

# Introduction to toolStability

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## Overview

The package `toolStability` is a collection of functions which implements various methods for describing the stability of a trait in terms of `genotype` and `environment`.

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('toolStability', dependencies=TRUE)

# Install development version from Github
devtools::install_github("Illustratien/toolStability")
```

Then the package can be loaded using the function

```
library(toolStability)
```

## Welcome to `toolStability`

This is an R package for calculating parametric, non-parametric, and probabilistic stability indices.

## Structure overview of `toolStability`

`toolStability` contains different functions to calculate stability indices, including:

1. adjusted coefficient of variation
2. coefficient of determination
3. coefficient of regression
4. deviation mean squares
5. ecovalence
6. environmental variance
7. genotypic stability
8. genotypic superiority measure
9. safety first index
10. stability variance
11. variance of rank

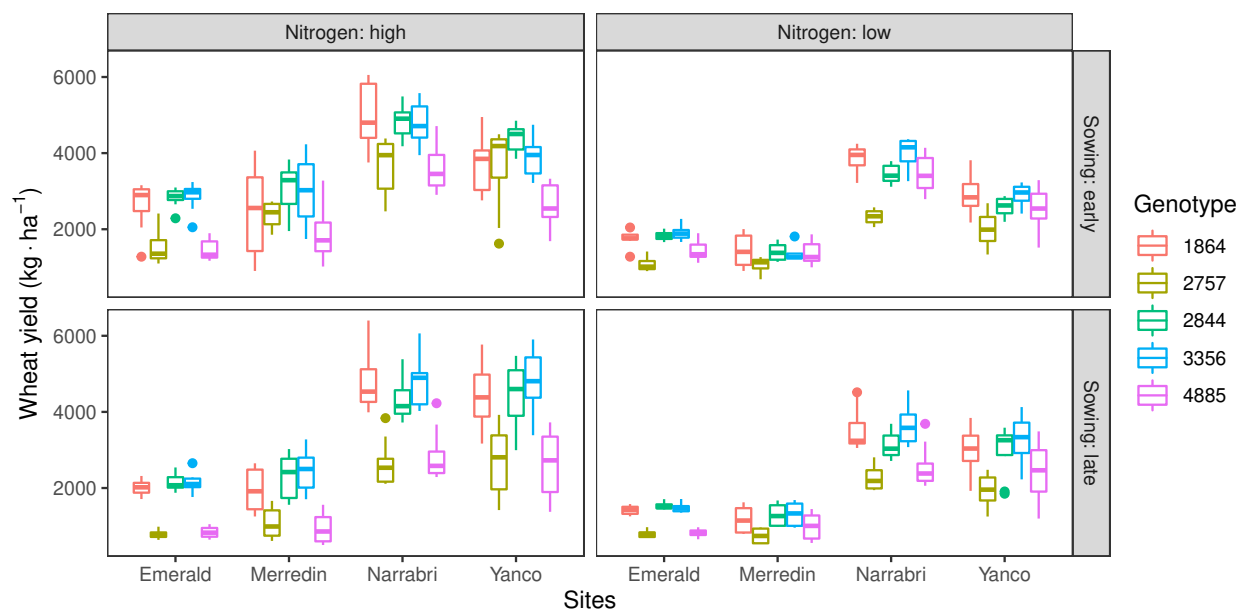
## Build-in data set

The default data set `Data` is the subset of *APSIM* simulated wheat data set, which includes 5 genotypes in 4 locations for 4 years, with 2 nitrogen application rates, 2 sowing dates, and 2  $CO_2$  levels of treatments (Casadebaig et al., 2016).

`Data` in this package is a data frame with 640 observations and 8 variables.

Table 1: Data Structure

Parameters	Number	Description
Trait		Wheat yield ( $kg\ ha^{-1}$ ).
Genotype	5	varieties.
Environment	128	unique combination of environments for each genotype.
Year	4	years.
Sites	4	locations.
Nitrogen	2	nitrogen application levels.
$CO_2$	2	$CO_2$ concentration levels.
Sowing	2	sowing dates.



## Tutorial

### 1. Data preparation

In order to calculate stability index, you will need to prepare a data frame with 3 columns containing `trait`, `genotype`, and `environment`.

- `trait`: numeric and continuous, trait value to be analyzed.
- `genotype`: character or factor, labeling different genotypic varieties.
- `environment`: character or factor, labeling different environments.

### 2. Input formats of function

Most of the functions in the package work with the following format:

```
function(data = Data,  
         trait = "Trait_Column_Name",  
         genotype = "Genotype_Column_Name",  
         environment = "Environment_Column_Name")
```

For calculation of probabilistic stability index `safety_first_index`, an additional parameter `lambda` is required.

`lambda`: minimal acceptable value of `trait` that the user expected from crop across `environment`. `lambda` should be between the range of `trait` value.

Under the assumption of `trait` is normally distributed, safety first index is calculated based on the probability of trait below `lambda` across the `environment` for each `genotype`.

### 3. Function Features

`Functiontable_stability` generates the summary table containing all the stability indices in the package for every genotypes, also including the mean `trait` value and normality check results for the `trait` of each `genotype` across all the `environment`.

User can specify the interested combination of environments by entering a vector of column names which containing environmental factors. Option `normalize = TRUE` allow user to compare between different stability indices. Option `unit.correct = TRUE` is designed for getting the square root value of stability indices which have the squared unit of `trait`. For function `ecovalence`, option `modify = TRUE` takes the number of environments into account and make `modified_ecovalence` comparable between different number of environments.

## Examples

```
rm(list=ls())  
library(toolStability)  
### load data  
data("Data")  
### check the structure of sample dataset  
### be sure that the trait is numeric!!!
```

```
dplyr::glimpse(Data)
#> Rows: 640
#> Columns: 8
#> $ Genotype    <fct> 1864, 1864, 1864, 1864, 1864, 1864, 1864, 1864, 1864, 1864~
#> $ Yield       <dbl> 1278.6, 1746.0, 1753.9, 1851.8, 2176.6, 2783.3, 3113.3, 27~
#> $ Environment <fct> 1959 Emerald low control early, 1960 Emerald low control e~
#> $ Years       <int> 1959, 1960, 1961, 1962, 1959, 1960, 1961, 1962, 1959, 1960~
#> $ Sites       <fct> Emerald, Emerald, Emerald, Emerald, Yanco, Yanco, Yanco, Y~
#> $ Nitrogen    <fct> low, low, low, low, low, low, low, low, low, low, low, low~
#> $ CO2        <fct> control, control, control, control, control, control, cont~
#> $ Sowing     <fct> early, early, early, early, early, early, early, early, ea~

### calculate ecovalence for all genotypes
single.index.ecovalence <- ecovalence(data = Data,
                                     trait = 'Yield',
                                     genotype = 'Genotype',
                                     environment = 'Environment',
                                     unit.correct = FALSE,
                                     modify = FALSE)

### check the structure of result
dplyr::glimpse(single.index.ecovalence)
#> Rows: 5
#> Columns: 3
#> $ Genotype    <fct> 1864, 2757, 2844, 3356, 4885
#> $ Mean.Yield  <dbl> 2878.070, 1913.365, 2911.395, 3038.426, 2024.919
#> $ ecovalence  <dbl> 17802705, 27718900, 9365241, 12698454, 24133596

### calculate modified ecovalence for all genotypes
single.index.ecovalence.modified <- ecovalence(data = Data,
                                                trait = 'Yield',
                                                genotype = 'Genotype',
                                                environment = 'Environment',
                                                unit.correct = FALSE,
                                                modify = TRUE)

### check the structure of result
dplyr::glimpse(single.index.ecovalence.modified)
#> Rows: 5
#> Columns: 3
#> $ Genotype    <fct> 1864, 2757, 2844, 3356, 4885
#> $ Mean.Yield  <dbl> 2878.070, 1913.365, 2911.395, 3038.426, 2024.919
#> $ ecovalence.modified <dbl> 139083.63, 216553.91, 73165.94, 99206.67, 188543.72
```

```

### calculate all stability indices for all genotypes
summary.table <- table_stability(data = Data,
                                trait = 'Yield',
                                genotype = 'Genotype',
                                environment = 'Environment',
                                lambda = median(Data$Yield),
                                normalize = FALSE,
                                unit.correct = FALSE)
#> Warning in table_stability(data = Data, trait = "Yield", genotype = "Genotype", :
#> All of your genotypes didn't pass the Shapiro normality test!
#> Safety_first Index may not be accurate.
#### warning message means your data structure is not distributed as normal distribution

#### check the structure of result
dplyr::glimpse(summary.table)
#> Rows: 5
#> Columns: 15
#> $ Genotype <fct> 1864, 2757, 2844, 3356, 4885
#> $ Mean.Yield <dbl> 2878.070, 1913.365, 2911.395, 3038.4~
#> $ Normality <lgl> FALSE, FALSE, FALSE, FALSE, FALSE
#> $ Safety.first.index <dbl> 0.3523378, 0.6665326, 0.3242059, 0.2~
#> $ Coefficient.of.determination <dbl> 0.9398731, 0.8270000, 0.9485154, 0.9~
#> $ Coefficient.of.regression <dbl> 1.1596475, 0.8552736, 1.0316158, 1.1~
#> $ Deviation.mean.squares <dbl> 108789.28, 193280.79, 73052.65, 8677~
#> $ Environmental.variance <dbl> 1809327, 1117230, 1418923, 1630384, ~
#> $ Genotypic.stability <dbl> 29248135, 24360429, 14583562, 214768~
#> $ Genotypic.superiority.measure <dbl> 89307.69, 1004043.78, 70091.10, 3048~
#> $ Variance.of.rank <dbl> 1.770116, 2.281250, 1.561946, 1.7913~
#> $ Stability.variance <dbl> 173448.30, 303582.09, 62720.42, 1064~
#> $ Adjusted.coefficient.of.variation <dbl> 50.31578, 47.87130, 44.31829, 46.565~
#> $ Ecovalence <dbl> 17802705, 27718900, 9365241, 1269845~
#> $ Ecovalence.modified <dbl> 139083.63, 216553.91, 73165.94, 9920~

### calculate all stability indices for all genotypes
normalized.summary.table <- table_stability(data = Data,
                                             trait = 'Yield',
                                             genotype = 'Genotype',
                                             environment = 'Environment',
                                             lambda = median(Data$Yield),
                                             normalize = TRUE,
                                             unit.correct = FALSE)
#> Warning in table_stability(data = Data, trait = "Yield", genotype = "Genotype", :
#> All of your genotypes didn't pass the Shapiro normality test!
#> Safety_first Index may not be accurate.
#### warning message means your data structure is not distributed as normal distribution

#### check the structure of result
dplyr::glimpse(normalized.summary.table)
#> Rows: 5
#> Columns: 15
#> $ Genotype <fct> 1864, 2757, 2844, 3356, 4885
#> $ Mean.Yield <dbl> 2878.070, 1913.365, 2911.395, 3038.4~
#> $ Normality <lgl> FALSE, FALSE, FALSE, FALSE, FALSE

```

```

#> $ Safety.first.index <dbl> 0.85683453, 0.00000000, 0.93355270, ~
#> $ Coefficient.of.determination <dbl> 0.07112157, 1.00000000, 0.00000000, ~
#> $ Coefficient.of.regression <dbl> 0.0000000, 0.9787025, 0.4116811, 0.1~
#> $ Deviation.mean.squares <dbl> 0.7027599, 0.0000000, 1.0000000, 0.8~
#> $ Environmental.variance <dbl> 0.0000000, 0.9389617, 0.5296575, 0.2~
#> $ Genotypic.stability <dbl> 0.0000000, 0.3333003, 1.0000000, 0.5~
#> $ Genotypic.superiority.measure <dbl> 0.9395799, 0.0000000, 0.9593184, 1.0~
#> $ Variance.of.rank <dbl> 0.8095988, 0.3420919, 1.0000000, 0.7~
#> $ Stability.variance <dbl> 0.5402844, 0.0000000, 1.0000000, 0.8~
#> $ Adjusted.coefficient.of.variation <dbl> 0.0000000, 0.4075840, 1.0000000, 0.6~
#> $ Ecovalence <dbl> 0.5402844, 0.0000000, 1.0000000, 0.8~
#> $ Ecovalence.modified <dbl> 0.5402844, 0.0000000, 1.0000000, 0.8~

### compare the result from summary.table and normalized.summary.table

### calculate the stability indices only based only on CO2 and Nitrogen environments
summary.table2 <- table_stability(data = Data,
  trait = 'Yield',
  genotype = 'Genotype',
  environment = c('CO2','Nitrogen'),
  lambda = median(Data$Yield),
  normalize = FALSE,
  unit.correct = FALSE)
#> Warning in table_stability(data = Data, trait = "Yield", genotype = "Genotype", :
#> All of your genotypes didn't pass the Shapiro normality test!
#> Safety_first Index may not be accurate.

#### check the structure of result
dplyr::glimpse(summary.table2)
#> Rows: 5
#> Columns: 15
#> $ Genotype <fct> 1864, 2757, 2844, 3356, 4885
#> $ Mean.Yield <dbl> 2878.070, 1913.365, 2911.395, 3038.4~
#> $ Normality <lgl> FALSE, FALSE, FALSE, FALSE, FALSE
#> $ Safety.first.index <dbl> 0.3523378, 0.6665326, 0.3242059, 0.2~
#> $ Coefficient.of.determination <dbl> 0.161086973, 0.138169855, 0.28644744~
#> $ Coefficient.of.regression <dbl> 1.1791003, 0.8614393, 1.3780191, 1.3~
#> $ Deviation.mean.squares <dbl> 1517867.6, 962862.6, 1012476.1, 1269~
#> $ Environmental.variance <dbl> 1809327, 1117230, 1418923, 1630384, ~
#> $ Genotypic.stability <dbl> 213741097, 130745446, 161091101, 189~
#> $ Genotypic.superiority.measure <dbl> 3688981, 6251668, 3333615, 3180826, ~
#> $ Variance.of.rank <dbl> 2644.454, 1623.286, 2007.764, 2479.2~
#> $ Stability.variance <dbl> 2025117, 1102709, 1229740, 1636649, ~
#> $ Adjusted.coefficient.of.variation <dbl> 50.31578, 47.87130, 44.31829, 46.565~
#> $ Ecovalence <dbl> 192140367, 121852817, 131532582, 162~
#> $ Ecovalence.modified <dbl> 1501096.6, 951975.1, 1027598.3, 1269~

### compare the result from summary.table and summary.table2
### see how the choice of environments affect the data

```

## Equation of stability indices

### adjusted coefficient variation

Adjusted coefficient of variation (Döring & Reckling, 2018) is calculated based on regression function. Variety with low adjusted coefficient of variation is considered as stable. Under the linear model

$$v_i = a + b m_i$$

where  $v_i$  is the  $\log_{10}$  of phenotypic variance and  $m_i$  is the  $\log_{10}$  of phenotypic mean.

$$\tilde{c}_i = \frac{1}{\tilde{\mu}_i} \left[ 10^{(2-b) m_i + (b-2) \bar{m} + v_i} \right]^{0.5} \times 100\%$$



**coefficient of determination**

Coefficient of determination (Pinthus, 1973) is calculated based on regression function. Variety with low coefficient of determination is considered as stable. Under the linear model

$$Y = \mu + \beta_i e_j + g_i + d_{ij}$$

where  $Y$  is the predicted phenotypic values,  $g_i$ ,  $e_j$  and  $\mu$  denoting genotypic, environmental and overall population mean, respectively.

The effect of GE-interaction may be expressed as:

$$(ge)_{ij} = \beta_i e_j + d_{ij}$$

where  $\beta_i$  is the coefficient of regression and  $d_{ij}$  a deviation.

$s_{di}^2$ , see *deviation mean squares* for formula.

Environmental variance can be expressed as:

$$S_{xi}^2 = \frac{\sum_j (X_{ij} - \bar{X}_{i.})^2}{E - 1}$$

Coefficient of determination may be expressed as:

$$r_i^2 = 1 - \frac{s_{di}^2}{s_{xi}^2}$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_{i.}$  and  $\bar{X}_{.j}$  denoting marginal means of genotype  $i$  and environment  $j$ , respectively.  $\bar{X}_{..}$  denote the overall mean of  $X$ .

**coefficient of regression**

Coefficient of regression (Finlay & Wilkinson, 1963) is calculated based on regression function. Variety with low coefficient of regression is considered as stable. Under the linear model

$$Y = \mu + \beta_i e_j + g_i + d_{ij}$$

where  $Y$  is the predicted phenotypic values,  $g_i$ ,  $e_j$  and  $\mu$  denoting genotypic, environmental and overall population mean, respectively.

The effect of GE-interaction may be expressed as:

$$(ge)_{ij} = \beta_i e_j + d_{ij}$$

where  $\beta_i$  is the coefficient of regression and  $d_{ij}$  a deviation.

Coefficient of regression may be expressed as:

$$b_i = 1 + \frac{\sum_j (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..}) (\bar{X}_{.j} - \bar{X}_{..})}{\sum_j (\bar{X}_{.j} - \bar{X}_{..})^2}$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_{i.}$  and  $\bar{X}_{.j}$  denoting marginal means of genotype  $i$  and environment  $j$ , respectively.  $\bar{X}_{..}$  denote the overall mean of  $X$ .  $b_i$  is the estimation of  $\beta_i$ .

**deviation mean squares**

Deviation mean squares (Eberhart & Russell, 1966) is calculated based on regression function. Variety with low stability variance is considered as stable.

Deviation mean squares may be expressed as:

$$s_{di}^2 = \frac{1}{E-2} \left[ \sum_j (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2 - (b_i - 1)^2 (\bar{X}_{.j} - \bar{X}_{..})^2 \right]$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_{i.}$  and  $\bar{X}_{.j}$  denoting marginal means of genotype  $i$  and environment  $j$ , respectively.  $\bar{X}_{..}$  denote the overall mean of  $X$ .  $b_i$  is the estimation of coefficient of regression.

**ecovalence**

Ecovalence (Wricke, 1962) is calculated based on square and sum up the genotype–environment interaction all over the environment. Variety with low ecovalence is considered as stable. Ecovalence is expressed as:

$$W_i = \sum_j (X_{ij} - \bar{X}_i - \bar{X}_{.j} + \bar{X}_{..})^2$$

To let  $W_i$  comparable between experiments, we also provide the modified ecovalence ( $W'_i$ ), which take the number of environments into account. User can get ( $W'_i$ ) by setting `modify = TRUE`.

$$W'_i = \frac{\sum_j (X_{ij} - \bar{X}_i - \bar{X}_{.j} + \bar{X}_{..})^2}{E - 1}$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_i$  denoting marginal means of genotype  $i$ .

**environmental variance**

Environmental variance (Römer, 1917) is calculated by squared and summing up all deviation from genotypic mean for each genotype. The larger the environmental variance of one genotype is, the lower the stability.

$$S_{xi}^2 = \frac{\sum_j (X_{ij} - \overline{X_i})^2}{E - 1}$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\overline{X_i}$  denoting marginal means of genotype  $i$ .

**genotypic stability**

Genotypic stability (Hanson, 1970) is calculated based on regression function. Variety with low stability variance is considered as stable. Under the linear model

$$Y = \mu + \beta_i e_j + g_i + d_{ij}$$

where  $Y$  is the predicted phenotypic values,  $g_i$ ,  $e_j$  and  $\mu$  denoting genotypic, environmental and overall population mean, respectively.

The effect of GE-interaction may be expressed as:

$$(ge)_{ij} = \beta_i e_j + d_{ij}$$

where  $\beta_i$  is the coefficient of regression and  $d_{ij}$  a deviation.

Genotypic stability:

$$D_i^2 = \sum_j (X_{ij} - \bar{X}_i - b_{min} \bar{X}_j + b_{min} \bar{X}_{..})^2$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_i$  and  $\bar{X}_j$  denoting marginal means of genotype  $i$  and environment  $j$ , respectively.  $\bar{X}_{..}$  denote the overall mean of  $X$ .

$b_{min}$  is the minimum value of coefficient of regression over all environments.

**genotypic superiority measure**

Genotypic superiority measure (Lin & Binns, 1988) is calculated based on means square distance between maximum value of environment  $j$  and genotype  $i$ . Variety with low genotypic superiority measure is considered as stable.

$$P_i = \sum_j^n \frac{(X_{ij} - M_j)^2}{2n}$$

where  $X_{ij}$  stands for observed trait and  $M_j$  stands for maximum response among all genotypes in the  $j^{th}$  location.

**safety first index**

Safety-first index ([Eskridge, 1990](#)) is calculated based on the normality assumption of trait over the environments. Among different environments, trait below a given critical level  $\lambda$  is defined as failure of trait. Safety-first index calculating the probability of trait failure over the environment. Variety with low safety first index is considered as stable.

$$Pr (Y_{ij} < \lambda) = \Phi [(\lambda - \mu_i)/\sqrt{\sigma_{ii}}]$$

where  $\lambda$  is the minimal acceptable value of trait that the user expected from crop across environments. Lambda should be between the range of trait value.  $\Phi$  is the cumulative distribution function of the standard normal distribution.  $\mu_i$  and  $\sigma_{ii}$  is the mean and variance of the system  $i$ . Under the assumption of trait is normally distributed, safety first index is calculated based on the probability of trait below lambda across the environments for each genotype.



**stability variance**

Stability variance (Shukla, 1972) is calculated based on linear combination of ecovalence and mean square of genotype-environment interaction. Variety with low stability variance is considered as stable.

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)} \left[ G(G-1) \sum_j (X_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}_{..})^2 - \sum_i \sum_j (X_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}_{..})^2 \right]$$

where  $X_{ij}$  is the observed phenotypic mean value of genotype  $i$  ( $i = 1, \dots, G$ ) in environment  $j$  ( $j = 1, \dots, E$ ), with  $\bar{X}_i$  and  $\bar{X}_j$  denoting marginal means of genotype  $i$  and environment  $j$ , respectively.  $\bar{X}_{..}$  denote the overall mean of  $X$ .

Negative values of stability variance is replaced with 0.

**variance of rank**

Variance of rank (Nassar & Hühn, 1987) is calculated based on regression function. Variety with low variance of rank is considered as stable.

Correction for each genotype  $i$  was done by subtraction of marginal genotypic mean  $\overline{X_i}$  and the addition of overall mean  $\overline{X_{..}}$ .

$$X_{corrected\ ij} = X_{ij} - \overline{X_i} + \overline{X_{..}}$$

Then calculated the rank all genotypes for each environment  $j$

$$r_{ij} = rank(X_{correctedij})$$

Variance of rank is calculated as the following equation.

$$S_i^2 = \frac{\sum_j (r_{ij} - \overline{r_i})^2}{E - 1}$$

where  $r_{ij}$  is the rank of genotype  $i$  in environment  $j$  and  $\overline{r_i}$  is the marginal rank of genotype  $i$  over environment, based on the corrected  $X_{ij}$  values.

## Citing toolStability

```
#>
#> To cite the R package 'toolStability' in publications use:
#>
#> Wang, T-C. and Chen, T-W. ( 2022 ). toolStability: Tool for
#> stability indices calculation. R package version 0.1.1 ,
#> https://github.com/Illustratien/toolStability/
#> https://cran.r-project.org/package=toolStability .
#>
#> A BibTeX entry for LaTeX users is
#>
#> @Manual{,
#>   title = {toolStability: Tool for Stability Indices Calculation},
#>   author = {T.-C. Wang and T.-W. Chen},
#>   year = {2022},
#>   note = {R package version 0.1.1},
#>   note = {https://github.com/Illustratien/toolStability/},
#>   note = {https://cran.r-project.org/package=toolStability},
#> }
#>
#> 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.
```

## References

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