

## The concept and statistical method of drought resistance index in crops

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**Summary** There is evidence showing that stress susceptibility index (SSI)  $(1 - Y_d/Y_p)/(1 - \bar{Y}_d/\bar{Y}_p)$  used as a measure of drought resistance of crop on the field is an altered form of drought resistance coefficient (DRC)  $(Y_d/Y_p)$ . The correlative coefficient SSI and DRC is  $r = -1$ . Therefore, the SSI doesn't improve the defect of the DRC. After two years experiments performed by using thirty winter wheat varieties as trial materials, the concept of drought resistance index in crops was put forward. Its expressing equation is: the yield in dryland  $\times$  drought resistance coefficient/average yield in dryland. It makes the drought resistance coefficient (physical index) correlate well with the yield in dryland (agronomy index) and is suitable for breeder.

**Key words** crop, drought resistance index, cluster analysis

### Introduction

The measurement of crop's drought resistance in field is an integrated evaluation of various index of drought resistance. Although the difference of water status in different years and sites makes a considerable experimental error, the determination of various physiological, biochemical and ecological index will depend upon field measurement. The regression of actual yield of a cultivar to environment index was used by Finlay et al. (1963) to determine its adaption, and later this method was improved by Eberhart et al. (1966). Using millet as experimental material, Bidinger et al. (1982) proposed the concept of stress resistance index expressed as

$$\text{Index} = (Y_a - Y_s) / SE_s$$

where  $Y_a$  is the actual yield under stress condition;  $Y_s$  is the expected yield under stress, which is function of non-stress yield  $Y_c$  and days to flowering  $bl$ .  $SE_s$  is the standard error of  $Y_s$ .

$$Y_s = a + b_1(Y_c) + b_2(bl) - b_3(bl)^2$$

As the methods above is complicated in calculation, they are not well accepted by crop breeders. At present, what is commonly accepted is drought resistance coefficient (yield in stress condition divided by that in non-stress condition). But its defect is also obvious. Suppose variety *A* yields 3.0 t/ha, 4.5 t/ha in dryland and irrigated land, respectively, with its drought resistance coefficient 0.67. Variety *B* yields 3.8 t/ha and 6.8 t/ha, respectively, with the coefficient 0.56. Breeders will simply selected *B* rather than *A*. Later, Fischer et al. (1978) suggested the 'susceptibility index'  $S$  expressed in the relationship

$$Yd = Yp(1 - SD)$$

Where  $Yd$  is yield under stress;  $Yp$  is yield without stress, and  $D = 1 - \bar{Y}d / \bar{Y}p$ , where  $\bar{Y}d$  and  $\bar{Y}p$  represent average yield over all varieties under stress and without stress conditions. The advantage of this method is that it takes environment component into consideration. But, in application, we found that it's only an altered form of drought resistance coefficient and doesn't provide more information for the breeders. Therefore, based on experiments, we suggested the concept of drought resistance index to improve drought resistance coefficient substantially.

### Materials and methods

Thirty winter wheat varieties were evaluated in the field at the Experiment Station of Dryland Farming Institute, Hebei Academy of Agricultural and Forestry Sciences from 1986 to 1988. Each variety was grown in irrigated plot and non-irrigated plot. The plants in irrigated plot was irrigated for 3 times before harvest, at a rate of 750 m<sup>3</sup>/ha. In the non-irrigated plot, the plants only received natural precipitation. A randomized block design was used with three replications. After harvest, the yield records were analyzed by using three methods of drought resistance coefficient, susceptibility index and drought resistance index.

Drought resistance coefficient =  $Yd/Yp$

Susceptibility index =  $(1 - Yd/Yp) / (1 - \bar{Y}d/\bar{Y}p)$

Drought resistance index =  $Yd \times (Yd/Yp) / \bar{Y}d = Yd/Yp \times Yd/\bar{Y}d$

where  $Yd$  is the yield under stress;  $Yp$  is the yield under non-stress;  $\bar{Y}d$  is the average yield of all varieties under water stress;  $\bar{Y}p$  is the average yield of all varieties under non-stress. Clustering analysis was used by method of T. Calinski (1985).

### Results and discussion

#### *Drought resistance coefficient and stress susceptibility index*

The results of 30 varieties was listed in Table 1.

1. The susceptibility index is an altered form of drought resistance coefficient. According to Fischer, the susceptibility index 'S' is expressed in the following relationship.

$$Yd = Yp(1 - SD)$$

$$S = (1 - Yd/Yp) / D$$

$$\text{where } D = 1 - \bar{Y}d/\bar{Y}p$$

$$SD = 1 - Yd/Yp$$

where  $D$  is a constant. It may be seen from the above equations that the value of the 'S' increases by  $D$  times as compared with drought resistance coefficient. SSI and DRC are correlative completely. The statistical analysis of 30 varieties showed that the coefficient of correlation of the SSI and DRC is  $-1$  ( $r = -1$ ). Therefore, the susceptibility index has not made real improvement for the drought resistance coefficient.

2. The susceptibility index has serious disadvantage of drought resistance coefficient. Luhan 264, Jimai 6, Jimai 3, Jimai 19, for example, have the same drought resistance co-

**Table 1.** The drought resistance coefficient(DRC) and stress susceptibility index(SS1) of 30 varieties

No	Variety	DRC	SSI
1	Pingyang 1	0.83	0.58
2	Hengshui 6404	0.80	0.69
3	Taishan 5	0.79	0.72
4	Shite 14	0.78	0.74
5	Weimai 5	0.77	0.79
6	Aiganzhao	0.76	0.83
7	Beijing 10	0.75	0.86
8	Yuandong 96	0.74	0.89
9	Fengkang 13	0.74	0.89
10	Dong 87	0.73	0.93
11	Jinfeng 1	0.73	0.93
12	Jinmai 11	0.73	0.93
13	Hanxuan 3	0.72	0.96
14	Jimai 7	0.72	0.96
15	Jimai 6	0.71	1.00
16	Dongfanghong 3	0.71	1.00
17	Jimai 19	0.70	1.03
18	4001	0.70	1.03
19	Taiyuan 633	0.70	1.03
20	Jimai 3	0.70	1.03
21	Luhan 264	0.70	1.03
22	Han 10	0.70	1.03
23	Ai 781	0.68	1.10
24	Changle 5	0.67	1.14
25	Fengkang 10	0.67	1.14
26	Shannong 587	0.65	1.21
27	Jingshuang 12	0.62	1.31
28	Weimai 4	0.62	1.31
29	Jimai 18	0.57	1.48
30	Luoflin	0.55	1.55

efficient and susceptibility index, but the fact of the matter is that the Jimai 6 is the control variety in the north China dryland regional test and generally recognized as drought resistant variety, and the Jimai 3 is a famous variety cultivating in irrigated condition. Luhan 264 is a drought resistant variety, while Jimai 19 has been cultivated in irrigated field for many years. The above facts, therefore, have led us to believe that using SSI and DRC for determining the drought resistance of the crops is not very effective.

#### *Product of average yield in stress and drought resistance coefficient*

The product is the basis of drought resistance index (DRI) proposed by us. The performance of variety in stress is the core of Finley model (1963) and Eberhart model (1966). Since both the models are complicated in calculation, they are not well received by breeders. However it's desirable that DRC represents well the potential production of variety. We multiple the yield under stress and drought resistance coefficient so as to turn the drought resistance coefficient (a physiological parameter) into an agronomy parameter suitable for breeders' requirement. The data of 30 varieties were shown in Table 2.

**Table 2.** The product of average yield in stress and drought resistance coefficient of 30 varieties

Variety	1	2	3	4	5	6	7	8	9	10
Product	533.8	530.3	422.0	461.0	511.8	436.2	439.5	337.2	449.0	401.2
Variety	11	12	13	14	15	16	17	18	19	20
Product	384.7	348.5	411.3	421.3	433.2	430.3	346.2	307.5	443.3	340.3
Variety	21	22	23	24	25	26	27	28	29	30
Product	422.5	373.5	366.3	463.5	377.5	290.8	297.2	322.8	244.5	188.5

#### 1. The improvement of drought resistance coefficient

The product obviously improved the accuracy in determining drought resistance compared with drought resistance coefficient and susceptibility index. For example, the product of Luhan 264 is 422.5, Jimai 6 is 433.2, Jimai 3 is 340.3 and Jimai 19 is 346.2. Jimai 6 and Luhan 264 have obviously stronger drought resistance in water stress than Jimai 3 and Jimai 19.

## 2. Cluster analysis of the product or the test varieties

The cluster method of T. Calinski and L. C. A. Corsten was used. First, the  $C_a = (K - 1)S^2F_a$  was calculated. ( $K - 1$ ) is the df of variety.  $S^2$  is the mean square of error.  $F_a$  is the  $F$  value in probability 0.05. Then the  $S(I) = r \sum (Y_i - \bar{Y})^2$  was calculated.

If  $S(I) < C_a$ , the calculation was stopped and the grouping can be acceptable.

$$C_a = (k - 1)S^2F_a = 29 \times 8935.6 \times 1.7 = 440525.1$$

$$S(I)(1 - 30) = r \sum (Y_{ij} - \bar{Y}_i)^2 = 1110735.6$$

$S(I) > C_a$ , the cluster is needed. Least cluster methods were used in Calinski's paper. In this study, we used  $t$  test method.  $S\bar{d} = 54.57$ , when  $\alpha$  is 0.05 and  $S\bar{d}$  is 54.57, the least difference is  $54.57 \times 1.96 = 106.9$ . The largest number in Table 2 is 533.8. Therefore,  $533.8 - 106.9 = 426.9$ . Clustering was made from large to small according to the value. As a result, wheat varieties of Ping yang 1, Hengshui 6404, Weimai 5, Changle 5, Shite 14,

**Table 4.** The DRI value of 30 wheat varieties

DRI	Variety
1.36	Pingyang 1
1.35	Hengshui 6404
1.31	Weimai 5
1.18	Changle 5
1.18	Shite 14
1.15	Fengkang 13
1.13	Taiyuan 633
1.12	Beijing 10
1.11	Aiganzao
1.11	Jimai 6
1.10	Dongfanghong 3
1.08	Luhan 264
1.08	Taishan 5
1.08	Jimai 7
1.05	Hanxuan 3
1.03	Dong 87
0.98	Jinfeng 1
0.96	Fengkang 10
0.95	Han 10
0.94	Ai 781
0.89	Jimai 11
0.88	Jimai 19
0.87	Jimai 3
0.86	Yuandong 96
0.83	Weimai 4
0.79	4001
0.76	Jingshuang 12
0.74	Shannong 587
0.63	Jimai 18
0.48	Luoflin 10

**Table 3.** Analysis of variance of the varieties in Table 2.

Source	df	$S^2$	$F$
Replication	2	31935.0	
Variety	29	38301.8	4.29 * *
Error of experiment	58	8935.6	
Error of sample	90	31755.7	

Fengkang 13, Taiyuan 633, Beijing 10, Aiganzao, Jimai 6, Dongfanghong 3, all belong to drought resistance group. The others belong to the another group.

$$S(II) = S(1 - 11)(12 - 30) = 519158.5 > C_a$$

The result indicates that further grouping is needed for other 18 varieties.

### Drought resistance index

Although the product of average yield under water stress and drought resistance coefficient has a fairly good accuracy in determining drought resistance, it is not a standard parameter. For the convenient application, we gave it in the form of index.

$$\text{Drought resistance index (DRI)} = \frac{Yd \times (Yd/Yp)}{\bar{Y}d}$$

Where  $Yd$  is the yield under water stress of a given variety.  $Yp$  is the yield of a given variety under non-stress of water.  $\bar{Y}d$  is average yield under stress of all varieties.

Compared with the clustering results in section 2, the DRI value of the 11 varieties which were grouped as drought resistant group is between 1.10—1.36. Therefore, we recognize that all the varieties with DRI value above 1.10 should be classified to the drought resistant type.

The varieties with DRI value below 1.10 can be further divided into two groups, i. e. medium group and sensitive group. Various clustering methods can be used but variety performance in dryland condition should be taken as the criteria. We suggested that the varieties with DRI value between 0.90–1.09 belong to the medium group, the varieties with DRI value below 0.89 belong to the sensitive group. Then

$$S(\text{III}) = S(1-11)(12-20)(21-30) < C_{\alpha}$$

The above evidence indicates that the result of clustering is acceptable.

## Conclusion

The drought resistance index made a considerable improvement to the drought resistance coefficient. It is developed according to actual need in the process of combining drought-resistant physiological research with crop breeding.

The express formula of drought resistance index is rather simple for the purpose of convenient utilization. Along with the development of statistical genetic research, the authors believe, the drought resistance index should be revised to a fairly complete selection criteria.

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