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# A new approach for quantifying and scaling the drought resistance of crop plants during vegetative growth phase

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**Research Article**

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# Title page

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# A new approach for quantifying and scaling the drought resistance of crop plants during vegetative growth phase

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## Abstract

All known methods for evaluating crops resilience under water deficit stress are relative and need a reference experiment, and up till now no method is available for quantification and scaling plants performance in this harsh habitat. In this study, an equation was established for quantifying the absolute drought resistance (ADRI) of crops plants with a scale of 0.0 to 100. This approach was based on datasets of 5 parameters: chlorophyll, RWC, drought period, soil moisture content and temperature index of 14 species (43 cultivars /treatments), and a practical experiment was executed to test this approach . Application of the new graduation displayed a reasonable ADRI values for the examined crops. Rice (*Oryza sativa* L.) appeared to be the most drought sensitive species with a value of 3.48-5.20., whereas the xerophytic species *Aloe vera* L. manifested the highest value (90.03). Noteworthy, this approach was also sensitive to the extent of stress and cultivar type, for example *Aloe vera* achieved ADRI value of 84.52 only at severe water deficit. The order of 14 evaluated species depending on their ADRI values were: Aloe > Opuinta > Toothbrush > Date palm > Cassava > Grape vine > Sorghum > Lotus > Barley > Wheat > Maize > Banana > Rice. Practical experiment supported the rightness of this approach with ADRI values of 77.5 and 18.5 for *Aloe vera* and *Zea maize*, respectively. This new approach for quantification of drought resistance would be a time and cost effective guide for farmers, plant breeders and physiologist.

• **Key words**: Chlorophyll -drought index - equation– Likert scale- RWC -SMC.

## Introduction

Drought remains the most significant stressful factor which threatens the world food security where about 40% world land and 20% of the cultivated area are under water shortage; climate changes will exacerbate this problem [1, 2, 3]. This stress is a complex phenomenon which affects world population more than any other environmental factor [4,5].

Plants are developed to deal with water shortage by different adaptation mechanisms which could be divided into drought escape and drought resistance strategies. Drought escape or ephemerals plants are able to complete their life cycle before the onset of serious water stress [6, 7]. Drought resistance is the ability of plant to withstand external water deficit stress and could be achieved by two major components termed drought tolerance (active) and drought avoidance (passive) mechanisms, with most plants using a combination of the two. Through avoidance mechanisms, plants avoid internal water deficit by ways such as regulation of stomatal opening, reduction of leaves area and enhancing root / shoot ratio. Conversely, in tolerance mechanisms plants can tolerate internal water deficit by osmotic adjustment, and stability of cellular membranes and vital molecules [6, 8, 9].

Exploring the drought resistant genotypes or species is an important target for farmers, physiologists and breeders. So different methods were developed to asses drought resistance in plants. The pioneer Levitt [6] stated an equation to estimate drought resistance based on water potential measurement, however this method was not popular may because it need an expensive instrument for measuring water potential. Also, Fischer and Maurer [10] established a helpful formula based on economic yield which was widely used but it estimates drought resistance relatively, requires long time and needs carrying out the evaluation experiment meanwhile for all compared genotypes or species. Some authors used derivatives to this equation [11]. Apparently, all these methods eliminated the effect of drought period length and without definite scale. So, looking for a new method for quantification of drought resistance that nullify these defectives is being a necessary objective.

Some plant physiological aspects can be used as drought resilience markers. Chlorophyll acts as primary electron donor during the light reactions of photosynthesis and its concentration is important for plant growth and grain yield [12,13]. This biochemical component is largely affected by water shortage and its concentration could be used as a marker of plant tolerance to this stress (14,15]. Biophysical parameters such as relative water content (RWC) and water potential are a promising parameters for evaluating the impact of drought on plants. RWC is being more superior because it allow comparisons among different morphologies, easily estimated and can be detected by remote sensing [16]. Correlation between RWC and drought resistance was frequently observed [17].

Soil water shortage is detrimental for plant growth and its level is reliable way for exploring drought impact on plant growth [18,19] The length of drought period is also crucial for manifestations of water deficiency symptoms in plants [20]. Additionally, temperatures rise due to seasonal variation or climate changes results in a decreased air relative humidity and increased deficiency of vapor pressure which exacerbates drought impact [21. 22] .

According to the available literature, no previous study has used chlorophylla, RWC, SMC, drought period length and temperature collectively in drought quantification. Therefore, this study was undertaken to deduce a new equation for quantification and scaling the absolute drought resistance of crop plants based on these five parameters. After that, an experiment was conducted to test the rightness of this approach.

## Materials and Methods

### 1.Dataset collection

Published literatures about the impact of drought stress on plants during vegetative growth stage which contain values of RWC, Chla, SMC, drought period and atmospheric temperature at the experiment site were searched from Web of Science (ISI), Google Scholar, Scopus, and Egyptian Knowledge Bank (EKB). Although thousands of published works about the impact of drought stress on plants appeared in database, very little number of papers clearly determine

these important parameters collectively. Hardly, dataset of 43 species, cultivar and treatments were collected which contained directly or indirectly the required information.

**2.Ordinal scale for plants drought resistance and PCA analysis**

Based on Likert scale [23] the plants of our dataset were categorized into 5 ordinal groups with converting their qualitative response to drought stress into quantitative data as following: very sensitive = 1, moderately sensitive =2, moderately resistant =4, resistant =7, xerophyte =10. Then Principle Component Analysis (PCA) was performed by OriginPro version 26 program to explore the relations between TChl, RWC, SMC, drought period, temperature and the suggested Likert drought resistance scale.

**3.The new approach for estimating absolute drought resistance:**

In this study, an equation was achieved for quantification of the absolute drought resistance in plants based on values of total chlorophyll a content, RWC, SMC, drought period, air temperature around the targeted plant and PCA output. Drought performance was expressed as absolute drought resistance index with a value estimated from the following equation:

Absolute drought resistance index(ADRI) =

$$[(0.1\ RWC + 4TChl)/SMC^{(1/7)}]\ 0.4\ [DP^{(1/2)}]\ [TI]$$

Where:

RWC is leaf relative water content (%); TChl is total chlorophyll content as % of dry mass; SMC is the soil moisture content (% of soil dry mass); DP is the length of drought period (days) ; TI is the temperature index . It was found that temperature extremes for growth of most plant species is in between 5 -55 °C with a mean value of 30°C [24]. So TI was suggested to be air temperature in Kelvin degree divided by that at 30 ºC. Kelvin scale was used because it is the SI unit for temperature measurement and to prevent complication (possibility of negative sign) due to very low temperature.

Through this equation, the value of RWC was divided by 10 to balance this value with that of 4TChl. The seventh root of SMC was used because the soil moisture content decrease more rapidly than RWC and TChl in response to drought stress. Detection of RWC and

chlorophyll a content should take place in a surviving mature leaves after the plants manifested symptoms of water stress . The square root of drought period was introduced in the equation and multiplied by 0.4 instead of the actual value to restrict the resistance index scale inside 100 value.

**4.Data visualization and relation between the suggested index with Likert scale index:**

A heatmap for visualization of all data and the coefficient of determination ($R^2$) between absolute drought resistance index (ADRI) and Likert scale index were illustrated by Origin 2026b graphing and analysis software.

**5.Experimental study.**

Small plantlets of *Aloe vera* were regenerated from offshoots of mature plants during summer season in plastic pots (20 cm × 18 cm) filled with 2:1 clay: sand soil. After the plantlets were established (about one month from planting), grains of *Zea maize* Single Hybrid cultivar were obtained from the Agriculture Research Centre at Cairo, Egypt. Then the grains were presoaked in distilled water for 6 h and sown in the same soil and pots of *Aloe vera* plantlets. All pots were retained in the greenhouse at Faculty of Science, Port Said University, where the plants were exposed to natural day/night conditions, fertilized with NPK (1g/pot) and irrigated as needed. Minimum/maximum day temperature, relative humidity and photoperiod were 30/38°C, 50/62% and 13 /14 h, respectively. After further 40 days, the plants were exposed to water stress where soil moisture content were kept at 20-30% FC only. The stress period in maize was 21 days, whereas that of *Aloe vera* plants was extended for 135 days. At the end of stress period, samples were taken for determination of RWC, total chlorophylls and soil moisture content.

**5.1. Determination of total chlorophyll**

Leaf samples were homogenized with 80% cold acetone under dim light. After that, the homogenate was centrifuged and the spectrophotometer method was performed to quantify Chl a and Chl b at 663 and 647 nm using the equations of [25].

**5.2. Estimation of RWC**

For determination of RWC, leaf samples were cut into 2 cm segment and their fresh weight (FW) was obtained. Then these segments were floated in distilled water for 4 hours in dim light to obtain their full turgid weight (TW). Thereafter, samples dry mass was recorded after oven-drying at 70° C for 24 h (DW). RWC was estimated using the equation:

RWC (%) = [(FW-DW)/(TW-DW)] × 100 [26].

### 5.3. Evaluation of soil moisture content (SMC)

SWC was estimated gravimetrically by obtaining the fresh weight of a soil sample. Then this sample was oven dried for 2 days at 105°C to get dry soil mass (DW). The SWC was expressed as the mass of soil water per g of dry soil [27].

### 5.4. Recording drought period length

Number of days from the onset of drought until estimation of the resistance index can be obtained by conventional counting or from Meteorological stations database. Drought period should be continued until symptoms of water deficit stress appeared on plants under the study and this will take at least one week for annuals and three weeks for perennial crops.

### 5.5-Statistical analysis

Data were presented as means of 3 replicates ±SE. ANOVA and the significant differences between means of Aloe and maize aspects were estimated by the independent-sample t-test with IPM SPSS software version 19.

## Results

### Dataset scrutinization and PCA visualization

Data presented in table 1 show the effect of water shortage on RWC and total Chl values as parameters of drought resistance which were obtained directly or indirectly from 15 publications with 43 cultivars and treatments. Additionally, experimental SMC, drought period and atmospheric temperature were recorded. These datasets clarified that water deficit stress enormously reduced RWC and Chl level in leaves of different plant species. It is obvious that this effect increased with the increase of drought period and decrease of soil moisture content for the same species as in case of *Aloe vera* and *Sorghum bicolor*. The reported temperature

indicated seasonal variation between the selected species, where some of them were sampled at relatively high temperature (about 38°C) such as date palm and others at relatively low temperature (about 20 °C) such as wheat plants.

It is obvious that the gradient of decreased in SMC was more higher than those of RWC and total Chl due to water deficit stress. It can be estimated that the reduction of Chl and RWC in *Aloe vera* and *Sorghum bicolor* was about 20% which was corresponding to a about 50% decrease in SMC. Additionally, the longest drought period appeared in the database were 180 and 360 days for *Aloe vera* and *Phoenix dactylifera*, respectively, whereas the shortest period was 7 days for rice (*Oryza sativa*) plants.

Datasets visualization by Principle Component Analysis PCA (Fig. 1) elucidated that the direction of drought resistance (Based on Likert scale, 1-10), RWC, total Chl, drought duration and atmospheric temperature were at the positive side of PC1, whereas SMC points to the negative side. This biplot manifested the contrasting of all visualized parameters with soil moisture content (SMC). Drought resistance showed positive correlations (small angle) with RWC (as comparable with total Chl and stress period), weak correlation with temperature and negative correlation with SMC under water deficit conditions.

**Quantification of drought resistance**

Based on the previous principle component analysis of database, an equation was suggested for quantification of plants response to water deficit stress and details of this approach were included in the methods section. The estimated drought resistance indices, based on for 14 crop species (43 cultivars and treatments) were shown in table 2. Furthermore, the associated levels of RWC, total Chl, SMC, drought period and temperature index were visualized in fig. 2 heatmap. The highest index value was observed in *Aloe vera* at moderate stress with a value of 90.03. This value was decreased with the increase of water deficit stress to be 84.52 at severe stress. Date palm *(Phoenix dactylifera)* and cassava (*Manihot esculenta*) appeared to have a relatively high drought resistance index with values of 56.61 and 48.9, in the order presented.

However these values were more lower than those of *Aloe vera, Opuntia* sp. and *Manihot esculenta.*

Grape vine appeared to perform well under water stress with a DRI value ranged from 28 to 34 depending on cultivar type. A slight difference was noted between barley, wheat and maize in ability to withstand water shortage stress. Noteworthy, the proposed equation obviously reflected the difference in DRI between cultivars of the same species, for example in grape vine species Rotabi (ADRI= 34) was more drought resistant than Flame Seedless cultivar (ADRI = 26).

The six crops species (maize, sorghum, wheat, barley, potato and *Lotus* sp. ) showed a drought resistance index value ranged from about 21 to 24 depending on species and used cultivar. The lowest value of calculated drought resistance index was recorded for rice (*Oryza sativa*) and banana (*Musa acuminata*) with values of about 4 and 9, respectively.

The performance order of all 14 species depending on their mean absolutes drought resistance index value were:

Aloe > Opuinta > Toothbrush > Date palm > Cassava > Grape vine > Sorghum > Lotus > Barley > Wheat > Maize > Banana > Rice

**Strength of relationship between the estimated ADRI and Likert scale index**

Likert scale index for ordinal data with a range of 1 -10 was used to assess the resistance of various crops to water deficit stress based on background information of every species. During this scale, very sensitive =1, moderately sensitive = 2, moderately resistant =4, resistant =7 and xerophytes =10. Coefficient of determination ($R^2$) value in fig.3 manifested a direct and very strong positive relationship between the estimated absolute drought resistance index (ADRI) and Likert index for plant performance under stress ($R^2 = 0.95$).

**Scaling the response of various crop plants to drought stress**

Depending on the estimated absolute drought resistance index for various crop plants which was derived from the new equation, the plants were classified into 5 groups in response to water shortage and the results were illustrated in fig. 4. These groups are: very sensitive with

ADRI of 0-10, moderately sensitive with ADRI more than 10 to 20, moderately tolerant with ADRI more than 20 to 40, resistant with DRI more than 40 up to 100 and xerophytes with ADRI of more than 70 up to 100. For example, *Aloe vera* appeared to be xerophytic plant, whereas *P dactylifera* was drought resistant plant only. Furthermore, grape vine was moderately drought tolerant, whereas rice was very sensitive plant to water shortage.

**Experimental confirmation: The absolute drought resistance index for maize and *Aloe vera***

Experimental results of *Zea maize* and *Aloe vera* plants exposed to water stress for 21 and 135 days, respectively were illustrated in fig 5 and 6. It can be seen that total chlorophylls and RWC of *Aloe vera* were significantly higher than those of maize plants under these water shortage conditions. The estimated ADRI of maize was 18.4, whereas that of *Aloe vera* plants was 77.43. It can be calculated that these values of ADRI were about 90% of the deduced ones from datasets.

## Discussion

Drought issue is expected to be maximized during the upcoming decades due to global warming and climate changes, and this would adversely affects the sustainability of food production for many developing countries [43]. Currently, foods of about 16% of world population are severely affected by water shortage stress ([1, 2]. Developing a new, easy and time effective approach for quantifying and scaling of crops drought resistance is a crucial objective for physiologists and breeders, and would help not only in screening for drought resilience, but also for developing new genotypes which are more resistant to water shortage. To achieve this target, a new equation was developed based on the datasets of RWC, TChl, drought period, soil moisture content and temperature index.

Relative water content (RWC) is a better indicator of water status in plant tissues due to its relation with cell volume which would disclose the balance between water absorption and transpiration rate [44]. The lowest value of RWC, in the obtained database, was in rice plants (about 40%) and this was consistent with general reputation that rice is one of the

most sensitive crops to water shortage [45]. Conversely, *Aloe vera* plants appeared to have high RWC under water stress (about 84%) and this was compatible with the succulence and xerophytic properties of this species [46]. *Phoenix dactylifera*, a drought tolerant crop, had a value of RWC (about 62%), which was lower than other species such as *Sorghum bicolor* ( 67%) and *Hordeum vulgare* (75%) [27, 31, 32]. This variation between species in RWC under water shortage conditions could be related to difference in the mechanism of drought resistance which may be by tissue water deficit avoidance or by dehydration tolerance [8].

Chlorophylls are the main photosynthetic pigments and their level is directly related to aerial biomass and productivity of crops (11, 47]. Inspection of the obtained dataset under water limiting conditions displayed that xerophytic plants such as *Aloe vera* and *Opuntia* sp. had higher TChl than the sensitive plants such as rice. However, species such as *Phoenix dactylifera* appeared to have a lower level of these important photosynthetic pigments than *Zea maize* which contrast their pattern of drought resistance. So it can be deduced that neither TChl nor RWC each alone can be used as a true marker of drought resistance between different genotypes or species. Soil moisture content (SMC), water shortage period and atmospheric temperature are also key parameters for evaluation of crops drought resistance [22,34], however data visualization heatmap displayed that any of these parameters could not be used alone as an outstanding drought resilience marker. Using all these 5 parameters in a new approach known as ADRI to evaluate plants performance under water deficits conditions gave logic and obvious expression for approximately all tested species and genotypes. This was clear from the strong relation ($R^2$ =0.95) between the ADRI and Likert scale index.

The established equation was sensitive to stress severity for the same genotype, where *Aloe vera* genotype had ADRI of 90 and 84 in response to 10% and 5% SMC, respectively. Additionally, our approach discriminates the drought resistance degree of different genotypes across the same species. In this context, ADRI of Giza 179 genotype was about 5, whereas that of Sakha 101 genotype was about 3 only although they belongs to the same species (*Oryza sativa*) and this was consistent with the results of Ibrahim et al [31].

Experimental results of TChl, RWC, SMC, drought period and temperature index and the estimated ADRI for *Zea maize* and *Aloe vera* characterized these species as moderately sensitive and resistant to water shortage, respectively. This confirmed the deduced indices for these species from datasets by about 90% and could prove that drought resilience in plants is multigenic as stated by Ali et al. [48]. The provided approach can easily determine drought resistance for different species, or genotypes and scaling their capability of withstanding water deficit stress without need to grow them simultaneously. Furthermore, by using this equation there will be no need for a reference experiment during the evaluation of plants performance under stress, and this would save time and costs. However, for precise comparison of specific genotypes, water shortage experiments should be carried out at the at the same soil moisture content.

## Conclusion

A new equation was established for quantifying and scaling of the absolute drought resistance index (ADRI) of crops during the vegetative growth phase with scale of 0 to 100. This approach depended on 5 parameters which were TChl content, RWC, SMC, drought period and temperature index, and its implementation revealed logical and reasonable drought resistance index for the tested 14 crops. Experimental results with *Zea maize* and *Aloe vera* confirmed the deduced ADRI. This procedure does not need a reference experiment, and would save time and costs.

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## Author contribution

The author declares that he carried out the practical experiment, writhe the manuscript and analyzed the datasets of this work.

## Data availability

The datasets analysed during this study are included in this manuscript.

**Ethics approval and consent to participate**

The experiment was conducted in accordance with guidelines of the internal bylaw of Port Said University for ethics of scientific research with plants, soils and water. This work has given the approval code: ERN, PSU.SCI.188 from the Scientific Research Ethics Committee at Faculty of Science, Port Said University, Egypt.

**Consent for publication**

The author consent for publication.

**Competing interests**

The author declare that he has no competing interests.

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## Abbreviations

| | |
|---|---|
| ADRI | Absolute drought resistance index |
| TChl | Total chlorophylls |
| RWC | Relative water content |
| SMC | Soil moisture content |
| PCA | Principle component analysis |
| $R^2$ | Coefficient of determination |

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**Table 1.** Datasets of relative water content (RWC), chlorophyl a (Chl a), soil moisture content (SMC), drought period (DP) and atmospheric temperature (T) for 14 crops species (43 cultivars & treatments) grown under drought conditions.

| Species | RWC (%) | TChl (%) | SMC (%) | DP (d) | Temperature (K) | Reference |
|---|---|---|---|---|---|---|
| *Aloe vera* (M) | 84.0 | 3.68 | 10.0. | 180 | 305.66 | [28] |
| *Aloe vera* (S) | 71.0 | 3.18 | 5.0 | 180 | 305.66 | [28] |
| *Zea maize* | 60.0 | 2.10 | 11.3 | 28 | 302.66 | [29] |
| *Sorghum bicolor* | 67.0 | 2.40 | 2.3 | 17 | 304.36 | [30] |
| *Oryza sativa* Giza 179 | 58.0 | 0.33 | 14.0 | 7 | 305.16 | [31] |
| *Oryza sativa Sakha 101* | 40.0 | 0.19 | 14.0 | 7 | 305.16 | [31] |
| *Oryza sativa Sakha 106* | 45.0 | 0.18 | 14.0 | 7 | 305.16 | [31] |
| *Oryza sativa Giza 177* | 58.0 | 0.16 | 14.0 | 7 | 305.16 | [31] |
| *Triticum aestivum* (4 cultivars) | 60.0 | 3.30 | 17.5 | 20 | 293.66 | [32] |
| *Vitis vinifera* Flame seedless (Mi) | 82.3 | 1.83 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Flame seedless (M) | 80.2 | 1.37 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Flame seedless (S) | 73.4 | 1.00 | 6.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Perlette (Mi) | 83.2 | 1.52 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Perlette (M) | 79.2 | 1.98 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Perlette (S) | 77.9 | 1.52 | 6.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Rotabi (Mi) | 87.9 | 1.90 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Rotabi (M) | 85.3 | 1.60 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Rotabi (S) | 81.1 | 1.55 | 6.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Yaghouti (Mi) | 86.7 | 1.60 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Yaghouti (M) | 83.9 | 1.52 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Yaghouti (S) | 79.4 | 1.14 | 6.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Siah (Mi) | 86.1 | 1.37 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Siah (M) | 82.8 | 1.30 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Siah (S) | 74.4 | 1.52 | 6.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Samarghandi (Mi) | 84.6 | 1.74 | 18.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Samarghandi (M) | 79.7 | 1.52 | 12.0 | 60 | 294.66 | [33] |
| *Vitis vinifera* Samarghandi (S) | 74.2 | 1.68 | 6.0 | 60 | 294.66 | [33] |
| *Hordeum vulgare* Rahma | 75.0 | 3.00 | 7.0 | 15 | 293.66 | [34] |
| *Hordeum vulgare* Tissa | 65.0 | 2.90 | 7.0 | 15 | 293.66 | [34] |
| *Hordeum vulgare* Jaidor | 65.0 | 3.30 | 7.0 | 15 | 293.66 | [34] |
| *Hordeum vulgare* Acsad 176 | 68.0 | 3.00 | 7.0 | 15 | 293.66 | [34] |
| *Hordeum vulgare* El Fouara | 73.0 | 2.50 | 7.0 | 15 | 293.66 | [34] |
| *Phoenix dactylifera* | 62.0 | 0.88 | 8.0 | 360 | 310.16 | [35] |
| *Musa acuminata* (ratoon) | 56.0 | 0.35 | 30.0 | 30 | 298.16 | [36] |
| *Musa acuminata* Berangan | 85.0 | 0.30 | 25.0 | 14 | 300.16 | [37] |
| *Salvadora persica* | 76.0 | 1.55 | 2.8 | 245 | 305.16 | [38] |
| *Manihot esculenta* | 94.8 | 4.22 | 12.0 | 45 | 299.16 | [39] |
| *Opuntia* sp. | 44.3 | 4.52 | 12.5 | 180 | 294.16 | [40] |
| *Lotus corniculatus* | 65.0 | 1.91 | 23.5 | 42 | 301.66 | [41] |
| *Solanum tuberosum* | 57.0 | 2.43 | 22.5 | 38 | 296.16 | [42] |

Abbreviations: Mi, mild; M, moderate stress; S ,severe stress.

**Table 2.** Estimated absolute drought resistant index (ADRI) of 14 plant species (43 cultivars./treatments).

| No. | Species/Cultivars | ADRI | No. | Species/ Cultivars | ADRI |
|---|---|---|---|---|---|
| 1 | *Oryza sativa* Giza 179 | 5.20 | 21 | *Vitis vinifera* Perlette (M) | 33.44 |
| 2 | *Oryza sativa* Sakha 101 | 3.48 | 22 | *Vitis vinifera* Perlette (S) | 32.36 |
| 3 | *Oryza sativa* Skha 106 | 3.81 | 23 | *Vitis vinifera* Rotabi (Mi) | 32.69 |
| 4 | *Oryza sativa* Giza 177 | 4.71 | 24 | *Vitis vinifera* Rotabi (M) | 31.51 |
| 5 | *Musa acuminata* (ratoon) | 9.28 | 25 | *Vitis vinifera* Rotabi (S) | 34.40 |
| 6 | *Musa acuminata* Berangan | 9.08 | 26 | *Vitis vinifera* Yaghouti (Mi) | 30.02 |
| 7 | *Zea mays* | 21.53 | 27 | *Vitis vinifera* Yaghouti (M) | 30.57 |
| 8 | *Hordeum vulgare* Rahma | 22.25 | 28 | *Vitis vinifera* Yaghouti (S) | 29.16 |
| 9 | *Hordeum vulgare* Tissa | 20.56 | 29 | *Vitis vinifera* Siah (Mi) | 28.08 |
| 10 | *Hordeum vulgare* Jaidor | 22.38 | 30 | *Vitis vinifera* Siah (M) | 28.42 |
| 11 | *Hordeum vulgare* Acsad176 | 21.36 | 31 | *Vitis vinifera* Siah (S) | 31.54 |
| 12 | *Hordeum vulgare* El Fouara | 19.66 | 32 | *Vitis vinifera* Samarghandi (Mi) | 30.96. |
| 13 | *Triticum aestivum* (4 cultivars) | 22.10 | 33 | *Vitis vinifera* Samarghandi (M) | 29.69 |
| 14 | *Solanum tuberosum* | 23.80 | 34 | *Vitis vinifera* Samarghandi (S) | 32.93 |
| 15 | *Lotus corniculatus* | 23.22 | 35 | *Phoenix dactylifera* | 56.61 |
| 16 | *Sorghum bicolor* | 24.55 | 36 | *Manihot esculenta* | 48.94 |
| 17 | *Vitis vinifera* Flame seedless (Mi) | 30.96 | 37 | *Salvadora persica* | 75.26 |
| 18 | *Vitis vinifera* Flame seedless (M) | 28.51 | 38 | *Opuntia* sp. | 81.42 |
| 19 | *Vitis vinifera* Flame seedless (S) | 26.48 | 39 | *Aloe vera* (S) | 84.52 |
| 20 | *Vitis vinifera* Perlette (Mi) | 28.73 | 40 | *Aloe vera* (M) | 90.03 |

**Abbreviations:** Mi, mild stress; M, moderate stress; S ,severe stress.

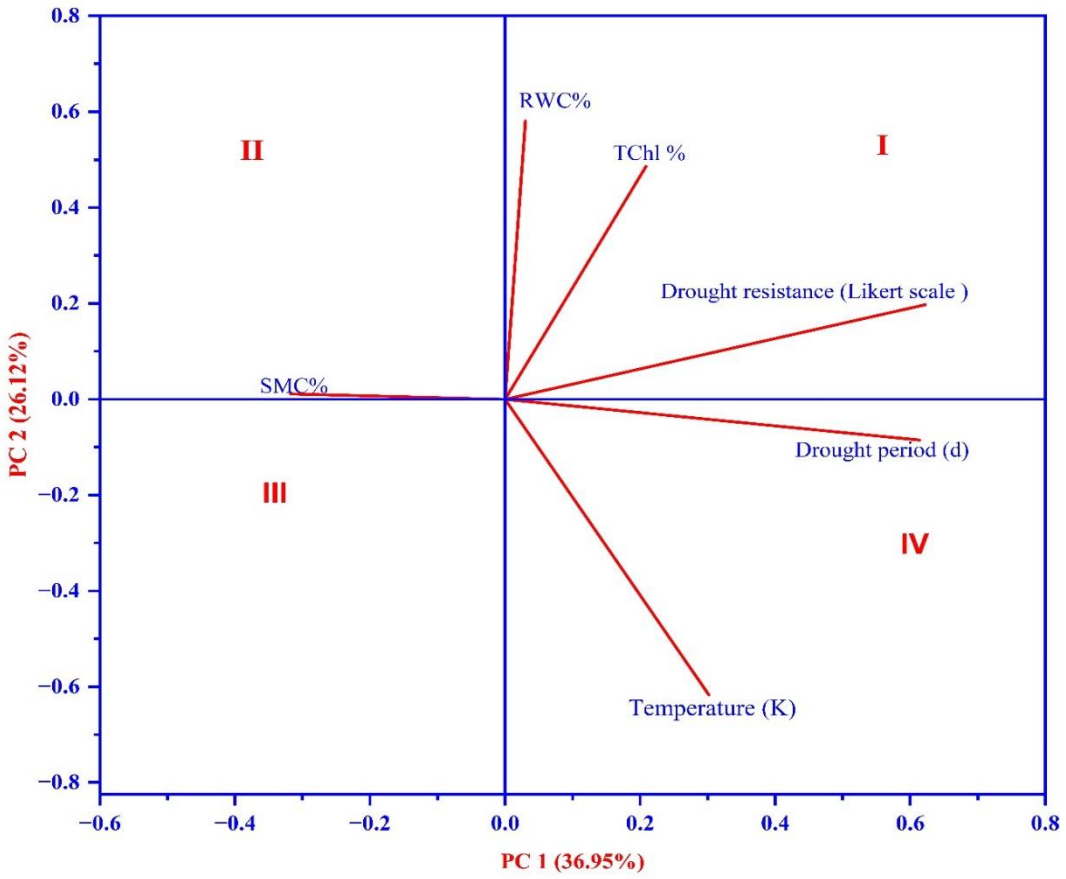



**Fig.1.** Principle component analysis of datasets from 43 cultivars/treatments under drought conditions.

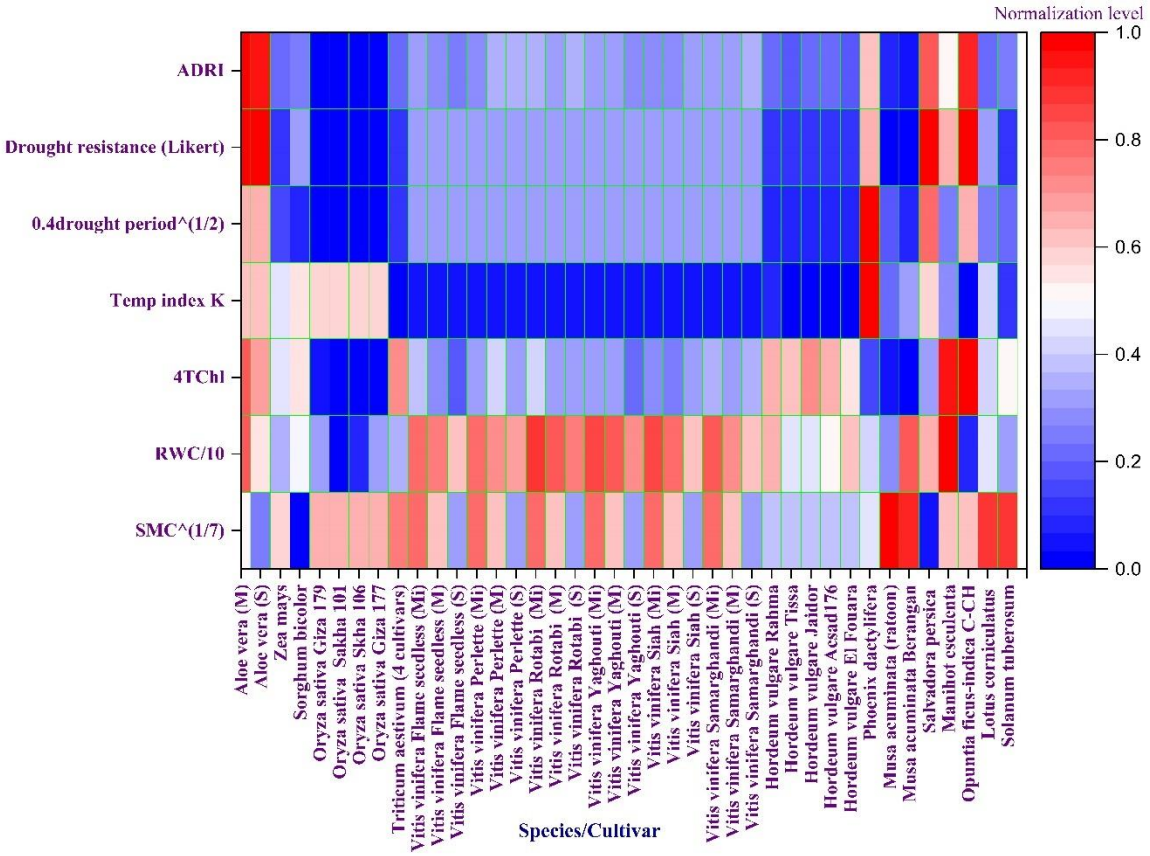



**Fig.2.** Heatmap for visualization of datasets and drought resistance for 43 cultivars/ treatments under water deficit conditions.

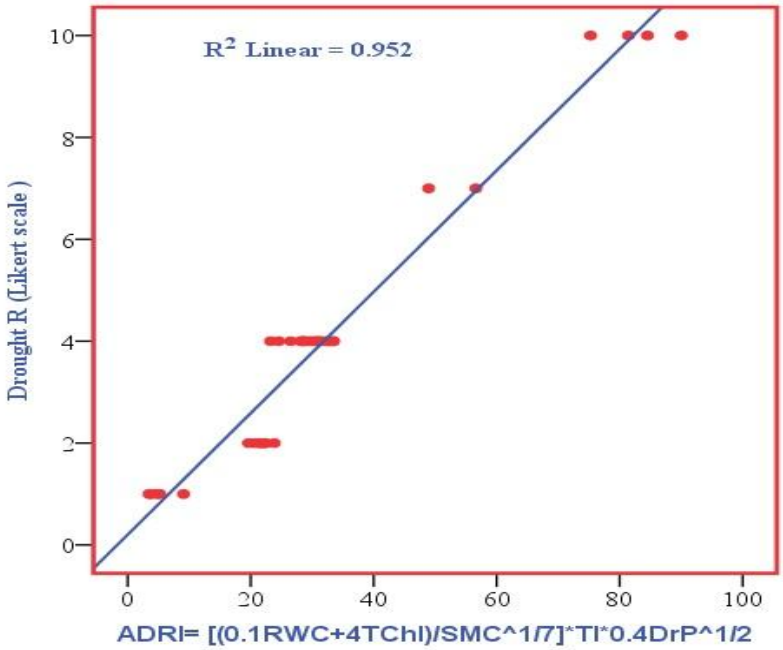



**Fig.3.** Fitting line between the absolute drought resistance index (ADRI) and Likert scale index of ordinal data.

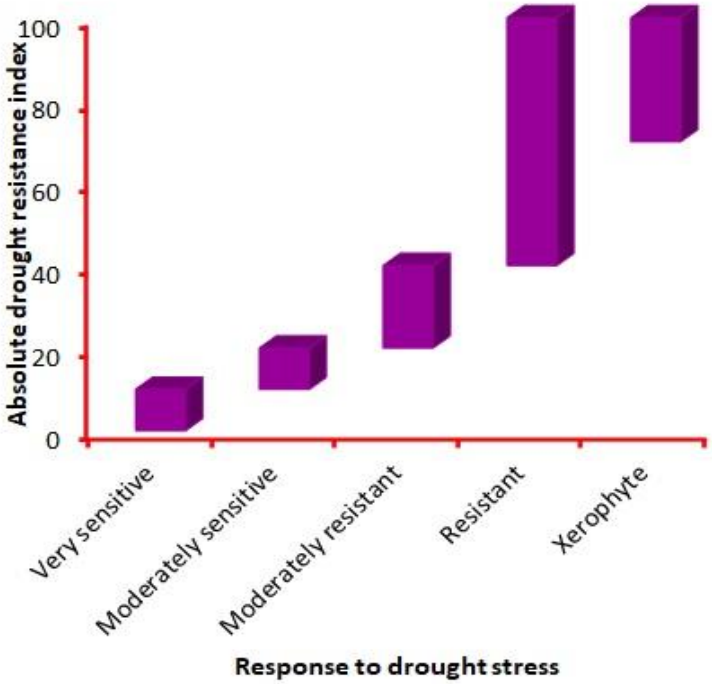



**Fig.4.** Quantification and scaling of drought resistance of various crop plants.



**Fig.5.** Effect of water deficit stress for 21 d on *Zea maize* (5a) and 135 d on *Aloe vera* (5b).

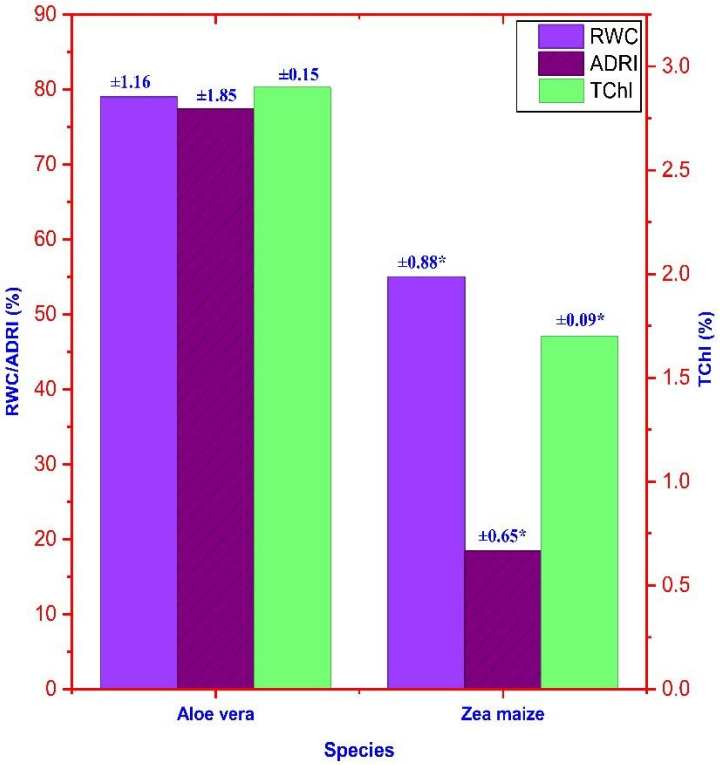



**Fig.6.**Changes in total chlorophyll, RWC and absolute drought resistance index of *Zea maize* and *Aloe vera* after 21 and 135 d of water stress, respectively.