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EVALUATION OF DROUGHT TOLERANCE IN TOMATO (*Solanum lycopersicum*) USING TOLERANCE INDICES

Evaluación de la tolerancia a la sequía en tomate (*Solanum lycopersicum*) utilizando los índices de tolerancia

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ABSTRACT. The present work was carried out with the aim of evaluating drought stress tolerance in 28 germplasm accessions of tomato (*Solanum* L. section *Lycopersicon* subsection *Lycopersicon*) *ex situ* preserved in Cuban collections as well as identifying the most tolerant accessions to be used in plant breeding programs. Thus, crop fruiting percentage was evaluated at the optimal period and under drought conditions (stressful period), which was used to calculate stress criteria: stress susceptibility index (SSI), geometric mean productivity (GMP), mean productivity (MP), stress tolerance index (STI), fruiting index (FI), harmonic mean (HARM), fruiting stability index (FSI), drought tolerance index (DI), stress susceptibility percentage index (SSPI), relative drought index (RDI), sensitivity drought index (SDI), modified stress tolerance indices (MSTI) and abiotic tolerance index (ATI). Accessions were classified according to their drought stress tolerance at plant level based on fruiting percentage, whereas the relationship among tolerance indices was evaluated by Biplot analysis. At the evaluated germplasm, there were accessions with high tolerance indices and fruiting percentages under stressful and non-stressful environments. This indicates that *ex situ* preserved germplasm in Cuba has tolerant accessions which can be used in breeding programs, in order to obtain adequately-performing cultivars or hybrids under these conditions.

RESUMEN. El presente trabajo se desarrolló con el objetivo de evaluar la tolerancia al estrés por déficit hídrico en una muestra de 28 accesiones del germoplasma de tomate (*Solanum* L. sección *Lycopersicon* subsección *Lycopersicon*) conservado *ex situ* en las colecciones cubanas e identificar las accesiones más tolerantes para su empleo en los programas de mejoramiento genético. Para ello, se evaluó el porcentaje de fructificación en el período óptimo y en condiciones de déficit hídrico (período estresante) del cultivo, que se utilizó para el cálculo de los criterios de estrés: índice de susceptibilidad al estrés (SSI) según sus siglas en inglés, productividad geométrica media (GMP), productividad media (MP), índice de tolerancia al estrés (STI), índice de fructificación (FI), media armónica (HARM), índice de estabilidad de la fructificación (FSI), índice de tolerancia a la sequía (DI), índice de porcentaje de susceptibilidad al estrés (SSPI), índice relativo de sequía (RDI), índice de sensibilidad a la sequía (SDI), índices modificados de tolerancia al estrés (MSTI) e índice de tolerancia abiótica (ATI). Se clasificaron las accesiones por su tolerancia al estrés por déficit hídrico a nivel de planta en base al porcentaje de fructificación, mientras que la relación entre los índices de tolerancia se evaluó mediante análisis Biplot. Se pudo comprobar que, en el germoplasma evaluado, existieron accesiones con índices de tolerancia y porcentajes de fructificación altos en ambientes estresantes y no estresantes, lo cual indica que en el germoplasma que se conserva *ex situ* en Cuba existen accesiones tolerantes que pueden ser explotadas en los programas de mejoramiento genético, para obtener cultivares o híbridos con buen comportamiento en estas condiciones.

Key words: multivariate analysis, water, , fruit set, drought response

Palabras clave: análisis multivariante, estrés hídrico, fructificación, respuesta a sequía

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INTRODUCTION

Drought is one of the largest environmental limitations of agricultural crop productivity, as it causes devastating effects (1).

Tolerance to drought varies among species and even within the same species in different crops such as tomatoes (2, 3, 4). Hence various breeding programs have as fundamental aim to obtain drought tolerant genotypes (5, 6, 7).

However, genetic improvement aimed at obtaining drought tolerant genotypes is complicated by the lack of efficient techniques, reproducible and rapid screening usable in diagnosing tolerant plants (1, 8, 9). That is why to identify tolerant genotypes to drought in field conditions have been proposed various indices or criteria based on mathematical relationships tolerance, from the differences in performance in stressful and non-stressful conditions (10, 11, 12). These indices have been used successfully in different cultures (13, 14, 15, 16).

Therefore, this study was conducted in order to evaluate drought tolerance in tomato using different indices or tolerance criteria, with a view to selecting genotypes with high percentages of fruitfulness and stability of this character in water stress conditions, with in order that they can be used in future breeding programs.

MATERIALS AND METHODS

The morphoagronomic analyzes were performed in the central area of the National Institute of Agricultural Sciences (INCA). For its development, a sample of 28 accessions of the collection of tomato (*Solanum* L. section *Lycopersicon,* Subsection *Lycopersicon*) conserved *ex situ*, including cultivars and wild species were included belonging to *S. lycopersicum* var. *Cerasiforme*, *S. pimpinellifollium* and *S. habrochaites* of different origin, was taken (Table I).

The percentage of fruiting was evaluated in the first four clusters of 28 accessions of tomato, seeded in the period between October 2012 and March 2013, asbestos cement flowerbed, outdoors, containing a mixture of Ferralitic Red compacted soil (Ferralsol eutric), according to the New Genetic Classification of Soils (17).

Table I. Accessions used in the study and its origin

Accession	Species	Origin
1. Accession 1000	*S. pimpinellifollium*	Peru
2. Amalia	*S. lycopersicum*	Cuba
3. AN-104-1	*S. lycopersicum*	Spain
4. Campbell-28	*S. lycopersicum*	USA
5. Ciapan 31-5	*S. pimpinellifollium*	México
6. Cl-1131-00-7-2-0-9	*S. lycopersicum*	Taiwán
7. CL-143-0-10-3-0-1-10	*S. lycopersicum*	Taiwán
8. CO-7040	*S. lycopersicum*	Cuba
9. FM 3019	*S. lycopersicum*	Cuba
10. LA-0094	*S. habrochaites*	Peru
11. LA-1255	*S. habrochaites*	Peru
12 LA-1731	*S. habrochaites*	Peru
13 LA-2128	*S. habrochaites*	Peru
14. LA-2807	*S. lycopersicum var. cerasiforme*	Bolivia
15. LA2871	*S. lycopersicum var. cerasiforme*	Bolivia
16. Mara	*S. lycopersicum*	Cuba
17. Mariana	*S. lycopersicum*	Cuba
18. Mariela	*S. lycopersicum*	Cuba
19. Mayle	*S. lycopersicum*	Cuba
20. Mercy	*S. lycopersicum*	Cuba
21. Mex-121-A	*S. pimpinellifollium*	Mexico
22. Nagcarlang	*S. lycopersicum var. cerasiforme*	Philippines
23. P-531	*S. lycopersicum var. cerasiforme*	Cuba
24. Rilia	*S. lycopersicum*	Cuba
25. Rojo Veracruz	*S. pimpinellifollium*	Mexico
26. Roma	*S. lycopersicum*	Italy
27. Santa Clara	*S. lycopersicum*	USA
28. Tropic	*S. lycopersicum*	USA

The cultural care in all cases were made by the Technical Instructions for organoponics and intensive orchards set for tomato[A] while under drought irrigation after established plants transplanted to anthesis was suspended, according Bita is the critical period for crop establishment (18). The plants were placed at 10 per accession for both stressful conditions as stressful, according to a completely randomized design.

The percentage values were used fruiting to calculate different rates of stress tolerance, based on differential behavior in stressful accessions and not stressful environments.

Rates stress tolerance used were: tolerance index (TOL), stress susceptibility index (SSI), average productivity geometric (GMP), mean productivity (MP), stress tolerance index (STI), fructification index (FI), harmonic mean (HARM), fruitfulness stability index (FSI), drought tolerance index (DI) stress susceptibility percentage index (SSPI), relative drought index (RDI), sensitivity drought index (SDI), modified stress tolerance index (MSTI) and abiotic tolerance index (ATI). Calculations tolerance indices used ,are refered below:

$$TOL = (FP-FE) \quad (19)$$

$$SSI = \frac{1-(\overline{FE})/(\overline{FP})}{1-(FE)/(FP)} \quad (20)$$

$$FMP = \sqrt{FE*FP} \quad (10)$$

$$MP = \frac{(FE+FP)}{2} \quad (19)$$

$$STI = \frac{\overline{(FP)(FE)}}{(FP)^2} \quad (10)$$

$$FI = \frac{(\overline{FE})}{(FE)} \quad (5)$$

$$HARM = \frac{2(FP*FE)}{(EP+FE)} \quad (21)$$

$$FSI = \frac{(FE)}{(FP)} \quad (22)$$

$$DI = \frac{FE*(FE/FP)}{\overline{FE}} \quad (23)$$

$$SSPI = \frac{(FE+FO)*100}{2} \quad (11)$$

$$RDI = \frac{(FE)/(FP)}{(\overline{FE})/(\overline{FP})} \quad (24)$$

$$SDI = \frac{(FP-FE)}{(FP)} \quad (12)$$

$$MSTI = kiSTI,\ k1 = \frac{(FP)^2}{(FP)^2},\ k2 = \frac{(FE)^2}{(FE)^2} \quad (25)$$

$$ATI = \left[\frac{(FP-FE)}{\overline{FP}\ \ \overline{FE}}\right] * (\sqrt{FP*FE}) \quad (11)$$

where:

FP: Percentage of potential fruitfulness of a genotype in non-stressful environment

FE: Percentage of fruitfulness of a genotype in the stressful environment (drought)

FP: Percentage of potential average fruitfulness of all accessions in the non-stressful environment

FE: Percent average fruitfulness of all accessions in the stressful environment

ki: correlation coefficient.

To analyze the data were transformed to arcsine $\sqrt{x}$ and also a Biplot Principal Component Analysis was made, which ran through Matlab package version 5.0, on Windows. The correlation was also evaluated among different evaluated tolerance levels and percentages of fruiting under stress and optimal conditions by simple correlation coefficient of Pearson. Analyses were performed using SPSS version 20.0 on Windows (26).

RESULTS AND DISCUSSION

Table II, estimates of different indices of stress tolerance, calculated from the differences in the percentages of fruitfulness in the optimal period or potential fruitfulness (FP) and fruiting in irrigation suspension conditions or fruiting in drought stress (FE) conditions are observed in evaluated tomato accessions. Generally, a percentage decrease in stressful environments fruiting with respect to those obtained at the optimum culture period was observed. This may be due to, among other factors, that during the course of the experiment, stress just limited the crop development.

[A] MINAG. *Instructivo Técnico para organopónicos y huertos intensivos*. Inst. MINAG, La Habana, Cuba, 1998, p. 74.

Table II. Stress tolerance indices in the 28 evaluated tomato accessions

	Accesion	FP	FE	TOL	GMP	MP	STI	YI	HARM	YSI	DI	SSPI	k1STI	k2STI	ATI
1	Accesion 1000	100,000	99,240	5,000	87,464	87,500	1,869	1,122	87,429	0,944	1,060	2,682	2,574	3,298	364,738
2	Amalia	87,619	73,585	10,330	64,027	64,235	1,001	0,779	63,820	0,851	0,664	5,541	0,820	0,854	551,626
3	AN-14-1	88,462	51,364	21,110	55,337	56,335	0,748	0,604	54,357	0,684	0,414	11,324	0,569	0,383	974,288
4	Campbell-28	85,714	81,981	2,910	66,319	66,335	1,074	0,856	66,303	0,957	0,820	1,561	0,839	1,105	160,958
5	Ciapan 31-5	100,000	100,000	0,000	90,000	90,000	1,979	1,188	90,000	1,000	1,189	0,000	2,725	3,915	0,000
6	CL-1131-0-0-7-2-0-9	100,000	71,880	32,020	72,237	73,990	1,275	0,765	70,526	0,644	0,493	17,176	1,756	1,047	1929,134
7	CL-143-0-10-3-0-1-10	96,280	81,354	14,470	71,279	71,645	1,241	0,850	70,914	0,817	0,695	7,762	1,313	1,258	860,220
8	CO-7040	86,111	48,915	23,740	54,983	56,250	0,738	0,586	53,745	0,651	0,370	12,735	0,583	0,355	1088,661
9	FM 3040	83,750	57,739	16,780	57,228	57,840	0,800	0,653	56,623	0,747	0,488	9,001	0,597	0,478	800,909
10	LA-0094	95,698	96,154	-0,650	78,354	78,355	1,500	1,038	78,354	1,008	1,048	-0,349	1,553	2,268	-42,477
11	LA-1255	100,000	93,649	14,600	82,377	82,700	1,658	0,995	82,056	0,838	0,834	7,832	2,283	2,302	1003,092
12	LA-1731	97,620	42,330	40,580	57,346	60,830	0,803	0,535	54,062	0,500	0,268	21,768	0,899	0,323	1940,880
13	LA-2128	100,000	89,342	19,060	79,904	80,470	1,560	0,936	79,341	0,788	0,739	10,224	2,148	1,917	1270,195
14	LA-2807	100,000	98,810	6,260	86,814	86,870	1,841	1,105	86,757	0,930	1,029	3,358	2,535	3,154	453,255
15	LA-2871	100,000	98,670	6,630	86,622	86,685	1,833	1,100	86,558	0,926	1,020	3,556	2,524	3,112	478,983
16	Mara	83,333	67,860	10,440	60,455	60,680	0,893	0,732	60,231	0,842	0,616	5,600	0,659	0,671	526,398
18	Mariela	87,083	65,139	15,120	60,903	61,370	0,906	0,710	60,439	0,781	0,555	8,111	0,732	0,641	768,012
18	Mariana	87,546	62,611	17,040	60,220	60,820	0,886	0,690	59,626	0,754	0,521	9,141	0,724	0,592	855,841
19	Mayle	90,380	47,060	28,620	55,815	57,620	0,761	0,572	54,066	0,602	0,344	15,352	0,669	0,349	1332,292
20	Mercy	81,940	53,230	18,000	55,120	55,850	0,742	0,618	54,400	0,722	0,447	9,656	0,531	0,398	827,491
21	Mex-121-A	100,000	100,000	0,000	90,000	90,000	1,979	1,188	90,000	1,000	1,189	0,000	2,725	3,915	0,000
22	Nagcarlang	100,000	98,720	6,500	86,689	86,750	1,836	1,102	86,628	0,928	1,023	3,487	2,528	3,127	469,958
23	P-531	99,038	98,212	2,070	83,339	83,345	1,697	1,086	83,332	0,975	1,061	1,110	2,054	2,808	143,879
24	Rilia	93,889	60,722	24,500	62,246	63,440	0,946	0,676	61,075	0,676	0,457	13,142	0,922	0,606	1271,917
25	Rojo veracruz	100,000	99,430	4,330	87,808	87,835	1,883	1,131	87,782	0,952	1,077	2,323	2,594	3,377	317,106
26	Roma	89,080	60,600	19,580	60,118	60,910	0,883	0,675	59,336	0,723	0,488	10,503	0,750	0,564	981,745
27	Santa clara	87,880	54,763	21,900	57,649	58,680	0,812	0,630	56,637	0,685	0,432	11,748	0,669	0,452	1052,977
28	Tropic	88,500	66,520	15,540	61,924	62,410	0,937	0,721	61,443	0,779	0,562	8,336	0,784	0,683	802,590

FP: potential fruiting in the non-stressful environment; FE: Fruiting under stress conditions (drought); Tol: the index of stress tolerance; GMP: geometric mean productivity; MP: mean productivity; STI: stress tolerance index; FI: Fruiting index; HARM: harmonic mean; FSI: fruiting stability index; DI: resistance drought index; SSPI: susceptibility stress percentage index; RDI relative drought index; SDI: sensitivity drought index; k1STI and k2STI: modified stress tolerance indices and ATI: abiotic tolerance index

In this sense, several authors have reported decreases in the number of flowers and fruits, the average mass of fruits, fresh and dry mass of the plant and the fruiting percentage together with the water potential of the leaf and efficient use water, associated with increases in leaf temperature and stomatal resistance under dry conditions (27, 28).

The most affection in FE were observed in the CO-7040, Mayle and LA-1731 accessions, the latter belonging to *S. habrochaites* with fruit setting values below 50 % and cultivars AN-104-1, Mercy and Santa Clara, who presented very close to 50 % values under drought conditions. The rest of the accessions tested showed an intermediate behavior among them and Red Veracruz and Accession 100 of *S. pimpinellifollium*; LA-2807, LA-2871, Nagcarlan and P-531 from *S. lycopersicum*, *Cerasiforme* variety as well as LA-0094 and LA-1255 from *S. habrochaites*, who presented, in general, few affectations, with an average percentage of fructification above 90 %. It is noteworthy that the accessions of *S. pimpinellifollium*, Ciapán-31-5 and Mex-121A, were not influenced by the stress imposed because they had a 100 % of fruitfulness in environments, as well as the best indices GMP, STI, MP, HARM, DI and modified stress tolerance indices.

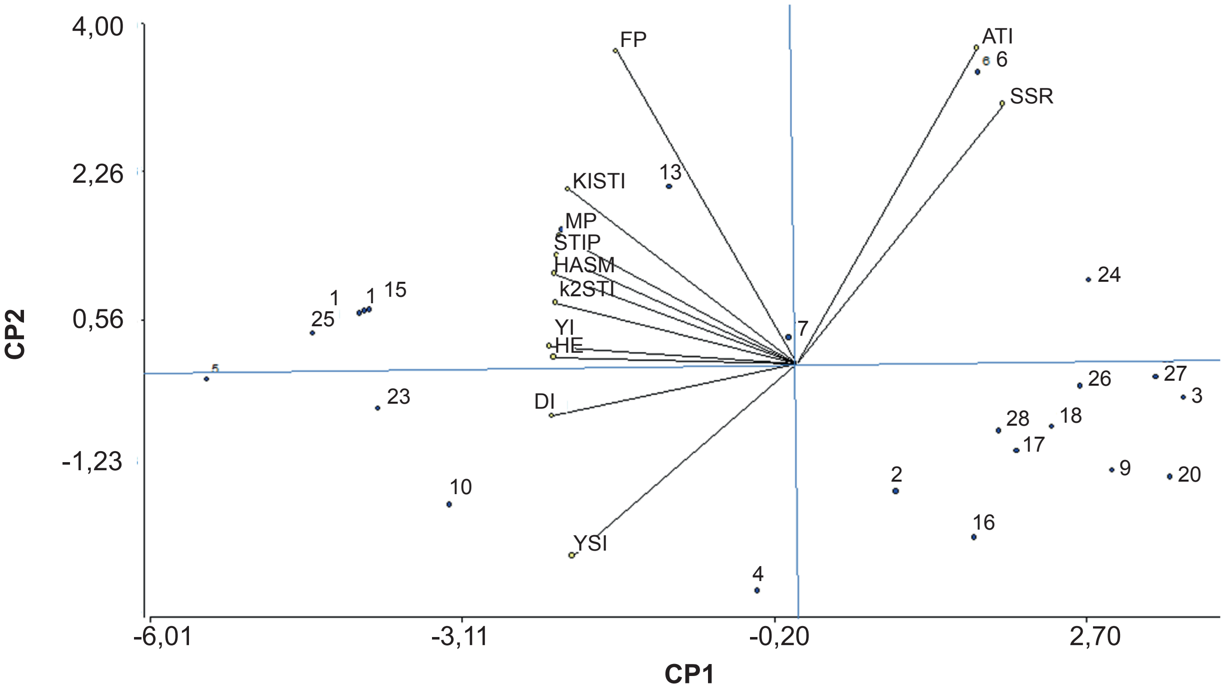
Some authors (7, 9, 11, 29, 30, 31) have used the differences in performance in stressful and non-stressful periods for the analysis of tolerance several criteria, in order to classify tolerant or susceptible accessions. In this study the percentage of fruiting was used, being an indicative nature of stress tolerance and have a higher heritability than yield (32, 33).

The relationship among the different accessions and criteria for stress related to heat tolerance in level plant was checked by the Principal Component Analysis Biplot (Table III and Figure), which revealed that the first two components explained 99 % variability found.

Regarding the behavior of accessions, it was perceived that LA-1731 (number 12 in the figure) was the worst in the stressful environment, located on the top right of the xy plane, characterized by having high values of ATI and SSPI and as the lowest values of DI, YSI and YI.

Table III. Values of absorbed and accumulated energy in the first two components as Principal Component Analysis (Biplot)

	Component 1	Component 2
Absorbed inertia (%)	0,85	0,85
Accumulated inertia (%)	0,14	0,99



FP: potential fruiting in the non-stressful environment; FE: Fruiting under stress conditions (drought); Tol: the index of stress tolerance; GMP: geometric mean productivity; MP: mean productivity; STI: stress tolerance index; FI: Fruiting index; HARM: harmonic mean; FSI: fruiting stability index; DI: resistance drought index; SSPI: susceptibility stress percentage index; RDI relative drought index; SDI: sensitivity drought index; k1STI and k2STI: modified stress tolerance indices and ATI: abiotic tolerance index

Biplot analysis results in 122 accessions studied

In the center to left, accessions with higher values of FE, FP, STI; k1STI, k2STI, HARM and YI , and low values of ATI and SSPI, which were represented mainly by numbered as: 25 (Veracruz Rojo), 1 (Accession 1000), 14 (LA-2807), 15 (LA-2871) 23 (P-531), 10 (LA-0094), 22 (Nagcarlan), 5 (Ciapán-31-5) and 21 (Mex-121-A), which are the most tolerant in the two environments studied.

The existence of accessions with percentages of high fruitfulness, both stressful environment as stressful and for different tolerance criteria assessed, indicate that these can be used as progenitors in breeding programs for drought tolerance, with the aim of obtain cultivars that present increased levels of tolerance of current commercial cultivars.

These results allow us to infer that a selection of individual accessions based on the percentage of fruit set in contrasting environments can be made, based on these tolerance criteria.

It is noteworthy that these criteria have been used successfully in a form or another for the selection of accessions tolerant to drought, mainly in wheat (*Triticum aestivum* L.), (15, 16, 34, 35), hard wheat (*Triticum durum* Desf.) (11, 36), rice (*Oryza sativa* L.) (37), chickpea (*Cicer arietinum* L.) (12), sunflower (*Helianthus annuus* L.) (6, 38), sesame (*Sesamum indicum* L.), (13), soybean (*Glycine max* L. Merrrill) (7), tobacco (*Nicotiana tabacum* L.) (39), barley (*Hordeum vulgare* L.), (1, 14) and maize (*Zea mays* L.), (29, 40, 41), among others.

The interrelation among the different indices and tolerance criteria evaluated with fruiting percentage shown in Table IV. Notably evaluated tolerance indices showed high and significant correlations with the percentage of fruiting in the stressful environment, being these negative contributions to TOL, SSPI and ATI. Fruiting percentage in non-stressed conditions also showed significant correlations with high most of these criteria; however, this character was not associated with SSPI or ATI indices. Similar associations were found by various authors (11, 12, 13, 37, 42), who point out the usefulness of these indices in the selection of tolerant genotypes in different cultures.

The presence of accessions with high percentages of fruitfulness in water stress conditions indicates that germplasm remains *ex situ* in Cuba there are some tolerant, which can be exploited in breeding programs to obtain cultivars or hybrids with good morpho-agronomic performance in periods of drought.

Table IV. Simple correlation coefficients among indices of drought tolerance and fruiting percentage in stressful and non-stressful conditions

	FP	FE	TOL	GMP	MP	STI	YI	HARM	YSI	DI	SSPI	k1STI	k2STI	ATI
FP	1													
FE	0,726**	1												
TOL	-0,254	-0,819**	1											
GMP	0,855**	0,964**	-0,690**	1										
MP	0,877**	0,952**	-0,657**	0,999**	1									
STI	0,851**	0,955**	-0,690**	0,999**	0,998**	1								
YI	0,751**	0,985**	-0,817**	0,981**	0,972**	0,980**	1							
HARM	0,834**	0,973**	-0,718**	0,999**	0,996**	0,997**	0,987**	1						
YSI	0,401*	0,904**	-0,983**	0,794**	0,767**	0,790**	0,895**	0,817**	1					
DI	0,656**	0,970**	-0,890**	0,939**	0,925**	0,940**	0,987**	0,950**	0,947**	1				
SSPI	-0,254	-0,819**	1,000**	-0,690**	-0,657**	-0,690**	-0,817**	-0,718**	-0,983**	-0,890**	1			
k1STI	0,896**	0,902**	-0,571**	0,983**	0,988**	0,987**	0,936**	0,976**	0,684**	0,874**	-0,571**	1		
k2STI	0,789**	0,933**	-0,745**	0,977**	0,974**	0,985**	0,979**	0,978**	0,822**	0,958**	-0,745**	0,963**	1	
ATI	-0,110	-0,688**	0,974**	-0,557**	-0,523**	-0,563**	-0,706**	-0,586**	-0,924**	-0,806**	0,974**	-0,435*	-0,650**	1

FP: potential fruiting in the non-stressful environment; FE: Fruiting under stress conditions (drought); Tol: the index of stress tolerance; GMP: geometric mean productivity; MP: mean productivity; STI: stress tolerance index; FI: Fruiting index; HARM: harmonic mean; FSI: fruiting stability index; DI: resistance drought index; SSPI: susceptibility stress percentage index; RDI relative drought index; SDI: sensitivity drought index; k1STI and k2STI: modified stress tolerance indices and ATI: abiotic tolerance index

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