	95.91837		5		13			
14	1	0	0		48	91.66667		5		12			
15	0	0	0		48	87.50000		5		11			
	PeakGermTime	TimeSpreadGerm	t50_Coolbear	t50_Farooq	MeanGermTime	VarGermTime							
1	6		6	5.970588	5.941176	6.700000	1.446154						
2	6		8	6.192308	6.153846	6.857143	2.027875						
3	6		8	6.000000	5.972222	6.866667	2.572727						
4	6		7	6.041667	6.000000	6.891304	2.187923						



5	6	8	5.975000	5.950000	6.812500	2.368351
6	6	7	5.976190	5.952381	6.869565	2.071498
7	6	6	5.972222	5.944444	6.690476	1.389663
8	6	8	6.208333	6.166667	6.875000	2.112179
9	6	8	6.000000	5.973684	6.866667	2.300000
10	6	7	6.076923	6.038462	6.822222	1.831313
11	6	8	5.928571	5.904762	6.791667	2.381206
12	6	7	5.975000	5.950000	6.886364	2.149577
13	6	8	6.083333	6.041667	6.936170	2.539315
14	6	7	5.928571	5.904762	6.772727	1.900634
15	6	6	6.050000	6.000000	6.809524	1.670151

	SEGermTime	CVGermTime	MeanGermRate	VarGermRate	SEGermRate	CVG
1	0.1901416	0.1794868	0.1492537	0.0007176543	0.004235724	14.92537
2	0.2197333	0.2076717	0.1458333	0.0009172090	0.004673148	14.58333
3	0.2391061	0.2335882	0.1456311	0.0011572039	0.005071059	14.56311
4	0.2180907	0.2146419	0.1451104	0.0009701218	0.004592342	14.51104
5	0.2221275	0.2259002	0.1467890	0.0010995627	0.004786184	14.67890
6	0.2122088	0.2095140	0.1455696	0.0009301809	0.004496813	14.55696
7	0.1818989	0.1761967	0.1494662	0.0006935558	0.004063648	14.94662
8	0.2297923	0.2113940	0.1454545	0.0009454531	0.004861721	14.54545
9	0.2260777	0.2208604	0.1456311	0.0010345321	0.004794747	14.56311
10	0.2017321	0.1983606	0.1465798	0.0008453940	0.004334343	14.65798
11	0.2227295	0.2272072	0.1472393	0.0011191581	0.004828643	14.72393
12	0.2210295	0.2129053	0.1452145	0.0009558577	0.004660905	14.52145
13	0.2324392	0.2297410	0.1441718	0.0010970785	0.004831366	14.41718
14	0.2078370	0.2035568	0.1476510	0.0009033254	0.004531018	14.76510
15	0.1994129	0.1897847	0.1468531	0.0007767634	0.004300508	14.68531

	GermRateRecip_Coolbear	GermRateRecip_Farooq	GermSpeed_Count	GermSpeed_Percent
1	0.1674877	0.1683168	6.138925	12.27785
2	0.1614907	0.1625000	6.362698	12.47588
3	0.1666667	0.1674419	6.882179	14.33787
4	0.1655172	0.1666667	6.927417	13.58317
5	0.1673640	0.1680672	7.318987	14.63797
6	0.1673307	0.1680000	6.931782	14.14649
7	0.1674419	0.1682243	6.448449	13.43427
8	0.1610738	0.1621622	6.053175	12.87909
9	0.1666667	0.1674009	6.830592	13.13575
10	0.1645570	0.1656051	6.812698	13.62540
11	0.1686747	0.1693548	7.342796	14.39764
12	0.1673640	0.1680672	6.622258	12.98482
13	0.1643836	0.1655172	7.052320	14.39249
14	0.1686747	0.1693548	6.706782	13.97246
15	0.1652893	0.1666667	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	0.07673656	0.4326958 47.42857
2	0.07726134	0.4315642 47.89916
3	0.07340991	0.4085040 54.46429
4	0.07680397	0.4288937 52.24090
5	0.07623944	0.4271652 56.14286
6	0.07383855	0.4130508 54.51895
7	0.07369656	0.4158338 51.93452
8	0.07112480	0.3968068 49.39210
9	0.07893128	0.4404413 50.27473
10	0.07569665	0.4243919 52.57143
11	0.07801721	0.4374793 55.18207
12	0.07675799	0.4289379 50.00000
13	0.07352419	0.4096608 55.24781
14	0.07316490	0.4112171 53.86905
15	0.07273057	0.4079653 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_Melville EmergenceRateIndex_Melville_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	Day11
1	G1	1	0	0	0	0	4	17	10	7	1	0	1
2	G2	1	0	0	0	1	3	15	13	6	2	1	0
3	G3	1	0	0	0	2	3	18	9	8	2	1	1
4	G4	1	0	0	0	0	4	19	12	6	2	1	1
5	G5	1	0	0	0	0	5	20	12	8	1	0	0
6	G1	2	0	0	0	0	3	21	11	7	1	1	1
7	G2	2	0	0	0	0	4	18	11	7	1	0	1
8	G3	2	0	0	0	1	3	14	12	6	2	1	0
9	G4	2	0	0	0	1	3	19	10	8	1	1	1
10	G5	2	0	0	0	0	4	18	13	6	2	1	0
11	G1	3	0	0	0	0	5	21	11	8	1	0	0
12	G2	3	0	0	0	0	3	20	10	7	1	1	1
13	G3	3	0	0	0	0	4	19	12	8	1	1	0
14	G4	3	0	0	0	0	3	21	11	6	1	0	1
15	G5	3	0	0	0	0	4	17	10	8	1	1	1
	Day12	Day13	Day14	Total	Seeds	a	b	c	y0	lag	Dlag50		
1	0	0	0	50	80.00000	9.881947	6.034954	0	0	0	6.034954		
2	1	0	0	51	82.35294	9.227667	6.175193	0	0	0	6.175193		
3	1	0	0	48	93.75000	7.793055	6.138110	0	0	0	6.138110		
4	1	0	0	51	90.19608	8.925668	6.125172	0	0	0	6.125172		
5	1	1	0	50	96.00000	9.419194	6.049641	0	0	0	6.049641		
6	1	0	0	49	93.87755	9.450187	6.097412	0	0	0	6.097412		
7	0	0	0	48	87.50000	10.172466	6.029851	0	0	0	6.029851		
8	1	0	0	47	85.10638	8.940702	6.189774	0	0	0	6.189774		
9	1	0	0	52	86.53846	8.617395	6.125121	0	0	0	6.125121		
10	1	0	0	50	90.00000	9.608849	6.109503	0	0	0	6.109503		
11	1	1	0	51	94.11765	9.400248	6.018759	0	0	0	6.018759		
12	1	0	0	51	86.27451	9.162558	6.108449	0	0	0	6.108449		
13	1	1	0	49	95.91837	8.995233	6.149011	0	0	0	6.149011		

```

14      1      0      0      48 91.66667 10.391898 6.015907 0 0 6.015907
15      0      0      0      48 87.50000 9.136762 6.121580 0 0 6.121580
      t50.total t50.Germinated      TMGR      AUC      MGT Skewness
1  6.355122      6.034954 5.912195 1108.975 6.632252 1.098973
2  6.473490      6.175193 6.031282 1128.559 6.784407 1.098655
3  6.244190      6.138110 5.938179 1283.693 6.772742 1.103392
4  6.276793      6.125172 5.972686 1239.887 6.739665 1.100323
5  6.103433      6.049641 5.914289 1328.328 6.654980 1.100062
6  6.182276      6.097412 5.961877 1294.463 6.702470 1.099232
7  6.202812      6.029851 5.914057 1213.908 6.622417 1.098272
8  6.439510      6.189774 6.036193 1164.346 6.804000 1.099232
9  6.352172      6.125121 5.961631 1188.793 6.745241 1.101242
10 6.253042      6.109503 5.978115 1240.227 6.711899 1.098600
11 6.099434      6.018759 5.883558 1305.200 6.624247 1.100600
12 6.326181      6.108449 5.964079 1188.021 6.718636 1.099892
13 6.207500      6.149011 5.998270 1316.407 6.762272 1.099733
14 6.122385      6.015907 5.905179 1273.386 6.604963 1.097916
15 6.317392      6.121580 5.976088 1203.664 6.732267 1.099760
      msg isConv txp.total_10
1 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.956266
2 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.983236
3 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.673022
4 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.850876
5 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.814126
6 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.868635
7 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.930423
8 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.940058
9 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.836659
10 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.920629
11 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.798630
12 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.893597
13 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.841310
14 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.915143
15 #1. Relative error in the sum of squares is at most `ftol'. TRUE 4.892505
      txp.total_60 Uniformity_90 Uniformity_10 Uniformity
1  6.744598      7.537688      4.831809 2.705880
2  6.872603      7.835407      4.866755 2.968652
3  6.608437      8.137340      4.630062 3.507277
4  6.614967      7.834806      4.788598 3.046208
5  6.386788      7.639025      4.790947 2.848078
6  6.477594      7.693458      4.832474 2.860984
7  6.510495      7.483642      4.858477 2.625165
8  6.823299      7.914162      4.841106 3.073056
9  6.733275      7.904040      4.746574 3.157466
10 6.566505      7.679176      4.860681 2.818494
11 6.391288      7.603603      4.764249 2.839354
12 6.684521      7.763844      4.806015 2.957830
13 6.509952      7.850339      4.816395 3.033943
14 6.397486      7.432360      4.869401 2.562960
15 6.667247      7.785804      4.813086 2.972718

```

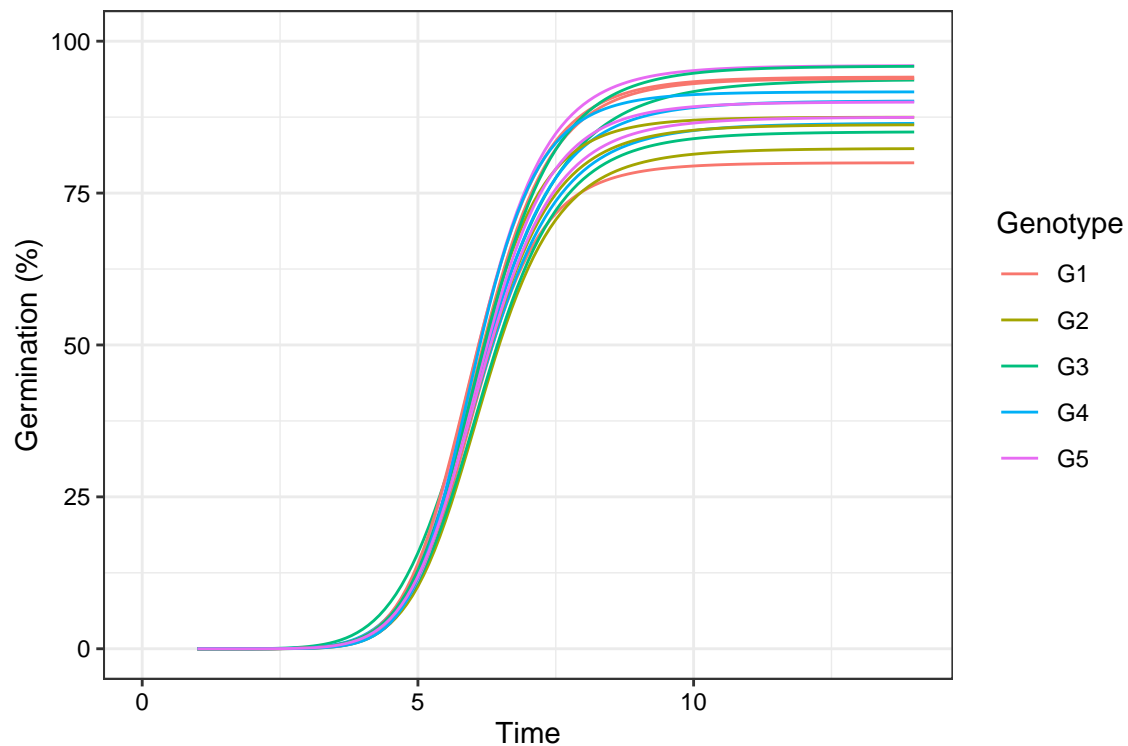
Multiple fitted curves generated in batch can also be plotted.

```
data(gcdata)
```

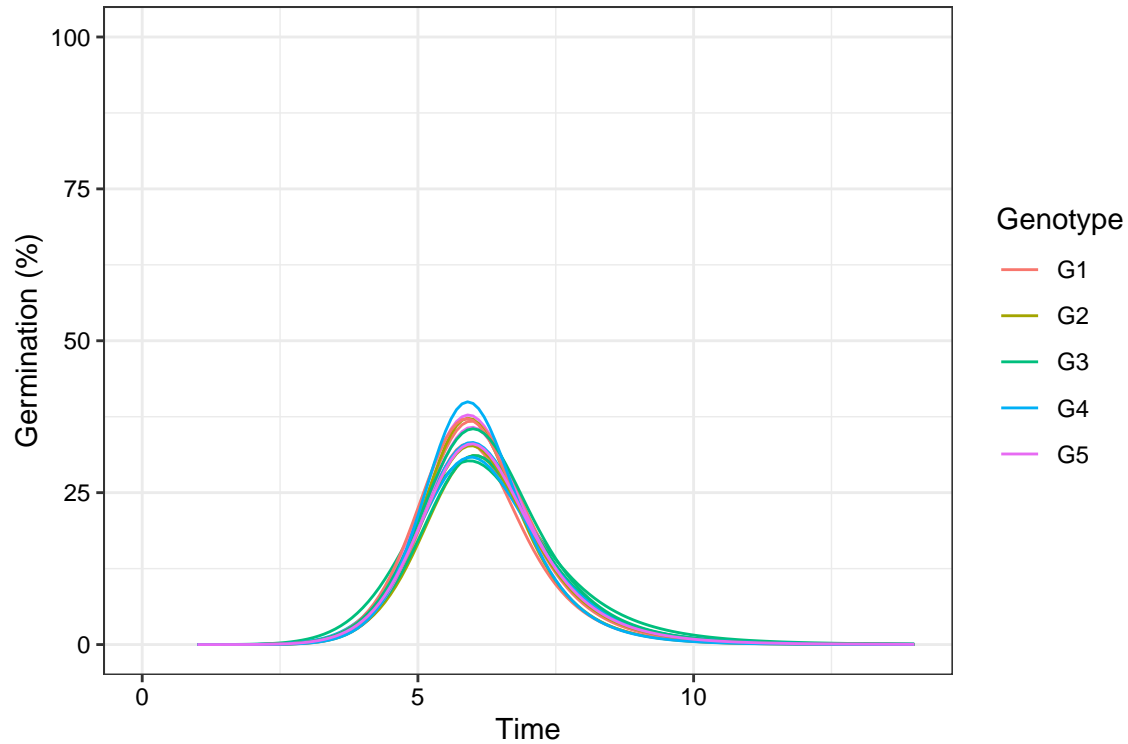
```
counts.per.intervals <- c("Day01", "Day02", "Day03", "Day04", "Day05",
                          "Day06", "Day07", "Day08", "Day09", "Day10",
                          "Day11", "Day12", "Day13", "Day14")

fits <- FourPHFfit.bulk(gcddata, 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)

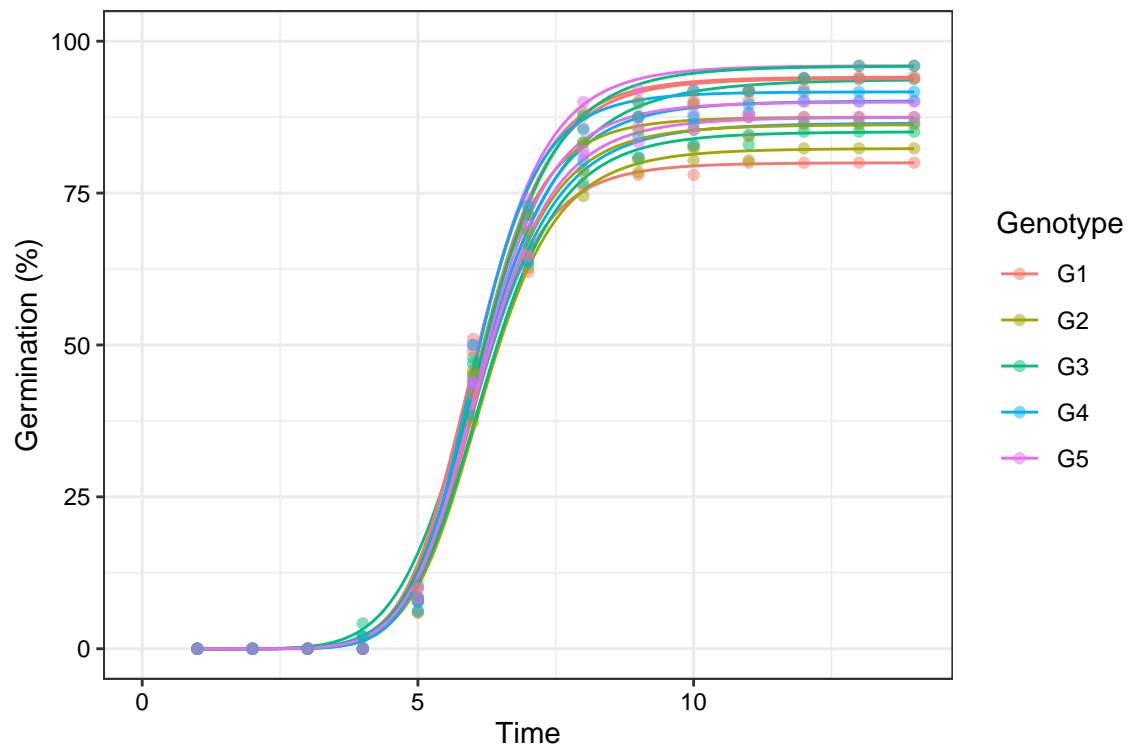
# Plot FPHF curves
plot(fits, group.col = "Genotype")
```



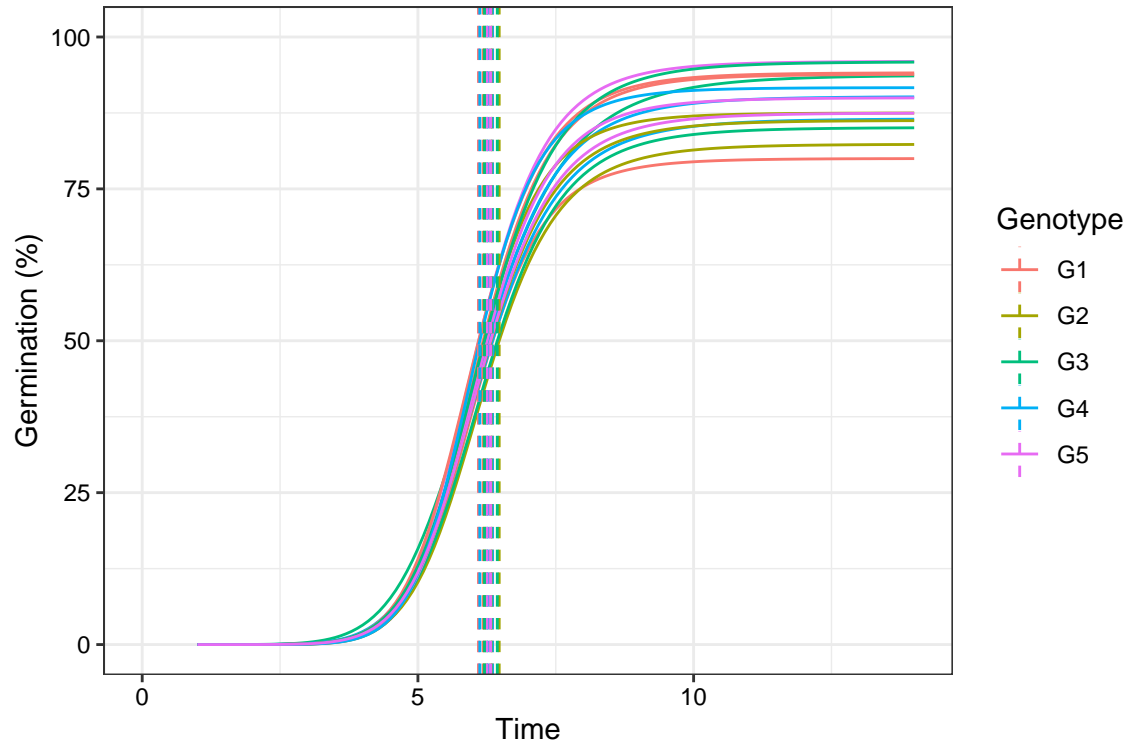
```
# Plot ROG curves
plot(fits, rog = TRUE, group.col = "Genotype")
```



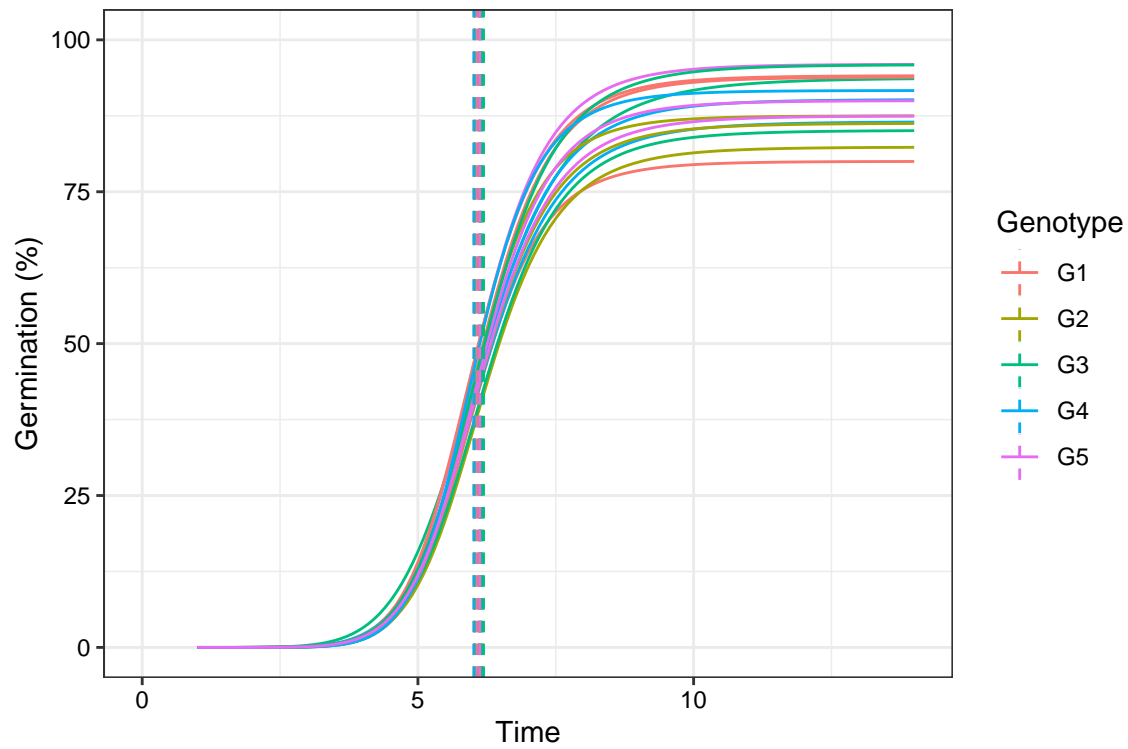
```
# Plot FPHF curves with points
plot(fits, group.col = "Genotype", show.points = TRUE)
```



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

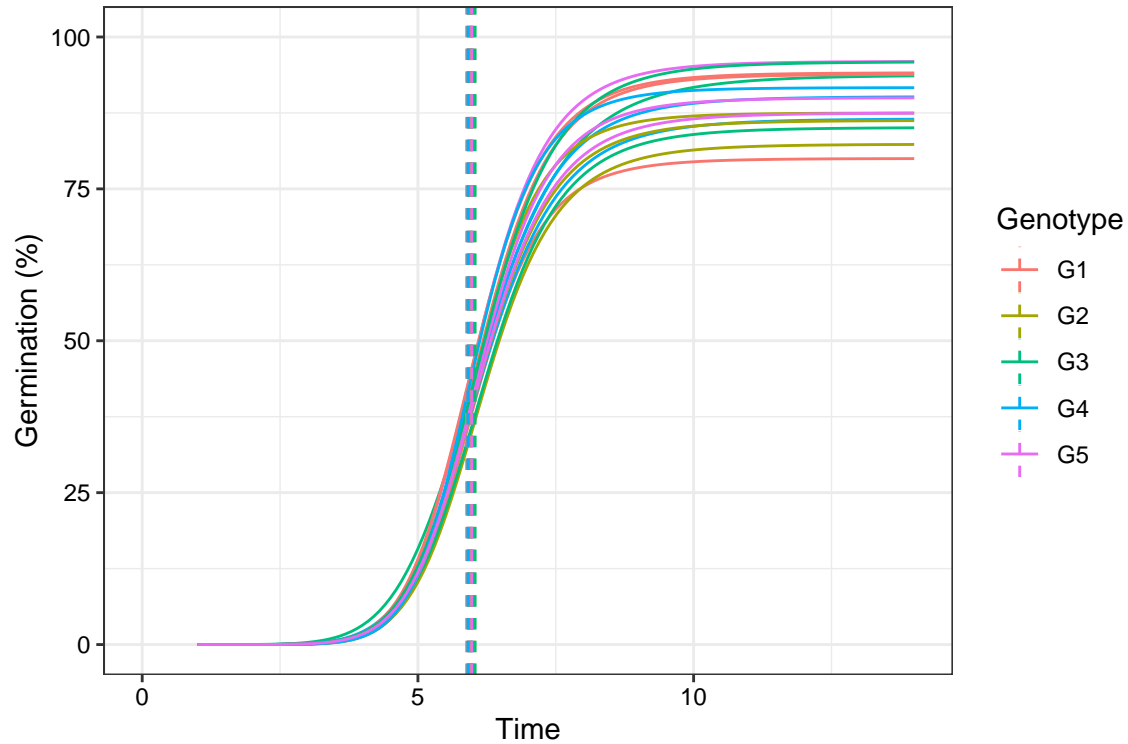


```
plot(fits, group.col = "Genotype", annotate = "t50.germ")
```

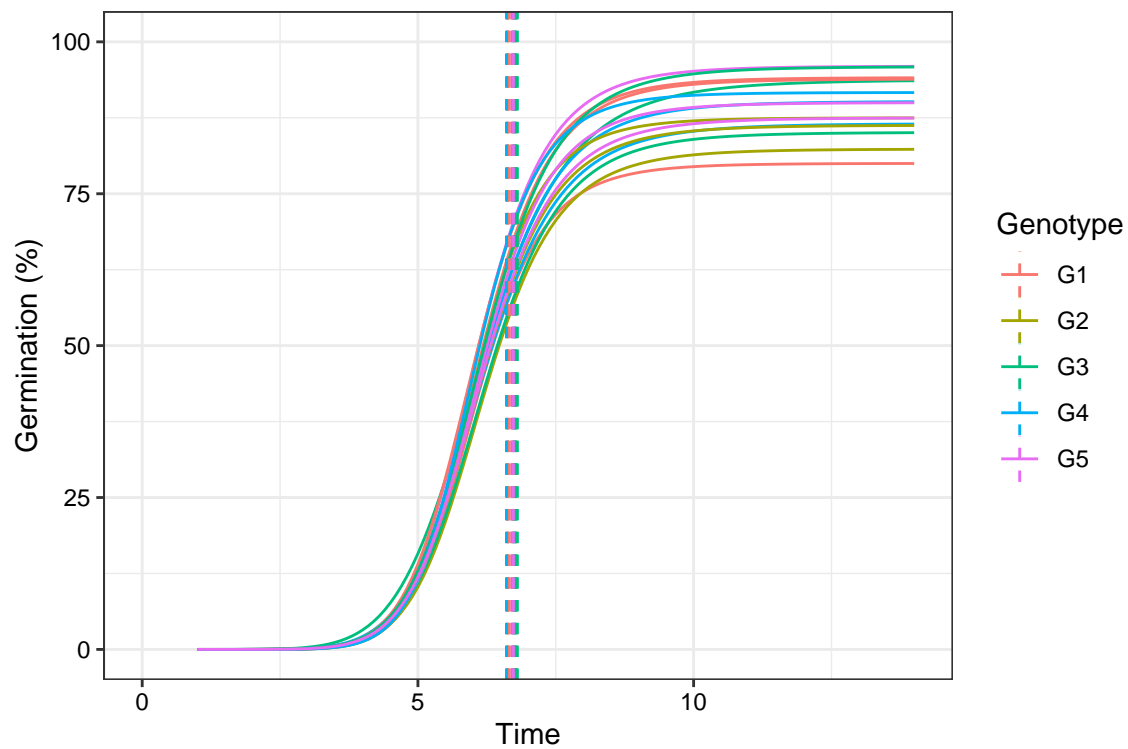


```
plot(fits, group.col = "Genotype", annotate = "tmgr")
```





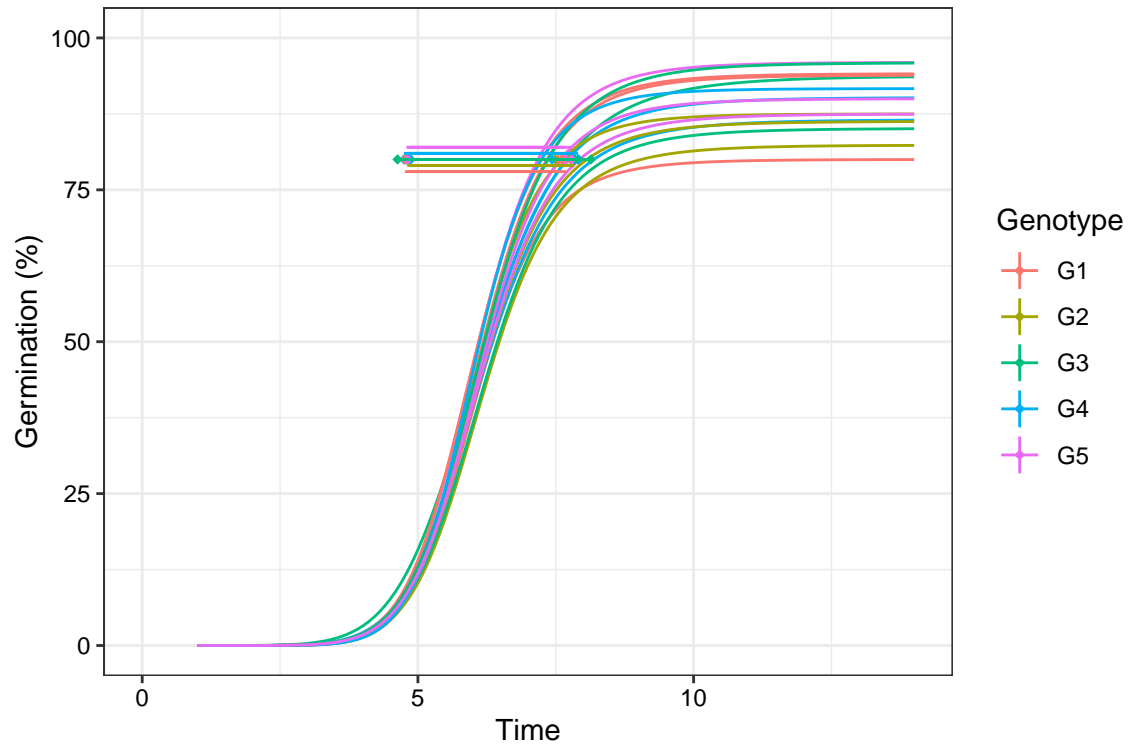
```
plot(fits, group.col = "Genotype", annotate = "mgt")
```



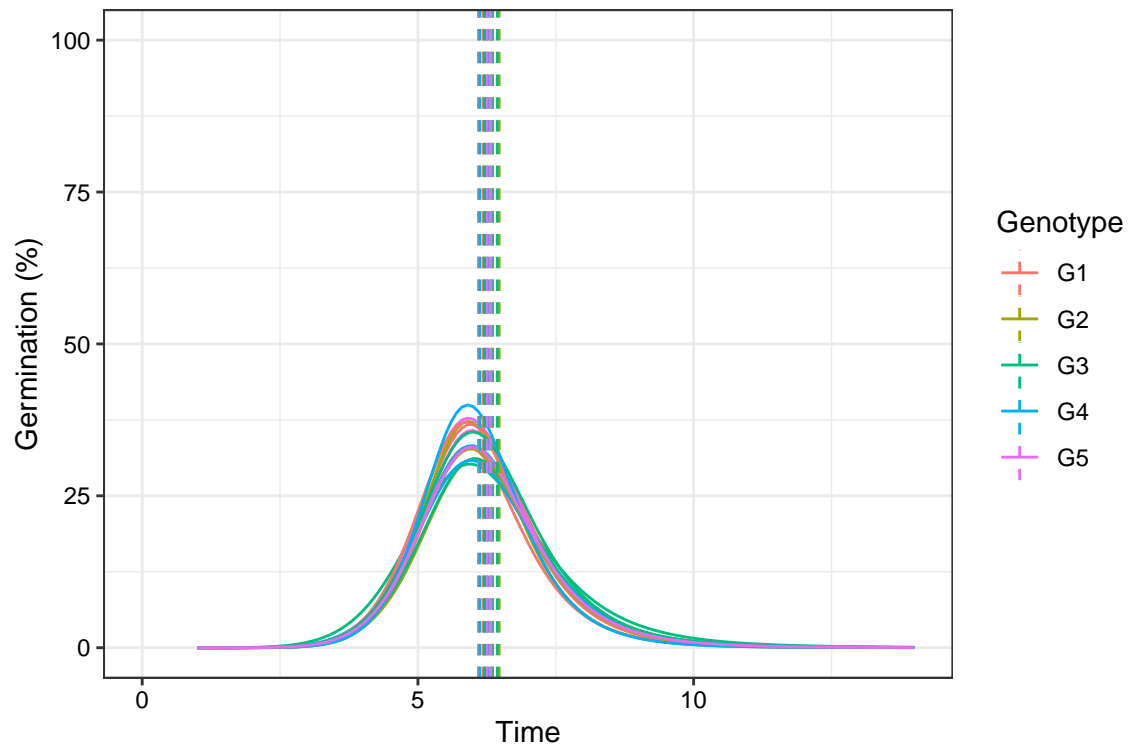
```
plot(fits, group.col = "Genotype", annotate = "uniformity")
```

Warning: position\_dodge requires non-overlapping x intervals

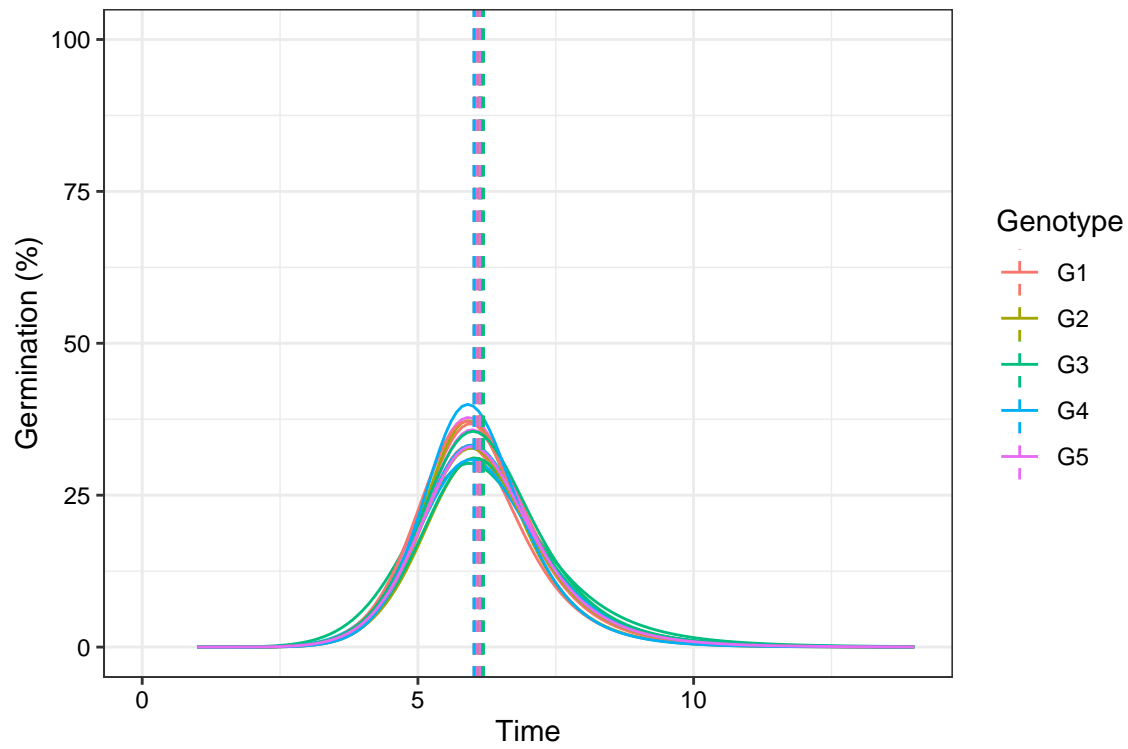
Warning: `position_dodge` requires non-overlapping x intervals



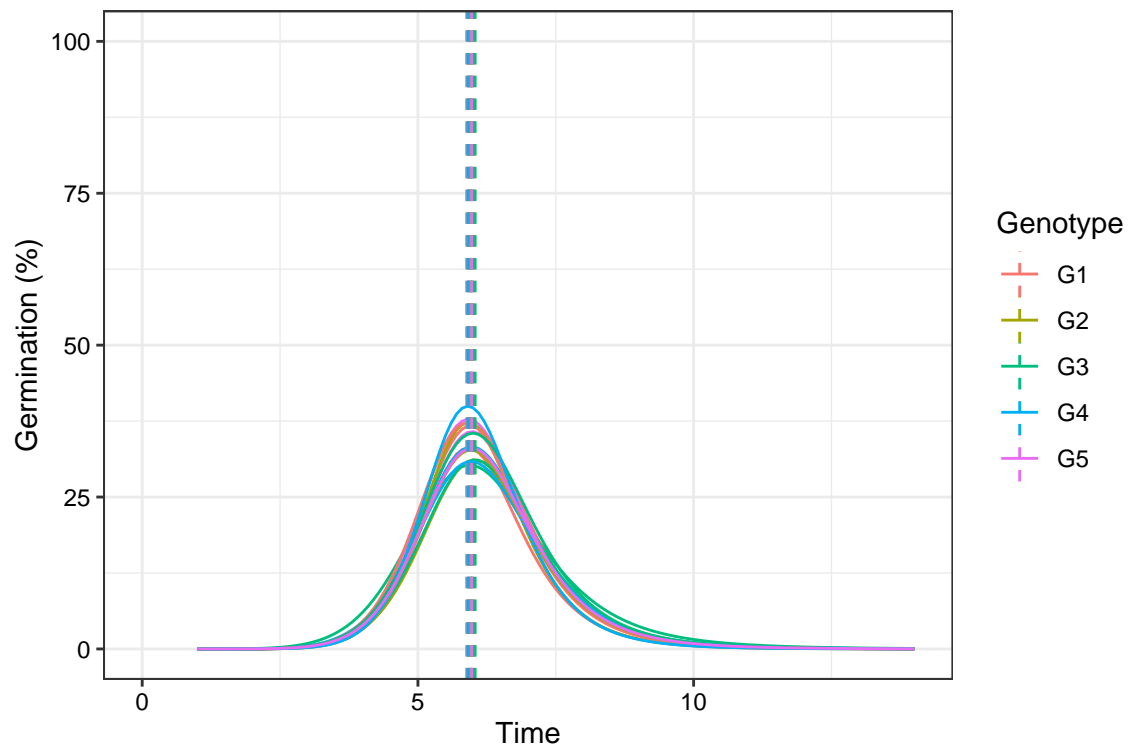
```
# Plot ROG curves with annotations
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "t50.total")
```



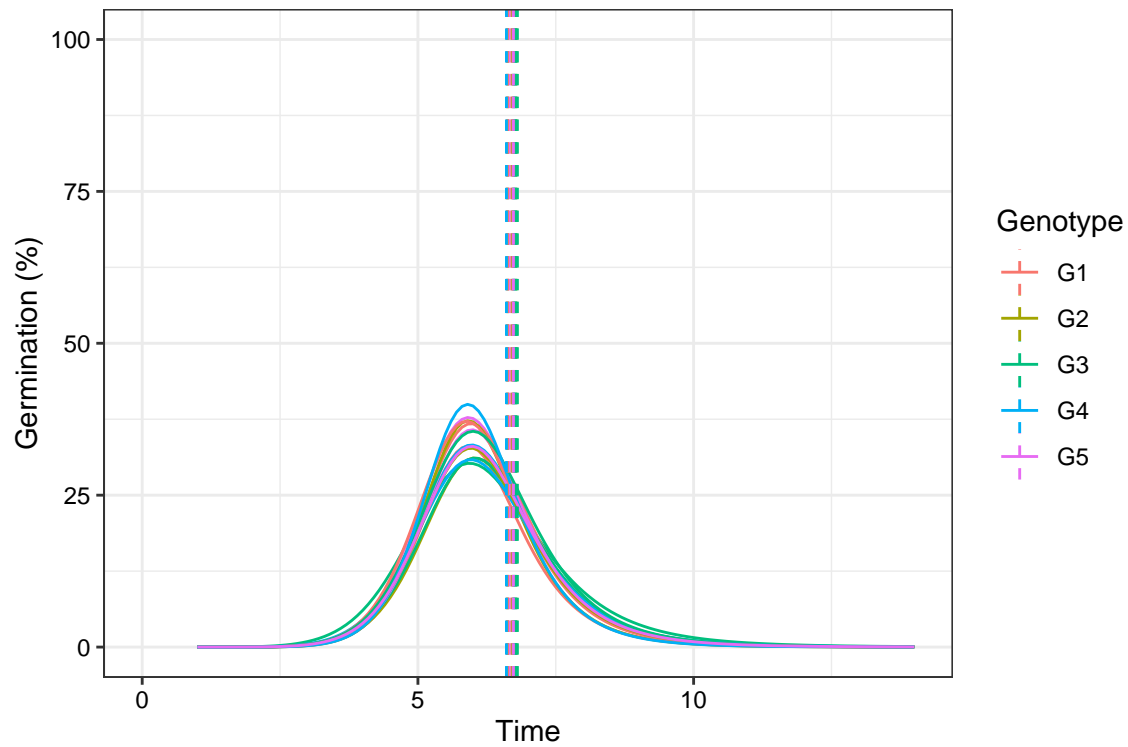
```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "t50.germ")
```



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



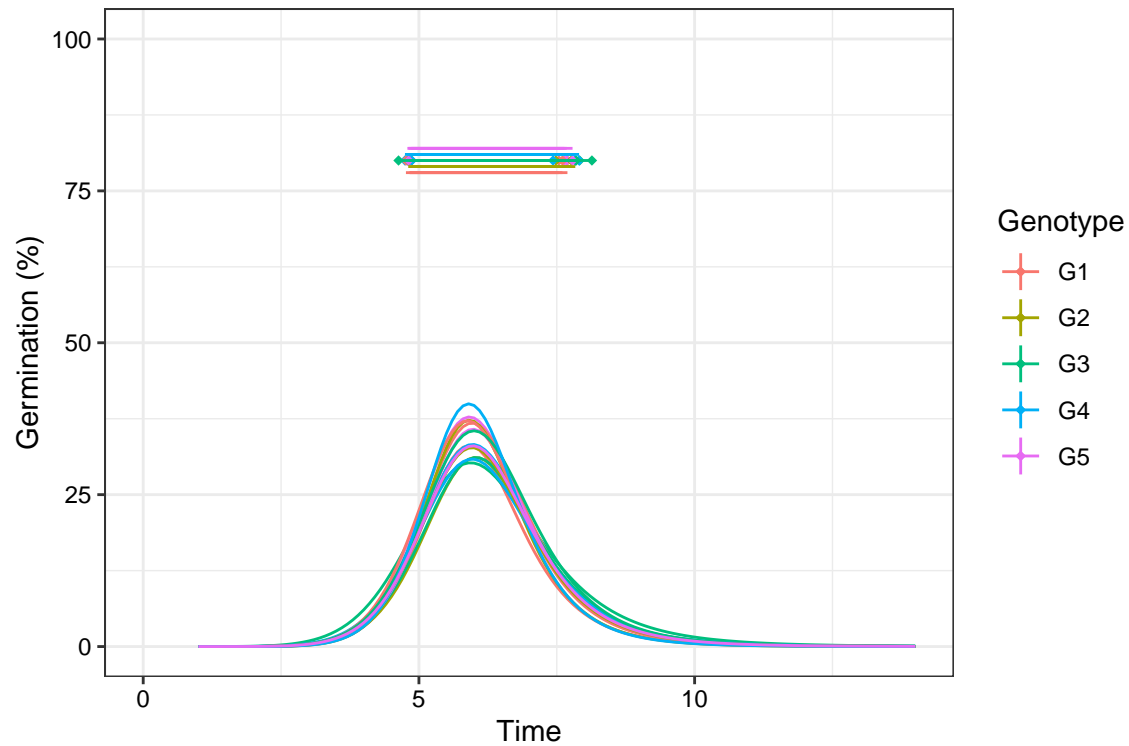
```
plot(fits, rog = TRUE, group.col = "Genotype", annotate = "mgt")
```



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

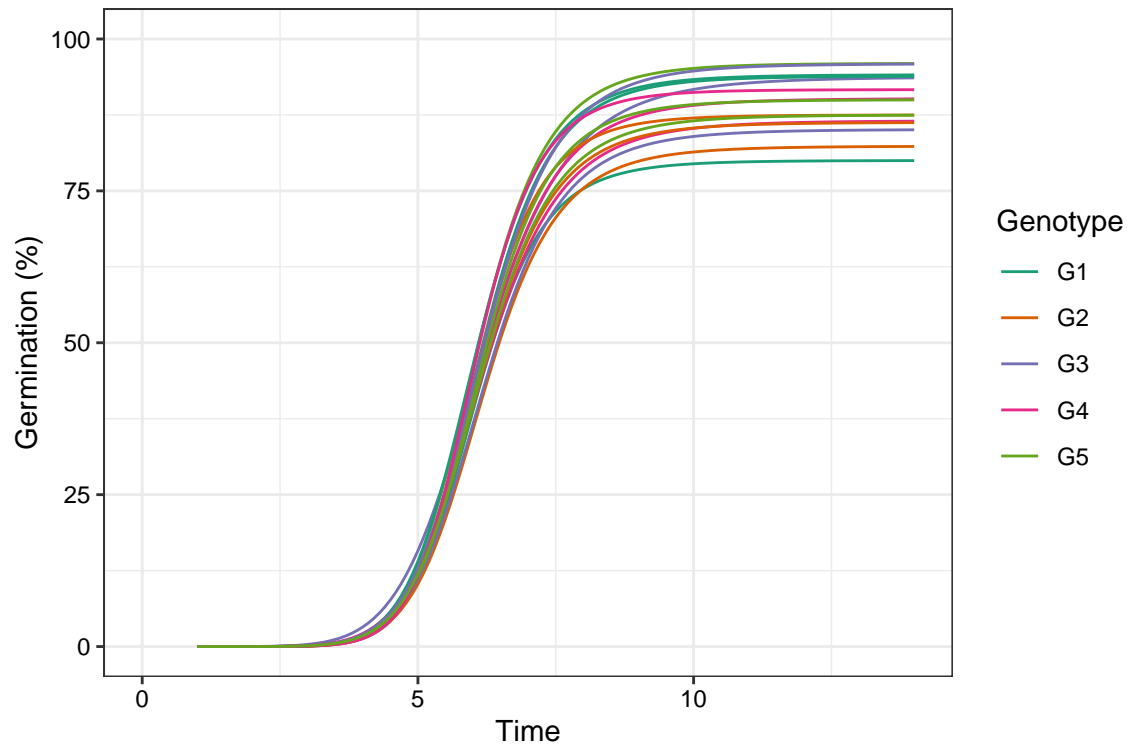
Warning: position\_dodge requires non-overlapping x intervals

Warning: position\_dodge requires non-overlapping x intervals

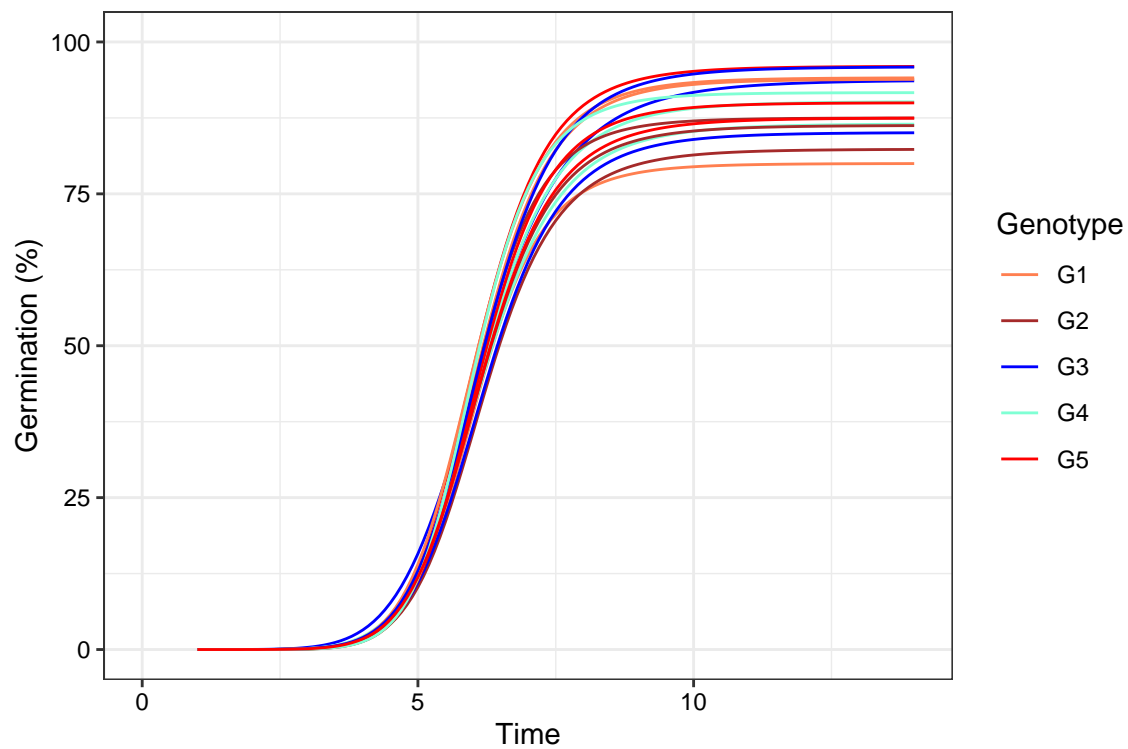


```
# Change colour of curves using ggplot2 options
library(ggplot2)
curvesplot <- plot(fits, group.col = "Genotype")

# '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 (2021). `germinationmetrics`: Seed Germination Indices and Curve Fitting. R package version 0.1.5.9000,  
<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}},
  year = {2021},
  note = {R package version 0.1.5.9000},
  note = {https://github.com/aravind-j/germinationmetrics},
  note = {https://cran.r-project.org/package=germinationmetrics},
}
```

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 version 4.0.4 (2021-02-15)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)
```

```
Matrix products: default
```

```
locale:
[1] LC_COLLATE=English_India.1252 LC_CTYPE=English_India.1252
[3] LC_MONETARY=English_India.1252 LC_NUMERIC=C
[5] LC_TIME=English_India.1252
```

```
attached base packages:
```

```
[1] stats      graphics  grDevices  utils      datasets  methods    base
```

```
other attached packages:
```

```
[1] germinationmetrics_0.1.5.9000 ggplot2_3.3.3
```

```
loaded via a namespace (and not attached):
```

```
[1] whoami_1.3.0          bitops_1.0-6          fs_1.5.0
[4] xopen_1.0.0           usethis_2.0.1         devtools_2.3.2
[7] covr_3.5.1            RColorBrewer_1.1-2    httr_1.4.2
[10] rprojroot_2.0.2       hunspell_3.0.1        tools_4.0.4
[13] backports_1.2.1       R6_2.5.0              DBI_1.1.1
[16] lazyeval_0.2.2        colorspace_2.0-0      withr_2.4.1
[19] tidyselect_1.1.0      prettyunits_1.1.1     processx_3.4.5
[22] curl_4.3              compiler_4.0.4        cli_2.3.0
```

[25] <code>xml2_1.3.2</code>	<code>desc_1.2.0</code>	<code>labeling_0.4.2</code>
[28] <code>scales_1.1.1</code>	<code>callr_3.5.1</code>	<code>goodpractice_1.0.2.9000</code>
[31] <code>pkgdown_1.6.1</code>	<code>stringr_1.4.0</code>	<code>digest_0.6.27</code>
[34] <code>rmarkdown_2.6</code>	<code>lintr_2.0.1</code>	<code>pkgconfig_2.0.3</code>
[37] <code>htmltools_0.5.1.1</code>	<code>sessioninfo_1.1.1</code>	<code>fastmap_1.1.0</code>
[40] <code>highr_0.8</code>	<code>rlang_0.4.10</code>	<code>rstudioapi_0.13</code>
[43] <code>generics_0.1.0</code>	<code>farver_2.0.3</code>	<code>jsonlite_1.7.2</code>
[46] <code>dplyr_1.0.4</code>	<code>RCurl_1.98-1.2</code>	<code>magrittr_2.0.1</code>
[49] <code>Rcpp_1.0.6</code>	<code>munsell_0.5.0</code>	<code>lifecycle_1.0.0</code>
[52] <code>stringi_1.5.3</code>	<code>yaml_2.2.1</code>	<code>mathjaxr_1.2-0</code>
[55] <code>gbRd_0.4-11</code>	<code>pkgbuild_1.2.0</code>	<code>plyr_1.8.6</code>
[58] <code>grid_4.0.4</code>	<code>ggrepel_0.9.1</code>	<code>crayon_1.4.1</code>
[61] <code>pander_0.6.3</code>	<code>knitr_1.31</code>	<code>ps_1.5.0</code>
[64] <code>pillar_1.4.7</code>	<code>reshape2_1.4.4</code>	<code>clisymbols_1.2.0</code>
[67] <code>pkgload_1.1.0</code>	<code>XML_3.99-0.5</code>	<code>glue_1.4.2</code>
[70] <code>praise_1.0.0</code>	<code>evaluate_0.14</code>	<code>rex_1.2.0</code>
[73] <code>data.table_1.13.6</code>	<code>remotes_2.2.0</code>	<code>vctrs_0.3.6</code>
[76] <code>Rdpack_2.1</code>	<code>testthat_3.0.2</code>	<code>gtable_0.3.0</code>
[79] <code>purrr_0.3.4</code>	<code>rcmdcheck_1.3.3</code>	<code>tidyr_1.1.2</code>
[82] <code>assertthat_0.2.1</code>	<code>cachem_1.0.4</code>	<code>xfun_0.21</code>
[85] <code>rbibutils_2.0</code>	<code>broom_0.7.4</code>	<code>roxygen2_7.1.1</code>
[88] <code>cyclocomp_1.1.0</code>	<code>minpack.lm_1.2-1</code>	<code>tibble_3.0.6</code>
[91] <code>tinytex_0.29</code>	<code>memoise_2.0.0</code>	<code>ellipsis_0.3.1</code>
[94] <code>xmlparsedata_1.0.4</code>		

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