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Original article

Evaluation of drought tolerance among wheat landraces based on yield and integral selection indices

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Extended abstract

Introduction

Wheat plays a key role in providing human food, providing 54% of the energy of every human being. Drought is a global problem that has placed major constraints on increasing wheat production in arid and semi-arid regions such as Iran. Among the various stresses, the most difficult to measure in terms of measurement is drought stress; Because different mechanisms lead to resistance. Drought stress is one of the most important factors that may be caused by low rainfall, high temperatures and high winds. The plant's reaction to it depends on the stage of growth in which the stress occurs. Different methods have been proposed for the identification and screening of drought tolerant, tolerant and drought sensitive cultivars. The most important of them include: drought Susceptibility Index, Yield Index (YI), Stress Tolerance Index (STI), Geometric Mean Productivity (GMP), Harmonic Mean (HMP), Modified Stress Tolerance Index (MSTI), Drought Resistance Index, Drought susceptible index, drought response index, non-biotic stress tolerance index, relative efficiency index (REI), Schneider stress intensity index (SSSI) and mean relative productivity (MRP). Also, the total rank has been used for better conclusions about all indicators. The aim of this study was to evaluate the drought tolerance of native bread wheats based on yield indices and integrated selection index under stress and non-stress conditions, as well as selection of water-tolerant stress-tolerant genotypes and to investigate the relationship between yield and drought resistance indices.

Materials and methods

To evaluate the drought tolerance of 25 wheat genotypes, this experiment was carried out based on a randomized complete block design with three replications under stress and non-stress conditions at Razi University of Kermanshah, Iran, from 2016 to 2017. Studied indices including: drought Susceptibility Index, Yield Index (YI), Stress Tolerance Index (STI), Geometric Mean Productivity (GMP), Harmonic Mean (HMP), Modified Stress Tolerance Index (MSTI), Drought Resistance Index, Drought susceptible index, drought response index, non-biotic stress tolerance index, relative efficiency index (REI), Schneider stress intensity index (SSSI) and mean relative productivity (MRP). All required statistical calculations including correlation coefficients, calculation of statistical indicators and parameters and drawing of biplot diagram were performed by EXCEL, SPSS and STATISTICA software.

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Results and discussion

Significant difference between genotypes for all indices and yield in both conditions were obtained. There is a significant and positive correlation between GMP, STI, HMP, MSTI, MRP, MP YI and REI indices with yield performance in non-stress and stress environments. STS and ISI indices showed that genotypes 10(WC.4987) and 15(WC.47638) were superior. Based on the bioplat obtained from the first and second main components, genotypes 24(WC.4583), 11(WC.47615), 4(WC.47341), 22(WC,47467), 21(WC, 47640), 12(WC.4612) and 16(WC.47638) are suitable for both conditions due to their proximity to the superior indices. Priciple components analysis in stress and non-stress conditions showed that the first two components (57.21%) and the second component (41%) together explained 98.21% of the variance. Drought tolerant cultivars show different results based on one index. For example, according to STI index, genotypes 10, 18, 15 and 20 were identified as drought tolerant, but according to GMP index, genotypes 10, 18, 15 and 13 were identified as drought tolerant genotypes. Due to differences in the results, the ranking was used for more accuracy. Based on total rankings, mean rankings and standard deviation of rankings, genotypes 8, 10 and 15 had the best rankings and were known as drought tolerant genotypes and genotypes 4, 11 and 22 as susceptible genotypes. As a result, these genotypes can be used for crossbreeding and genetic analysis for resistance, through various methods such as diallel analysis, mapping, marker selection, and so on.

Conclusions

The rate of yield reduction due to stress varies in different genotypes. Tolerant genotypes have the lowest yield loss and susceptible genotypes have the highest yield loss. The correlation between drought resistance and yield indices under stress and non-stress conditions showed that MP, STI, GMP, HMP, MSTI, YI, MRP and REI indices are suitable for selecting high yield genotypes under two conditions. According to the three-dimensional biplot, genotypes 10, 15 and 18 were superior in stress and non-stress conditions. According to STS and ISI indices, genotypes 8, 10 and 15 were more tolerant. Using one or a small number of indices to select drought tolerant cultivars will have different results, so ranking was used; In ranking based on total rankings, mean rankings and standard deviation of rankings, genotypes 8, 10 and 15 had the best rankings and were known as drought tolerant genotypes and genotypes 4, 11 and 22 as susceptible genotypes. . For more accurate results, these experiments should be repeated for more years so that these genotypes can be used as promising lines to increase production yield.

Keywords: Biplot, Bread wheat, Drought tolerance indices, Water deficit

Table 1. Code and name of wheat genotype

Genotype code	Genotype name	Genotype code	Genotype name	Genotype code	Genotype name
1	WC.4924	10	WC.4987	19	Pishtaz
2	WC.4582	11	WC.47615	20	Pishgam
3	WC.4592	12	WC.4612	21	WC.47640
4	WC.47341	13	WC.5001	22	WC.47467
5	WC.4965	14	WC.4994	23	WC-4553
6	WC.4840	15	WC.47638	24	WC.4583
7	WC.4958	16	WC.47583	25	WC.4554
8	WC.47399	17	WC.47522		
9	WC.4600	18	WC.47569		

Table 2. Geographic location and climate of the experiment site

Longitude	47° 9′
Latitude	34° 21′
Altitude	1319 m
Medium rainfall	480 –450 mm
Soil pattern	Silty-Clay
Climatic and natural conditions	Cold temperate, North Zagros Mountains
Average annual temperature	13.3 ºC
Rainfall in the year of the experiment	401.51 mm

Table 3- Average Grain Yield and Drought Sensitivity and Tolerance Indicators and their Ranking

Genotype	Y_P (g/m²)	R	Y_S (g/m²)	R	STI	R	MP	R	GMP	R	HMP	R
1	322.20	19	239.38	20	0.492	20	280.79	20	277.72	20	274.68	20
2	526.59	3	283.40	13	0.953	7	405.00	6	386.31	7	368.49	7
3	355.60	15	262.82	17	0.597	17	309.21	16	305.71	17	302.25	16
4	304.55	22	208.83	22	0.406	24	256.69	24	252.19	24	247.76	22
5	353.34	17	261.51	18	0.590	18	307.43	18	303.98	18	300.57	18
6	442.37	8	342.69	4	0.968	6	392.53	7	389.35	6	386.20	5
7	431.72	9	277.26	14	0.764	10	354.49	9	345.97	10	337.66	10
8	358.07	14	338.53	5	0.774	9	348.30	10	348.16	9	348.03	8
9	410.24	10	275.12	15	0.721	12.5	342.68	11	335.95	13	329.36	13
10	565.75	1	424.73	1	1.534	1	495.24	1	490.20	1	485.20	1
11	317.21	20	201.89	23	0.409	23	259.55	23	253.07	23	246.74	24
12	298.98	24	236.94	21	0.452	21	267.96	21	266.16	21	264.37	21
13	508.45	4	309.49	8	1.005	4	408.97	4	396.69	4	384.77	6
14	482.62	6	263.96	16	0.813	8	373.29	8	356.92	8	341.27	9
15	482.01	7	372.95	2	1.148	3	427.48	3	423.99	3	420.52	3
16	214.21	25	190.15	25	0.260	25	202.18	25	201.82	25	201.46	25
17	354.00	16	319.10	6	0.721	12.5	336.55	13	336.10	12	335.64	11
18	544.26	2	354.27	3	1.231	2	449.26	2	439.11	2	429.18	2
19	492.24	5	318.70	7	1.002	5	405.47	5	396.08	5	386.90	4
20	384.01	13	285.14	12	0.699	14	334.58	14	330.90	14	327.27	14
21	313.97	21	303.47	9	0.608	16	308.72	17	308.68	16	308.63	15
22	331.92	18	197.36	24	0.418	22	264.64	22	255.94	22	247.53	23
23	403.74	11	240.30	19	0.620	15	322.02	15	311.48	15	301.29	17
24	304.24	23	292.04	11	0.567	19	298.14	19	298.08	19	298.02	19
25	391.08	12	293.72	10	0.733	11	342.40	12	338.92	11	335.48	12

Y_P = Potential Yield, Y_S = Stress Yield, STI = Stress Tolerance Index, MP = Mean productivity, GMP = Geometric Mean Productivity, HMP = Harmonic Mean Productivity, R = Rank.

Table 3. Continued

Genotype	MSTI	R	YI	R	YSI	R	DI	R	RDI	R	REI	R
1	0.712	20	0.844	20	0.743	11.5	0.627	18	1.036	11.5	0.687	20
2	0.998	13	0.999	13	0.538	25	0.537	20	0.751	25	1.329	7
3	0.858	17	0.926	17	0.739	14	0.685	12	1.031	14	0.832	17
4	0.542	22	0.736	22	0.686	15	0.505	22	0.956	15	0.566	24
5	0.849	18	0.922	18	0.740	13	0.682	13	1.032	13	0.823	18
6	1.459	4	1.208	4	0.775	7	0.936	7	1.080	7	1.350	6
7	0.955	14	0.977	14	0.642	19	0.628	17	0.896	19	1.066	10
8	1.423	5	1.193	5	0.945	3	1.128	1	1.319	3	1.080	9
9	0.940	15	0.970	15	0.671	16	0.650	16	0.935	16	1.005	13
10	2.241	1	1.497	1	0.751	9.5	1.124	2	1.047	9.5	2.140	1
11	0.506	23	0.712	23	0.636	20	0.453	24	0.888	20	0.570	23
12	0.697	21	0.835	21	0.793	6	0.662	15	1.105	6	0.631	21
13	1.190	8	1.091	8	0.609	21	0.664	14	0.849	21	1.401	4
14	0.865	16	0.930	16	0.547	24	0.509	21	0.763	24	1.134	8
15	1.728	2	1.314	2	0.774	8	1.017	4	1.079	8	1.601	3
16	0.449	25	0.670	25	0.888	5	0.595	19	1.238	5	0.363	25
17	1.265	6	1.125	6	0.901	4	1.014	5	1.257	4	1.006	12
18	1.559	3	1.249	3	0.651	17	0.813	8	0.908	17	1.717	2
19	1.261	7	1.123	7	0.647	18	0.727	11	0.903	18	1.397	5
20	1.010	12	1.005	12	0.743	11.5	0.746	10	1.036	11.5	0.975	14
21	1.144	9	1.069	9	0.967	1	1.034	3	1.348	1	0.849	16
22	0.484	24	0.696	24	0.595	22.5	0.414	25	0.829	23	0.583	22
23	0.717	19	0.847	19	0.595	22.5	0.504	23	0.830	22	0.864	15
24	1.059	11	1.029	11	0.960	2	0.988	6	1.339	2	0.791	19
25	1.071	10	1.035	10	0.751	9.5	0.777	9	1.047	9.5	1.023	11

MSTI = Modified Stress Tolerance Index, YI = Yeild Index, YSI = Yeild Stability Index, DI = Drought Resistance Index, RDI = Relative Drought Index, REI = Relative Efficiency Index, R = Rank

Table 3. Continued

Genotype	MRP	R	SSI	R	TOL	R	ATI	R	SSPI	R	SSSI	R
1	1.658	20	0.908	11	82.82	7	16491.23	7	10.46	7	-0.026	11
2	2.329	6	1.632	25	243.20	25	67363.53	25	30.73	25	0.179	25
3	1.825	17	0.922	14	92.78	9	20338.07	10	11.72	9	-0.022	14
4	1.506	24	1.111	15	95.72	10	17308.13	8	12.09	10	0.031	15
5	1.815	18	0.918	13	91.83	8	20015.33	9	11.60	8	-0.023	13
6	2.326	7	0.796	7	99.69	13	27829.53	15	12.60	13	-0.058	7
7	2.068	10	1.264	19	154.46	19	38316.14	19	19.52	19	0.075	19
8	2.098	9	0.193	3	19.55	3	4879.41	4	2.47	3	-0.228	3
9	2.006	13	1.164	16	135.13	17	32549.55	16	17.07	17	0.046	16
10	2.926	1	0.881	10	141.01	18	49563.72	21	17.82	18	-0.034	9.5
11	1.513	23	1.285	20	115.32	15	20925.05	11	14.57	15	0.081	20
12	1.591	21	0.733	6	62.03	6	11838.52	6	7.84	6	-0.075	6
13	2.376	4	1.383	21	198.97	23	56592.22	23	25.14	23	0.108	21
14	2.150	8	1.601	24	218.66	24	55959.11	22	27.63	24	0.170	24
15	2.532	3	0.800	8	109.05	14	33152.77	17	13.78	14	-0.057	8
16	1.211	25	0.397	5	24.07	4	3482.80	3	3.04	4	-0.171	5
17	2.019	12	0.348	4	34.89	5	8408.92	5	4.41	5	-0.184	4
18	2.624	2	1.234	17	190.00	22	59819.17	24	24.01	22	0.066	17
19	2.367	5	1.246	18	173.55	21	49285.74	20	21.93	21	0.070	18
20	1.975	14	0.910	12	98.88	12	23460.44	12	12.49	12	-0.025	12
21	1.863	16	0.118	1	10.50	1	2324.45	1	1.33	1	-0.250	1
22	1.534	22	1.433	23	134.56	16	24693.86	14	17.00	16	0.122	22.5
23	1.867	15	1.430	22	163.44	20	36501.06	18	20.65	20	0.122	22.5
24	1.798	19	0.142	2	12.19	2	2606.02	2	1.54	2	-0.244	2
25	2.023	11	0.880	9	97.37	11	23661.33	13	12.30	11	-0.034	9.5

MRP = Mean Relative Performance, SSI = Stress Susceptibility Index, TOL = Tolerance, ATI = Abiotic Tolerance Index, SSPI = Stress susceptibility percentage index, SSSI = Schneider's Stress Severity Index, R = Rank

Table 3. Continued

Genotype	DSI	R	RDY	R	PEV	R	R Mean	Standard deviation	Sum of Ranking
1	0.908	11	-671.28	20	0.257	11.5	15.50	5.227	325.5
2	1.632	25	-1392.35	7	0.462	25	15.91	8.792	334
3	0.922	14	-834.60	17	0.261	14	14.62	2.674	307
4	1.111	15	-535.97	24	0.314	15	18.76	5.394	394
5	0.918	13	-824.04	18	0.260	13	14.91	3.576	313
6	0.796	7	-1415.95	6	0.225	7	7.29	2.918	153
7	1.264	19	-1096.96	10	0.358	19	14.67	4.305	308
8	0.193	3	-1112.17	9	0.055	3	5.76	3.404	121
9	1.164	16	-1028.64	13	0.329	16	14.55	1.987	305.5
10	0.881	10	-2302.93	1	0.249	9.5	6.10	6.651	128
11	1.285	20	-540.43	23	0.364	20	20.76	3.404	436
12	0.733	6	-608.40	21	0.207	6	14.43	7.626	303
13	1.383	21	-1473.63	4	0.391	21	12.71	8.289	267
14	1.601	24	-1173.90	8	0.453	24	16.48	7.420	346
15	0.800	8	-1697.65	3	0.226	8	6.24	4.403	131
16	0.397	5	-307.31	25	0.112	5	15.95	10.205	335
17	0.348	4	-1029.60	12	0.099	4	7.74	4.030	162.5
18	1.234	17	-1828.13	2	0.349	17	9.67	8.481	203
19	1.246	18	-1468.75	5	0.353	18	11.48	6.780	241
20	0.910	12	-994.96	14	0.257	11.5	12.55	1.172	263.5
21	0.118	1	-852.80	16	0.033	1	8.19	7.373	172
22	1.433	23	-555.07	22	0.405	22.5	21.55	2.945	452.5
23	1.430	22	-870.20	15	0.405	22.5	18.55	3.482	389.5
24	0.142	2	-788.50	19	0.040	2	10.14	8.157	213
25	0.880	9	-1048.67	11	0.249	9.5	10.52	1.145	221

DSI = Drought Susceptibility Index, RDY = Relative Decrease in Yield, PEV = Press Evaluation, R = Rank

Table 4. Ranking by STS and ISI indices

Genotype	STS	Rank	ISI	Rank
1	–6.93	19	–3.55	17
2	–10.42	20	6.96	7
3	–2.34	12	-11.53	21
4	–12.43	21	–8.93	20
5	–2.47	13	–3.79	18
6	11.45	6	9.12	4
7	–5.37	17	5.47	8
8	18.02	2	–2.64	16
9	–4.15	16	–0.01	15
10	23.78	1	16.67	1
11	–15.88	24	–13.80	23
12	–3.32	15	–17.78	25
13	–2.55	14	9.79	3
14	–12.59	22	7.08	6
15	16.26	3	15.54	2
16	–5.65	18	–16.50	24
17	13.68	4	4.09	9
18	6.68	8	8.49	5
19	0.99	11	3.72	10
20	1.06	10	2.87	11
21	11.91	5	1.91	13
22	–18.67	25	–4.20	19
23	–13.06	23	0.48	14
24	10.42	7	–12.02	22
25	2.75	9	2.84	12

STS = Stress tolerance score, ISI = Integrated Selection Index, R = Rank

Table 5. Correlation between drought indices and grain yield under stress and non-stress conditions

	Y$_s$	STI	MP	GMP	HMP	MSTI	YI	YSI	DI	RDI
Y$_p$	0.706**	0.923**	0.955**	0.933**	0.907**	0.696**	0.706**	-0.524**	0.180	-0.524**
YS		0.908**	0.884**	0.913**	0.937**	0.992**	1**	0.216	0.820**	0.216
STI			0.989**	0.992**	0.991**	0.914**	0.908**	-0.187	0.514**	-0.186
MP				0.998**	0.991**	0.874**	0.884**	-0.256	0.461*	-0.255
GMP					0.998**	0.904**	0.913**	-0.196	0.516**	-0.195
HMP						0.929**	0.937**	-0.134	0.569**	-0.134
MSTI							0.992**	0.212	0.812**	0.212
YI								0.215**	0.819**	0.216
YSI									0.729**	1**
DI										0.730**

Y$_P$ = Potential Yield, Y$_S$ = Stress Yield, STI = Stress Tolerance Index, MP = Mean productivity, GMP = Geometric Mean Productivity, HMP = Harmonic Mean Productivity, MSTI = Modified Stress Tolerance Index, YI = Yeild Index, YSI = Yeild Stability Index, DI = Drought Resistance Index, RDI = Relative Drought Index

Table 5. **Continued**

	REI	MRP	SSI	TOL	ATI	SSPI	SSSI	DSI	RDY	PEV
Y$_p$	0.923**	0.933**	0.524**	0.777**	0.901**	0.777**	0.524**	0.524**	-0.923**	0.524**
YS	0.908**	0.913**	-0.216	0.102	0.341	0.102	-0.216	-0.216	-0.908**	-0.216
STI	1**	0.991**	0.187	0.488*	0.737**	0.555**	0.255	0.256	-0.989**	0.256
MP	-0.088	0.989**	0.256	0.555**	0.737**	0.555**	0.255	0.256	0.989**	0.256
GMP	0.992**	1**	0.196	0.499*	0.691**	0.499*	0.195	0.196	-0.992**	0.196
HMP	0.991**	0.997**	0.134	0.440*	0.642**	0.440*	0.134	0.134	-0.991**	0.134
MSTI	0.914**	0.904**	-0.212	0.096	0.336	0.096	-0.212	-0.212	-0.914**	-0.212
YI	0.908**	0.914**	-0.215	0.102	0.341	0.102	-0.216	-0.215	-0.908**	-0.215
YSI	-0.186	-0.192	-1**	-0.928**	-0.799**	-0.928**	-1**	-1**	0.186	-1**
DI	0.515**	0.519**	-0.730**	-0.477*	-0.244	-0.477*	-0.730**	-0.730**	-0.515**	-0.729**
RDI	-0.186	-0.191	-1**	-0.928**	-0.799**	-0.928**	-1**	-1**	0.186	-1**
REI		0.991**	0.186	0.488*	0.688**	0.488*	0.186	0.186	-1**	0.186
MRP			0.192	0.498*	0.691**	0.498*	0.191	0.192	0.991**	0.192
SSI				0.928**	0.799**	0.928*	1**	1**	-0.186	1**
TOL					0.962**	1**	0.928**	0.928**	-0.488*	0.928**
ATI						0.962**	0.799**	0.799**	-0.689**	0.799**
SSPI							0.928**	0.928**	-0.488*	0.928**
DSI								1	-0.186	1
RDY										-0.186

REI = Relative Efficiency Index, MRP = Mean Relative Performance, SSI = Stress Susceptibility Index, TOL = Tolerance, ATI = Abiotic Tolerance Index, SSPI = Stress susceptibility percentage index, SSSI = Schneider's Stress Severity Index, DSI = Drought Susceptibility Index, RDY = Relative Decrease in Yield, PEV= Press Evaluation

Table 6. Study of drought resistance indices using principal component analysis

Indicies	The first component	The second component
YP	0.94	0.29
YS	0.43	0.89
STI	0.80	0.59
MP	0.85	0.49
GMP	0.82	0.56
HMP	0.75	0.65
MSTI	0.45	0.88
YI	0.43	0.89
YSI	–0.74	0.67
DI	–0.18	0.96
RDI	–0.74	0.67
REI	0.80	0.59
MRP	0.82	0.55
SSI	0.74	–0.67
TOL	0.92	–0.37
ATI	0.95	–0.22
SSPI	0.92	–0.37
SSSI	0.74	–0.67
DSI	0.74	–0.67
RDY	–0.80	–0.59
PEV	0.74	–0.67
eigenvalues	10.87	7.79
Percentage of variance	57.21	41.00
The cumulative percentage	57.21	98.21
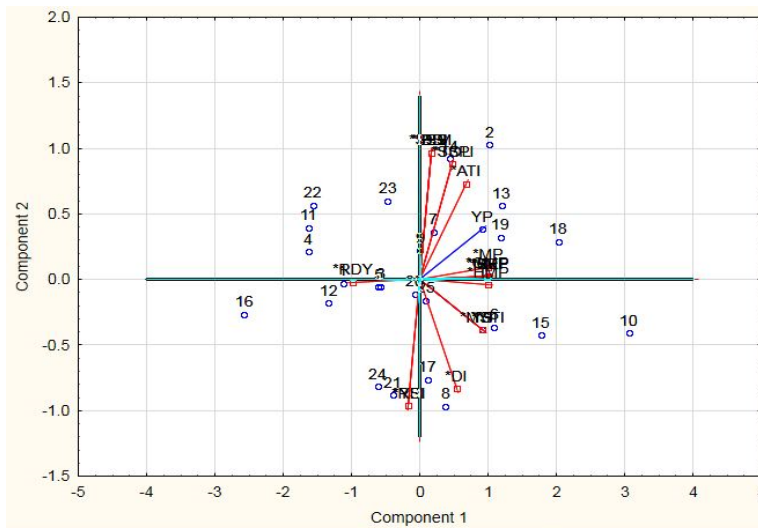
Fig. 1. Biplot plot of principal component analysis for drought resistance indices
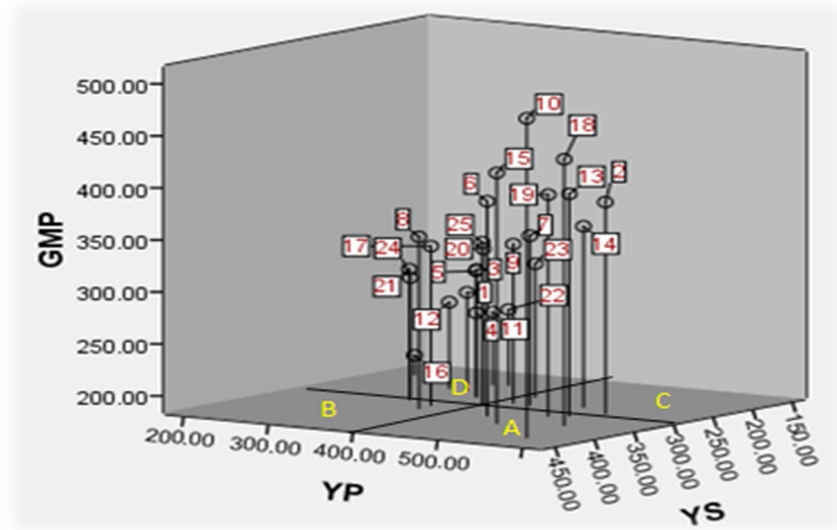
Fig. 2. Selection of genotypes based on Fernandez model using GMP. YP = Potential Yield, YS = Stress Yield, GMP = Geometric Mean Productivity
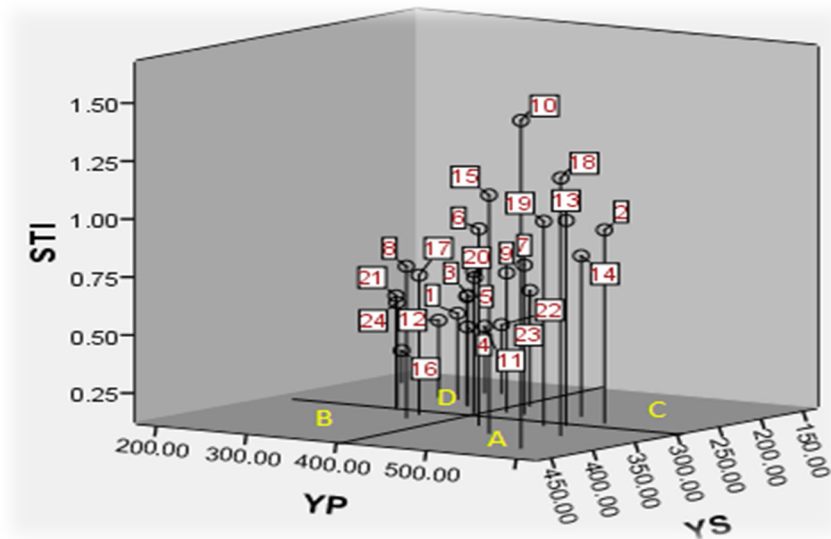

Fig. 3. Selection of genotypes based on Fernandez model using STI. YP = Potential Yield, YS = Stress Yield, STI = Stress Tolerance Index