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Drought Tolerance Indices, their Relationships and Manner of Application to Wheat Breeding Programs

Goodarz Najafian*

Cereal Research Department, Seed and Plant Improvement Research Institute (SPII), Karaj, Postal code: 3135933151, Iran

Correspondence: * goodarzn@gmail.com

ABSTRACT

Terminal moisture stress in irrigated wheat farms causes a significant reduction in quantity and quality of grain yield in Iran. In order to identify wheat varieties tolerant to late season shortage of water, and also to find how drought resistance indices should be applied in screening practices, this study was performed in a temperate region wheat breeding program of Iran for irrigated wheat. In this study 291 advanced breeding lines and cultivars of hexaploid wheat were planted in two field trials, one under normal irrigation and another one under water deficit. The normal trial received 6 times furrow irrigation from 3rd May until 21st June, while the water stressed trial received only one irrigation in spring at the anthesis stage. Drought resistance indices including stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), stress tolerance index (STI) and geometric mean productivity (GMP) were calculated for all investigated entries. Correlation coefficients among these indices were calculated and interpreted. STI and GMP were found to be the better indices than the other three for screening drought tolerant wheat varieties in breeding programs. In spite of this, the STI value was still significantly affected by higher yield in one of the normal or stressed conditions. To overcome this inefficiency a 2-step screening strategy was applied. At first grain yield in both conditions along with STI was used for clustering of evaluated genotypes to ensure grouping of genotypes based on high yield in both environments and a higher STI value. Using this method, approximately four genotype groups (A, B, C and D) were determined, which led to the selection of 50 desired genotypes. Then SSI index was used to reselect the more drought tolerant genotypes. This method led to a final selection of 33 breeding lines. This strategy is proposed to be applied in wheat breeding programs whose objective is drought tolerance.

Keywords: cluster analysis, hexaploid wheat, stress tolerance indices, terminal drought

Abbreviations: CIMMYT, international maize and wheat improvement center; **GMP**, geometric mean productivity; **MP**, mean productivity; **SI**, stress intensity; **SSI**, stress susceptibility index; **STI**, stress tolerance index; **TOL**, tolerance

INTRODUCTION

Late season water stress or imposed avoidance of irrigation by farmers in wheat irrigated farms due to any reason is a significant reducing constraint of yield in Iran. This avoidance may arise from water shortage or the preference of a farmer to allocate water to other parallel cash crops like maize and sugar beet (Jalal-Kamali 2000; Ghodsi *et al.* 2008). It appears that through releasing tolerant wheat varieties to late season water scarcity, this problem could be somehow managed. Selection for earliness or drought tolerance provides options for breeders in this area. Temperate regions of Iran have consistent conditions for this strategy, because wheat is grown in late October with irrigation and normally left to rainfall during winter and April. During May and June irrigation is necessary, but many farmers can irrigate only once or maximum twice. This kind of irrigation management is called supplemental irrigation and is not considered normal irrigation; consequently, the crop would not reach its potential performance regarding grain yield and seed quality. So far no variety suitable for a system between complete irrigation and rain fed system has been released in Iran. It appears that if early drought tolerant wheat varieties could be released for this system, there would be a significant gain in terms of yield quantity and quality.

At the international maize and wheat improvement center (CIMMYT), a so-called "open-ended system" has been proposed in which yield responsiveness is combined with adaptation to drought conditions. Most semi-arid environments differ significantly across years in their water availability and distribution pattern. Hence it is prudent to construct a genetic system in which plant responsiveness provides a bonus whenever the environmental conditions improve due to higher rainfall (Rajaram 2000). With such a system, improved moisture conditions immediately translate into greater gain to the farmer through cultivation of drought adapted varieties. There are some examples that have proved the feasibility of this proposed system. The 'VEERY'* genotypes represent a genetic system in which high yield performance in favorable environments and adaptation to drought can be combined in one genotype. This genotype carries a 1B/1R translocation from rye, whose buffering property has resulted in the release of many varieties from its genetic background (Najafian and Jalal-Kamali 2004). By the mid 1980's CIMMYT-bred germplasm occupied 45% of the semi-arid wheat areas with rainfall between 300-500 mm and 21% of the areas with less than 300 mm (Morris *et al*. 1991), including large tracts in west Asia and north Africa. By 1990, 63% of the dry land areas were planted with semi-dwarf wheat (Byerlee and Moya 1993), many carrying the 1B/1R translocation (Rajaram 2000).

Based on the above evidence, a strategy at CIMMYT is used which mainly involves crossing high performance and responsive genotypes with drought tolerant varieties, and screening of progenies (F3 and F4) under rainfed or very low water availability or, in other words, supplemental irrigation (Rajaram and Van Ginkel 1995). In this method F7

* "VEERY" stands for a name given to a bred wheat genotype at CIMMYT.

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and F8 are evaluated under both optimum and low water environments. Lines with outstanding performance are then selected, and to further verify their performance they are evaluated in different countries. This breeding methodology is also proposed by other researchers, even in crops other than wheat (Ehdaie *et al*. 1988 for wheat; Bramel-Cox *et al*. 1991; Duvick 1992 for maize; Uddin *et al*. 1992 for wheat; Zavala Garcia *et al*. 1992; Cooper *et al*. 1994 for wheat; Banziger *et al*. 2004 for maize; Jongdee *et al*. 2004 for rice; Najafian *et al*. 2005 for wheat; Denic *et al*. 2006 for maize; Muasya and Diallo 2006 for maize; Reynolds *et al*. 2007 for wheat). Najafian *et al*. (2004) reported the improved performance of tolerant wheat genotypes to terminal moisture stress compared to adapted wheat varieties to normal irrigation conditions, tested in wheat breeding program of a temperate zone in Iran. In following such a strategy, while materials are evaluated under normal and water-stressed environments, drought tolerance indices such as stress susceptibility index (SSI) (Fischer and Maurer 1978), stress tolerance index (STI) and geometric mean productivity (GMP) (Fernandez 1992), tolerance index (TOL) and mean productivity (MP) (Rosielle and Hamblin 1981) could be calculated for each genotype and used for screening drought tolerant materials. To calculate SSI index for every tested genotype, stress intensity index (SI) is needed to be calculated according to Fischer and Maurer (1978). So far, many studies have reported using drought resistance indices for identification of drought tolerant genotypes; in most of them two indices, STI and GMP, were highlighted as being better compared to SSI, TOL or MP indices (e.g. Parvizi Almani *et al.* 1998; Normand Moayed *et al*. 2001; Babaei *et al*. 2008; Khezri-Afravi *et al*. 2008). In almost all these reports STI, GMP or SSI has been used as a unique tool for screening or scoring drought tolerance. There is no report about using a combination of those indices in such a way that the efficiency of screening or identification of drought tolerant genotypes could be increased. On the other hand, SSI and TOL indices, when used as unique indices, can identify only drought tolerant genotypes which show less reduction in yield from a normal environment to a stressed one, but not those genotypes which are drought tolerant and have good yield potential (Najafian 2003). STI, GMP and MP indices can identify genotypes with high yield potential, but unfortunately not always perfect in identifying drought tolerant genotypes (Naderi *et al.* 1999; Najafian 2003). This is because when the yield of a particular genotype in one environment is high, its values for these three indices is raised, so this genotype might be selected as tolerant while its yield in another environment may be not favorable. This inefficiency is more important when breeding purposes are considered (Naderi *et al.* 1999; Moosavi *et al.* 2008). Najafian (2003) reported that the efficiency of applying STI for screening wheat breeding nurseries aimed at drought tolerance improvement could be increased through clustering genotypes in terms of STI along with grain yield in both normal and stressed environments. Therefore it is thought that a unique index cannot provide the best tool for identification of drought tolerant genotypes, especially for breeding purposes where the objective is always higher yield potential along with drought tolerance.

The objectives of this study were: (1) to find a more efficient manner of screening of large breeding nurseries (where many genotypes need to be analyzed) using drought resistance indices so that yield responsiveness and drought tolerance properties could be considered simultaneously; and (2) to identify hexaploid wheat genotypes tolerant to terminal moisture stress.

MATERIALS AND METHODS

Plant materials

The germplasm evaluated in this study was an irrigated hexaploid wheat selection nursery with a total of 291 genotypes including 276 advanced breeding lines and varieties and four recently released high potential wheat cultivars as checks. Check cultivars were repeated three to four times along the whole experiment in the field (after every 20 genotypes, one check cultivar was planted). These materials offered a wide genetic diversity advanced from five research stations of temperate zone breeding program of Iran for a multi-location test. These breeding lines originated mostly from distributed nurseries of CIMMYT or their derivative crosses made with domestic Iranian germplasm. The four irrigated wheat check cultivars were 'Mahdavi', 'Marvdasht', 'Pishtaz' and 'Shiraz'.

Field experiments and evaluations

The study included two trials of the mentioned materials planted in a systematic way without replication, one trial in normal (well-irrigated) conditions and the other stressed for water in heading stage onward conditions (no application of irrigation after heading/anthesis stage until maturity and there was also no rainfall from this stage until the end of the cropping season). The experiment was carried out in the 2001-2002 cropping season. Each plot was 5 m long and 1.2 m wide. The four checks were replicated three to four times throughout the experiments (after every 20 plots, one check cultivar was planted). The normal condition trial received 6 irrigations (furrow method) in spring during May 3 until June 21, 2002. The water-stressed trial received only a single irrigation in spring at the anthesis stage on May 24, 2002. The number of days to heading and maturity, grain yield per plot and 1000-kernel weight were recorded for all investigated materials under well watered and water stressed conditions.

Statistical analyses

Drought tolerance indices were calculated for all 291 entries for grain yield and 1000-kernel weight. These were SSI according to Fischer and Maurer (1978), TOL and MP according to Rosielle and Hamblin (1981) and STI with GMP according to Fernandez (1992). Correlation coefficients among these indices were calculated to study their relationships. Genotypes were clustered based on grain yield in both environments and STI values. The Ward method was applied for clustering. Desired genotypes were selected in 2-step screening. In the first step results of clustering based on STI and grain yield in both normal and stressed conditions were used. From this clustering favorable genotypes were selected from the clustered groups which showed higher values of STI, higher grain yield in normal conditions and higher grain yield in stressed conditions as well. In the 2nd step genotypes with SSI values higher than 0.8 were rejected. Since the SSI index shows the rate of susceptibility to an applied stress, it has been frequently used in many studies for that purpose and its properties have been reported by Fischer and Maurer (1978). It was also decided to use this index for screening in favor of drought tolerance in the 2nd step. The lower the calculated value of SSI for a tested genotype under a particular abiotic stress, the higher is its stress tolerance. Based on experience and the circumstances of this study targeted environments and also considering stress intensity index (SI) value which shows the intensity level of the stress applied to the experiment, I defined the cut off line for the amount of SSI to be 0.8, meaning genotypes with SSI values more than 0.8 will be rejected. One may increase this figure to nearly 1 or decrease it to lower values. In the former case mildly tolerant genotypes are captured and in case of the latest, more stress tolerant genotypes are kept. This could be decided by the breeder by considering the severity of the stress in their targeted environment.

RESULTS AND DISCUSSION

For all 291 entries evaluated, drought tolerance indices SSI, TOL, MP, STI and GMP were calculated (**Table 1**). To screen such a large number of lines for drought tolerance clustering based on the most efficient drought tolerance index could do well. But prior to that it should be clarified which index is most favorable for this purpose. Observing correlation coefficients among calculated drought tolerance indices and between each of them with grain yield in normal and water stressed conditions can to some extent deter-

Table 1 Normal and stressed conditions grain yield along with values of drought tolerance indices for 291 genotypes of the study.

Genotype №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
1	4183	3324	0.76	858	3754	0.80	3729
2	4125	3300	0.74	825	3713	0.78	3690
3	4462	2896	1.30	1567	3679	0.74	3595
4	3719	3193	0.52	526	3456	0.68	3446
5	2991	2453	0.67	538	2722	0.42	2709
6	3334	2623	0.79	712	2978	0.50	2957
7	4038	3403	0.58	635	3720	0.79	3707
8	3576	2961	0.64	615	3269	0.61	3254
9	4011	3281	0.67	731	3646	0.76	3628
10	3840	3457	0.37	383	3649	0.76	3644
11	3378	2710	0.73	668	3044	0.53	3026
12	3784	3379	0.40	405	3582	0.74	3576
13	3089	3927	-1.00	-838	3508	0.70	3483
14	3407	3058	0.38	349	3232	0.60	3228
15	2732	3301	-0.77	-569	3017	0.52	3003
16	2974	3289	-0.39	-316	3132	0.56	3128
17	2871	2303	0.73	567	2587	0.38	2571
18	4282	3488	0.69	794	3885	0.86	3865
19	3804	3248	0.54	556	3526	0.71	3515
20	3249	2760	0.56	489	3005	0.52	2995
21	3561	3220	0.36	341	3390	0.66	3386
22	3611	3256	0.36	355	3434	0.68	3429
23	4073	2771	1.18	1302	3422	0.65	3360
24	5125	3144	1.43	1980	4135	0.93	4014
25	4156	2286	1.67	1870	3221	0.55	3083
26	3944	2676	1.19	1268	3310	0.61	3249
27	4845	2938	1.46	1907	3891	0.82	3773
28	5043	2887	1.58	2157	3965	0.84	3816
29	4632	3890	0.59	742	4261	1.04	4245
30	5160	3229	1.39	1931	4194	0.96	4081
31	4559	3986	0.47	573	4272	1.05	4263
32	4485	2791	1.40	1694	3638	0.72	3538
33	3756	3554	0.20	202	3655	0.77	3654
34	4267	3446	0.71	820	3857	0.85	3835
35	4481	3879	0.50	602	4180	1.00	4169
36	3320	3700	-0.42	-380	3510	0.71	3505
37	3253	3650	-0.45	-397	3451	0.68	3446
38	2704	2591	0.15	113	2647	0.40	2647
39	3485	3138	0.37	346	3311	0.63	3307
40	4107	2779	1.20	1328	3443	0.66	3379
41	4189	3526	0.59	663	3857	0.85	3843
42	4624	3261	1.09	1364	3943	0.87	3883
43	4358	2913	1.23	1445	3636	0.73	3563
44	4212	3964	0.22	248	4088	0.96	4086
45	3887	3780	0.10	107	3833	0.85	3833
46	3755	3850	-0.09	-96	3803	0.83	3802
47	4182	3360	0.73	822	3771	0.81	3749
48	3818	3270	0.53	549	3544	0.72	3533
49	4287	3607	0.59	680	3947	0.89	3932
50	3664	3635	0.03	29	3649	0.77	3649
51	4342	4048	0.25	294	4195	1.01	4192
52	3727	3500	0.23	227	3614	0.75	3612
53	4134	2907	1.10	1227	3521	0.69	3467
54	4451	3624	0.69	827	4038	0.93	4017
55	4359	3592	0.65	767	3975	0.90	3957
56	4256	3656	0.52	599	3956	0.90	3945
57	4630	3205	1.14	1425	3918	0.85	3852
58	5149	3774	0.99	1374	4462	1.12	4408
59	4857	4082	0.59	775	4469	1.14	4453
60	5209	3475	1.23	1734	4342	1.04	4255
61	4276	3640	0.55	636	3958	0.90	3945
62	4017	3221	0.73	796	3619	0.74	3597
63	4101	3173	0.84	928	3637	0.75	3607
64	4521	4205	0.26	316	4363	1.09	4361
65	3520	3877	-0.38	-357	3699	0.79	3695
66	3395	3316	0.09	79	3356	0.65	3355
67	3286	3252	0.04	34	3269	0.62	3269
68	3918	3675	0.23	243	3796	0.83	3794
69	4108	3851	0.23	257	3980	0.91	3978
70	3841	2725	1.08	1116	3283	0.60	3235
71	3919	2704	1.15	1216	3311	0.61	3255
72	4463	3592	0.72	871	4028	0.92	4004
73	4438	3033	1.17	1405	3735	0.77	3669
74	3847	2714	1.09	1133	3281	0.60	3231
75	4222	1611	2.29	2611	2917	0.39	2608
76	4261	2097	1.88	2164	3179	0.51	2989
77	4346	2682	1.42	1664	3514	0.67	3414
78	5418	2881	1.73	2537	4150	0.90	3951
79	4616	1674	2.36	2942	3145	0.44	2780
80	4958	2137	2.11	2822	3547	0.61	3255
81	4629	2793	1.47	1836	3711	0.74	3595
82	5095	2570	1.84	2524	3832	0.75	3619
83	4436	2849	1.32	1587	3642	0.73	3555
84	4740	3229	1.18	1511	3985	0.88	3912
85	4685	2903	1.41	1782	3794	0.78	3688
86	5110	3535	1.14	1575	4323	1.04	4250
87	5298	3425	1.31	1873	4362	1.04	4260
88	4477	2952	1.26	1525	3715	0.76	3636
89	4473	3959	0.43	514	4216	1.02	4208
90	4023	2982	0.96	1041	3502	0.69	3464
91	3440	2868	0.62	572	3154	0.57	3141
92	3910	2860	0.99	1049	3385	0.64	3344
93	3980	3742	0.22	238	3861	0.86	3859
94	4800	2999	1.39	1801	3899	0.83	3794
95	4663	2768	1.50	1895	3715	0.74	3593
96	4199	3968	0.20	231	4083	0.96	4082
97	4477	4176	0.25	301	4326	1.08	4324
98	4615	3453	0.93	1161	4034	0.92	3992
99	4188	2968	1.08	1220	3578	0.72	3526
100	3953	2874	1.01	1079	3414	0.65	3371
101	4183	2987	1.06	1196	3585	0.72	3535
102	4640	3097	1.23	1544	3869	0.83	3791
103	4175	2629	1.37	1545	3402	0.63	3313
104	4659	2829	1.45	1829	3744	0.76	3631
105	5201	3329	1.33	1872	4265	1.00	4161
106	4234	3191	0.91	1043	3712	0.78	3675
107	4207	3256	0.84	951	3732	0.79	3701
108	4062	3163	0.82	899	3613	0.74	3585
109	4324	2832	1.28	1492	3578	0.70	3499
110	3681	2829	0.86	852	3255	0.60	3227
111	4209	3046	1.02	1162	3628	0.74	3581
112	3948	3313	0.60	635	3630	0.75	3617
113	4611	2655	1.57	1956	3633	0.70	3499
114	5474	3356	1.43	2118	4415	1.06	4286
115	4639	3006	1.30	1633	3823	0.80	3734
116	4506	2888	1.33	1618	3697	0.75	3607
117	3635	3579	0.06	56	3607	0.75	3607
118	3847	3127	0.69	719	3487	0.69	3468
119	3994	3155	0.78	839	3574	0.73	3550
120	4558	3265	1.05	1292	3911	0.86	3858
121	4493	3322	0.97	1171	3907	0.86	3863
122	4615	3410	0.97	1205	4012	0.91	3967
123	4557	2440	1.72	2117	3498	0.64	3334
124	4523	2594	1.58	1928	3559	0.68	3425
125	4266	2484	1.55	1783	3375	0.61	3255
126	4450	2565	1.57	1885	3507	0.66	3378
127	5212	2199	2.14	3013	3705	0.66	3385
128	5096	2011	2.24	3085	3554	0.59	3201
129	5083	2452	1.92	2630	3767	0.72	3530
130	5113	1777	2.42	3335	3445	0.52	3015
131	5704	2218	2.26	3486	3961	0.73	3557
132	5150	2252	2.08	2898	3701	0.67	3406
133	3365	2359	1.11	1007	2862	0.46	2817
134	5312	2643	1.86	2669	3978	0.81	3747
135	5035	2485	1.88	2550	3760	0.72	3538

Table 1 (Cont.)

Genotype №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
136	4984	2471	1.87	2513	3727	0.71	3509
137	3730	2526	1.20	1204	3128	0.54	3069
138	4579	2769	1.46	1810	3674	0.73	3561
139	4910	2801	1.59	2109	3856	0.79	3709
140	4879	3178	1.29	1701	4028	0.89	3937
141	4566	3082	1.20	1485	3824	0.81	3751
142	3791	3114	0.66	677	3452	0.68	3436
143	3718	3019	0.70	699	3368	0.65	3350
144	3917	3016	0.85	901	3466	0.68	3437
145	4797	2883	1.48	1914	3840	0.80	3719
146	4124	3105	0.91	1019	3615	0.74	3579
147	4214	3603	0.54	611	3908	0.87	3896
148	4284	3026	1.09	1258	3655	0.75	3600
149	4046	3222	0.75	824	3634	0.75	3611
150	3365	3943	-0.64	-578	3654	0.76	3642
151	4177	3411	0.68	766	3794	0.82	3775
152	3883	3502	0.36	381	3692	0.78	3688
153	4306	3072	1.06	1234	3689	0.76	3637
154	4231	2865	1.20	1366	3548	0.70	3482
155	4340	4257	0.07	84	4299	1.06	4298
156	4259	3526	0.64	734	3893	0.86	3875
157	4713	4061	0.51	652	4387	1.10	4375
158	5237	3237	1.41	2000	4237	0.98	4117
159	4675	3938	0.58	738	4306	1.06	4291
160	4716	2682	1.60	2034	3699	0.73	3557
161	3967	3959	0.01	7	3963	0.90	3963
162	3533	3419	0.12	114	3476	0.70	3476
163	3735	3885	-0.15	-150	3810	0.84	3809
164	4161	3310	0.76	851	3736	0.79	3711
165	4555	2984	1.28	1571	3770	0.78	3687
166	4035	3498	0.49	537	3766	0.81	3757
167	3946	3260	0.64	686	3603	0.74	3587
168	4045	3324	0.66	722	3685	0.77	3667
169	4123	2354	1.59	1768	3239	0.56	3116
170	4718	3157	1.22	1560	3938	0.86	3860
171	4252	3316	0.82	936	3784	0.81	3755
172	4633	2901	1.38	1732	3767	0.77	3666
173	4167	3254	0.81	913	3710	0.78	3682
174	5366	3120	1.55	2247	4243	0.96	4092
175	4798	3091	1.32	1707	3945	0.85	3851
176	3360	3441	-0.09	-81	3400	0.67	3400
177	4768	2596	1.69	2172	3682	0.71	3519
178	4174	2583	1.41	1590	3379	0.62	3284
179	5054	2649	1.76	2405	3852	0.77	3659
180	4611	2287	1.87	2324	3449	0.61	3247
181	4706	2749	1.54	1957	3728	0.74	3597
182	5053	2403	1.94	2650	3728	0.70	3484
183	5296	2505	1.95	2790	3901	0.76	3643
184	5289	3092	1.54	2197	4190	0.94	4044
185	5447	2691	1.87	2756	4069	0.84	3829
186	5307	2515	1.95	2792	3911	0.77	3653
187	4371	2678	1.43	1693	3524	0.67	3421
188	4164	3012	1.02	1151	3588	0.72	3541
189	4523	3047	1.21	1475	3785	0.79	3713
190	5054	3850	0.88	1204	4452	1.12	4411
191	4760	3180	1.23	1580	3970	0.87	3891
192	4977	3166	1.35	1811	4072	0.91	3970
193	5241	3488	1.24	1753	4365	1.05	4276
194	4517	3316	0.98	1200	3916	0.86	3870
195	4832	3324	1.16	1507	4078	0.92	4008
196	3687	3500	0.19	187	3594	0.74	3592
197	4283	3418	0.75	865	3850	0.84	3826
198	3343	2681	0.73	662	3012	0.52	2994
199	4848	3636	0.93	1212	4242	1.01	4198
200	5973	2651	2.06	3322	4312	0.91	3980
201	4941	3623	0.99	1318	4282	1.03	4231
202	3241	3419	-0.20	-178	3330	0.64	3329
203	3208	2877	0.38	331	3043	0.53	3038

Table 1 (Cont.)

Genotype №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
204	3595	2771	0.85	825	3183	0.57	3156
205	4658	3011	1.31	1647	3834	0.81	3745
206	4025	3286	0.68	739	3656	0.76	3637
207	3139	2867	0.32	272	3003	0.52	3000
208	3133	3504	-0.44	-371	3319	0.63	3313
209	3015	3340	-0.40	-324	3178	0.58	3173
210	3157	2466	0.81	691	2812	0.45	2790
211	4236	3758	0.42	478	3997	0.92	3990
212	4674	2546	1.69	2128	3610	0.69	3450
213	2865	2559	0.40	306	2712	0.42	2707
214	3150	3323	-0.20	-173	3237	0.60	3235
215	4061	3021	0.95	1040	3541	0.71	3503
216	3581	3144	0.45	437	3363	0.65	3355
217	3319	2840	0.54	480	3079	0.54	3070
218	4920	3299	1.22	1621	4109	0.93	4029
219	4917	3124	1.35	1794	4021	0.88	3919
220	4572	3035	1.25	1538	3804	0.80	3725
221	4322	2664	1.42	1658	3493	0.66	3393
222	2585	2338	0.35	247	2462	0.35	2458
223	3484	3404	0.08	80	3444	0.68	3443
224	2802	3639	-1.11	-837	3221	0.59	3193
225	3351	3363	-0.01	-12	3357	0.65	3357
226	2509	3446	-1.38	-937	2977	0.50	2940
227	3037	3148	-0.14	-111	3093	0.55	3092
228	4266	2884	1.20	1382	3575	0.71	3508
229	2889	2853	0.05	36	2871	0.47	2871
230	4419	3049	1.15	1370	3734	0.78	3671
231	4670	2472	1.74	2198	3571	0.66	3398
232	3938	2551	1.30	1387	3245	0.58	3170
233	3626	2094	1.56	1532	2860	0.44	2756
234	2930	1684	1.57	1246	2307	0.28	2221
235	4039	2436	1.47	1602	3238	0.57	3137
236	3483	2349	1.21	1133	2916	0.47	2860
237	3777	2939	0.82	838	3358	0.64	3332
240	4345	2406	1.65	1939	3376	0.60	3233
250	4124	3509	0.55	615	3817	0.83	3804
251	4208	3122	0.96	1086	3665	0.76	3625
252	4603	3292	1.05	1311	3948	0.87	3893
253	3817	3305	0.50	511	3561	0.73	3552
254	3729	3570	0.16	160	3649	0.77	3648
255	3155	3622	-0.55	-467	3388	0.66	3380
256	2798	2733	0.09	65	2766	0.44	2765
257	3060	2612	0.54	448	2836	0.46	2827
258	3107	3326	-0.26	-219	3217	0.59	3215
259	2423	2699	-0.42	-276	2561	0.38	2557
260	3443	2405	1.12	1038	2924	0.48	2878
261	3235	2810	0.49	425	3023	0.52	3015
262	2949	3373	-0.53	-424	3161	0.57	3154
263	4204	3558	0.57	646	3881	0.86	3868
264	3328	3644	-0.35	-316	3486	0.70	3483
265	2953	3509	-0.70	-556	3231	0.60	3219
266	2442	2933	-0.74	-491	2688	0.41	2676
267	3260	3210	0.06	49	3235	0.60	3235
268	4030	3213	0.75	817	3622	0.75	3599
269	4873	3132	1.32	1742	4003	0.88	3907
270	5117	3722	1.01	1396	4420	1.10	4364
271	4818	3437	1.06	1381	4128	0.95	4070
272	3540	3591	-0.05	-51	3566	0.73	3566
273	2691	3024	-0.46	-333	2858	0.47	2853
274	4012	3600	0.38	412	3806	0.83	3801
275	3495	4042	-0.58	-547	3768	0.81	3758
276	3411	3572	-0.17	-161	3492	0.70	3491
277	4221	3235	0.87	986	3728	0.79	3695
278	4009	2814	1.10	1194	3412	0.65	3359
279	4727	2473	1.77	2253	3600	0.67	3419
280	4960	2273	2.01	2687	3616	0.65	3357
281	5406	2864	1.74	2542	4135	0.89	3935
282	3935	1428	2.36	2507	2681	0.32	2370

Table 1 (Cont.)

Genotype №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
283	3955	1609	2.20	2347	2782	0.37	2523
284	4645	2024	2.09	2621	3335	0.54	3066
285	3723	2601	1.12	1122	3162	0.56	3112
286	4566	1825	2.22	2741	3196	0.48	2887
287	4282	1855	2.10	2427	3069	0.46	2819
288	4374	1860	2.13	2514	3117	0.47	2853
289	5049	1575	2.55	3474	3312	0.46	2820
290	5155	1606	2.55	3549	3380	0.48	2877
291	4911	2157	2.08	2755	3534	0.61	3255
292	3851	1427	2.33	2424	2639	0.32	2344
293	5118	2318	2.03	2800	3718	0.68	3444
294	4155	2612	1.38	1543	3384	0.62	3294
295	4615	1842	2.22	2772	3229	0.49	2916
296	4790	3413	1.06	1377	4101	0.94	4043
297	3382	2555	0.91	827	2968	0.50	2939
298	4231	2803	1.25	1427	3517	0.68	3444
299	3694	3222	0.47	471	3458	0.69	3450
300	4825	2665	1.66	2160	3745	0.74	3586
301	3409	2462	1.03	948	2936	0.48	2897
302	3223	2433	0.91	790	2828	0.45	2800

Genotype numbers 238, 239 and 241-249 are not listed as these genotypes were originally supposed to be included in the experiment but due to insufficient seed could not be placed in the stressed environment, therefore these were discarded from the analyses. The remaining genotypes, despite their numbers, total to 291. Plot size: 6 m^2

mine the desired index.

According to **Table 2**, SSI and TOL indices showed a highly significant positive correlation with yield in normal conditions. It is clear that the lower the SSI and TOL, the greater the drought tolerance. Due to the above tight positive correlation, when normal yield is increased SSI and TOL will also increase, which is not desired. This means that in high potential varieties yield in a stressed environment is always poor and consequently these two indices would be maximized. The MP index, due to its positive and highly significant correlation with yield in normal and stressed conditions, appears suitable because the maximum amount of this index is desired for drought tolerance. This index will be maximum even when yield in either normal or stressed environments is too high. On the other hand, the correlation coefficient of SSI and TOL with MP was positive and significant, which is not consistent with the direction of selection for drought tolerance using these indices. On the other hand, lower values of SSI and TOL are in favor of drought tolerance while higher values of MP are too, and this is controversial when they show such a positive correlation. Finally, two indices (STI and GMP) had a highly significant correlation with yield in both environments and had no relationship with SSI and TOL but were positively correlated to MP. The direction of selection for drought tolerance based on STI, GMP and MP is similar but among these, STI and GMP are preferred, because as mentioned above, MP is also positively correlated to SSI and TOL and that is a disadvantage for MP to be used. This result is in agreement with many previous reports (e.g. Parvizi-Almani *et al.* 1998; Normand Moayed *et al.* 2001; Najafian 2003; Babaei *et al.* 2008; Khezri-Afravi *et al.* 2008). In these studies, after calculation of those five drought stress tolerance indices, based on correlations among them and also their relationship with grain yield under normal and stressed environments, it is concluded that MP, GMP and STI (mostly GMP and STI) indices are more preferred for practical use. STI and GMP could also still be maximized even when yield in one environment (e.g. a normal environment) is considerably high and in the other low or moderate. This means that a drought tolerant variety with good yield in normal and stressed environments may show the same amount of STI or GMP as a variety with higher yield in normal conditions but lower yield in a stressed environment. This can be seen in **Table 4** for genotypes 196 and 268, whose STI and GMP values are approximately the same but their yield combination in different conditions are not.

Considering the above criticism regarding drought tolerance indices it was decided to use STI and yield in both environments for clustering of the germplasm. This ensures grouping of the lines based on values of these three factors, which leads to identification of four genotypic groups (group A with good yield in both environments, group B with good yield in normal environment but poor yield in stressed one, group C with better yield in stressed conditions and group D with poor yield in both conditions) introduced by Fernandez (1992).

The obtained dendrogram for 291 entries was too lengthy and is thus represented over two parts (**Fig. 1**). By assessment of the drawn dendrogram 4 distinct clusters were detected. In the first one 60 genotypes were located which their STI was variable from 0.76 to 1.14 and yield in both conditions was high or partially high. This cluster accommodated type A genotypes which had high yield in both conditions and were considered to be drought tolerant. In the second cluster 92 genotypes were located with mostly high yield in normal conditions but low yield in the water stressed trial. The amount of STI for these was variable, from 0.6 to 0.96. Three sub-clusters were located in this cluster, one of which was somewhat similar to the first cluster in terms of STI and grain yield for the genotypes included. The second cluster accommodated type B genotypes. The third cluster accommodated 97 genotypes which were located in three sub-clusters. One of these sub-clusters represented type C genotypes with better yield in stressed conditions than in normal trial. One of the reasons for their better performance in stressed conditions might be due to lodging and disease development in normal conditions, which are reducing factors for yield (in the case of very tall genotypes, when irrigated well, they lodge and under these conditions rusts develop more severely. Such genotypes always are better under less and stressed regimes of irrigation and consequently their yield would be better than normal conditions; pers. obs.). The two other sub-clusters mainly accommodated genotypes with a moderate yield in both conditions. Finally in the fourth cluster 42 entries were included and further subdivided into two sub-clusters. The genotypes of the first sub-cluster had poor yield in both

Table 2 Correlation coefficients among drought tolerance indices and between them with yield in normal and stressed conditions for 291 wheat genotypes (Yn: yield in normal conditions, Ys: yield in stressed conditions).

	Yn	Ys	SSI	TOL	MP	STI	GMP
Yn	1.000						
Ys	-0.099	1.000					
SSI	0.733**	-0.723**	1.000				
TOL	0.803**	-0.672**	0.978**	1.000			
MP	0.755**	0.579**	0.124*	0.215**	1.000		
STI	0.605**	0.723**	-0.057	0.017	0.973**	1.000	
GMP	0.606**	0.727**	-0.060	0.016	0.976**	0.996**	1.000

**: correlation is significant at 0.01 level (2-tailed)
*: correlation is significant at 0.05 level (2-tailed)

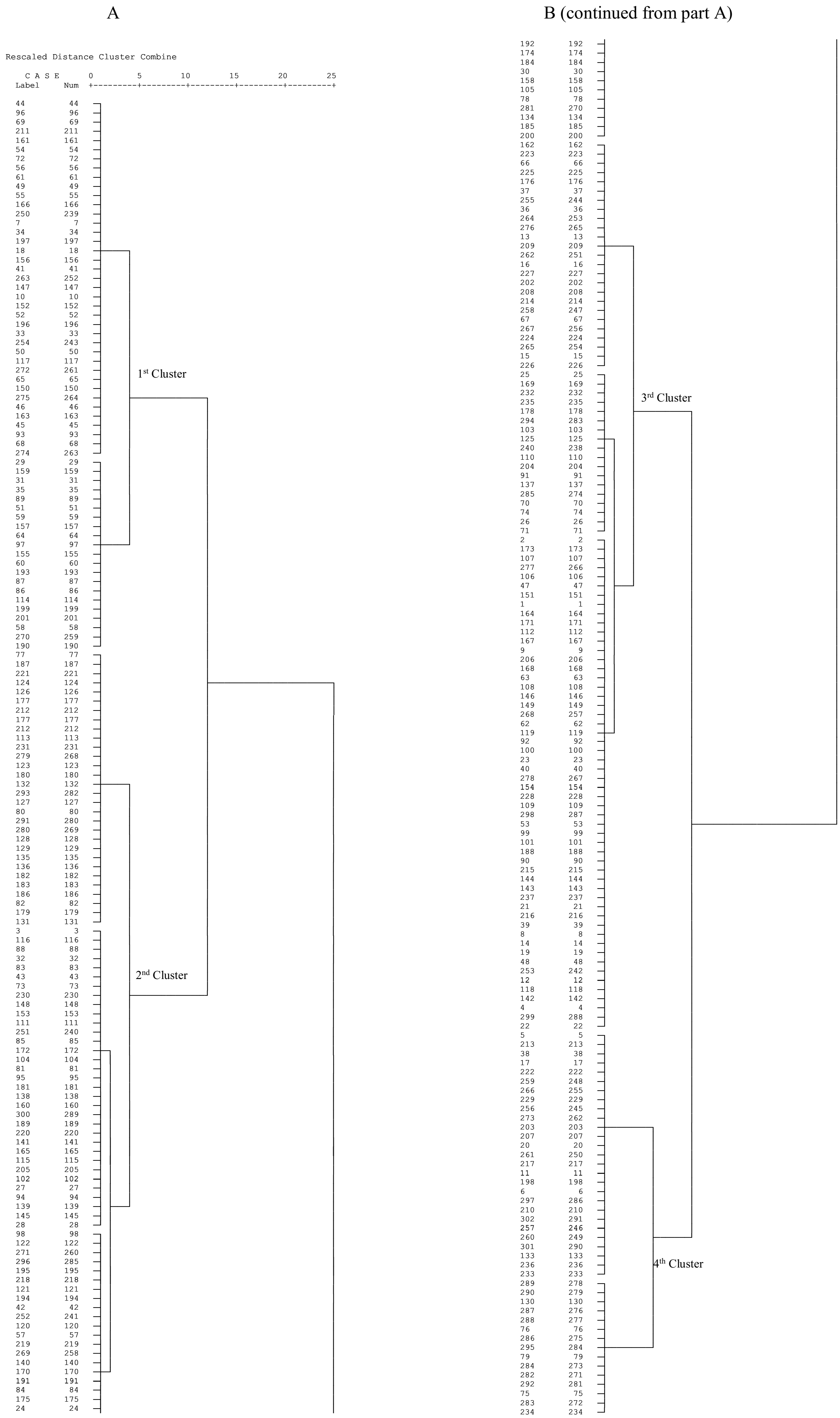

Fig. 1 Clustering Dendrogram of 291 wheat genotypes of the study based on STI, grain yield in normal and stressed conditions using Ward method which due to its length has been presented in two parts. (**A**) upper side of the dendrogram, (**B**) lower side of the dendrogram.

Table 3 Parentage of the some selected genotypes which are "VEERY" genotype descendants.

Genotype №	Parentage
157	Ww33G/**Vee"S"**//Mrn/3/Attila/Tjn
29	4777//Fkn/Gb/3/**Vee"S"**/4/Buc"S"/Pvn"S"/5/VF620
64	Shi#4414/Crow"S"//**Vee"S"**/Nac
162	Ww33G/**Vee"S"**//Mrn/4/HD2172/Bloudan….
163	Ww33G/**Vee"S"**//Mrn/4/HD2172/Bloudan…..
237	Zagross (Tans/**Vee"s"**//Opata)
159	Ww33G/**Vee"S"**//Mrn/3/Attila/Tjn
217	W462//**VEE**/KOEL/3/PEG//MRL/BUC CMBW91M03389T-…
143	M-70-4/5/Ures (**VEE**)/3/Gov/Az//Mus/4/Sara
258	URES (**VEE**)/3/FURY//SLN/ALDAN"S"/4/NS732/HER ICW93-0531-…
144	M-70-4/5/Ures (**VEE**)/3/Gov/Az//Mus/4/Sara
173	Seri82 (**VEE**)/Rsh2

Table 4 Normal and stressed conditions grain yield along with values of drought tolerance indices for selected lines of the study in step 1 and reselected genotypes in step 2 (indicated by S2).

Line №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
24	5125	3144	1.43	1980	4135	0.93	4014
190	5054	3850	0.88	1204	4452	1.12	4411
195	4832	3324	1.16	1507	4078	0.92	4008
145	4797	2883	1.48	1914	3840	0.8	3719
84	4740	3229	1.18	1511	3985	0.88	3912
157 (S2)	4713	4061	0.51	652	4387	1.1	4375
159 (S2)	4675	3938	0.58	738	4306	1.06	4291
29 (S2)	4632	3890	0.59	742	4261	1.04	4245
189	4523	3047	1.21	1475	3785	0.79	3713
64 (S2)	4521	4205	0.26	316	4363	1.09	4361
83	4436	2849	1.32	1587	3642	0.73	3555
51 (S2)	4342	4048	0.25	294	4195	1.01	4192
156 (S2)	4259	3526	0.64	734	3893	0.86	3875
111	4209	3046	1.02	1162	3628	0.74	3581
107	4207	3256	0.84	951	3732	0.79	3701
96 (S2)	4199	3968	0.2	231	4083	0.96	4082
173	4167	3254	0.81	913	3710	0.78	3682
146	4124	3105	0.91	1019	3615	0.74	3579
108	4062	3163	0.82	899	3613	0.74	3585
149 (S2)	4046	3222	0.75	824	3634	0.75	3611
268 (S2)	4030	3213	0.75	817	3622	0.75	3599
274 (S2)	4012	3600	0.38	412	3806	0.83	3801
71	3919	2704	1.15	1216	3311	0.61	3255
144	3917	3016	0.85	901	3466	0.68	3437
152 (S2)	3883	3502	0.36	381	3692	0.78	3688
253 (S2)	3817	3305	0.5	511	3561	0.73	3552
237	3777	2939	0.82	838	3358	0.64	3332
163 (S2)	3735	3885	-0.15	-150	3810	0.84	3809
254 (S2)	3729	3570	0.16	160	3649	0.77	3648
143 (S2)	3718	3019	0.7	699	3368	0.65	3350
196 (S2)	3687	3500	0.19	187	3594	0.74	3592
272 (S2)	3540	3591	-0.05	-51	3566	0.73	3566
162 (S2)	3533	3419	0.12	114	3476	0.7	3476
275 (S2)	3495	4042	-0.58	-547	3768	0.81	3758
223 (S2)	3484	3404	0.08	80	3444	0.68	3443
276 (S2)	3411	3572	-0.17	-161	3492	0.7	3491
301	3409	2462	1.03	948	2936	0.48	2897
150 (S2)	3365	3943	-0.64	-578	3654	0.76	3642
176 (S2)	3360	3441	-0.09	-81	3400	0.67	3400
217 (S2)	3319	2840	0.54	480	3079	0.54	3070
267 (S2)	3260	3210	0.06	49	3235	0.6	3235
302	3223	2433	0.91	790	2828	0.45	2800
255 (S2)	3155	3622	-0.55	-467	3388	0.66	3380
208 (S2)	3133	3504	-0.44	-371	3319	0.63	3313
258 (S2)	3107	3326	-0.26	-219	3217	0.59	3215
227 (S2)	3037	3148	-0.14	-111	3093	0.55	3092
265 (S2)	2953	3509	-0.7	-556	3231	0.6	3219
262 (S2)	2949	3373	-0.53	-424	3161	0.57	3154
273 (S2)	2691	3024	-0.46	-333	2858	0.47	2853
226 (S2)	2509	3446	-1.38	-937	2977	0.5	2940

Plot size: 6 m^2

conditions (group D genotypes) with an STI from 0.35-0.54. Another sub-cluster accommodated the entries which had very low yield in stressed condition but poor to moderate yield in the normal trial. The STI values varied from 0.28-

0.54 for this group. Using the clustering method 50 genotypes were selected in the first step. Observing the pedigree of the selected lines indicates that some of these genotypes are derivatives of 'VEERY', discussed above and by Rajaram (2000) (**Table 3**).

Most of the selected genotypes were from the first and third clusters, which were either genotypes with high yield in both environments (first cluster) or moderate yield in both environments (third cluster). The values of drought tolerance indices for these selected genotypes have been presented in **Table 4**, from which it can be observed that there are still many lines whose SSI values are high; these lines might be susceptible to drought. To reselect those lines whose STI value and grain yield in both conditions are good, a further screening step using SSI index was applied to the genotypes in **Table 4**. For this, genotypes with an SSI value of more than 0.8 were discarded.

Why has the cut off line for SSI been considered to be 0.8? It is stated that when SSI value is equal to 1.0 for a particular genotype, it means that the ratio of stressed yield/normal yield for that genotype is exactly equal to the same ratio for the whole population means. In other words, the reduction rate of grain yield for that genotype from a normal environment to a stressed one is equal to the mean reduction rate of grain yield for all investigated genotypes from a normal to a stressed environment. This is the property of SSI, whose formula can be calculated by SSI = {1-YS/YN}/{1-average YS of all genotypes/average YN of all genotypes}, where YS stands for yield of a genotype in a stressed environment and YN stands for yield of the same genotype in a normal environment and the denominator of this equation is defined as the SI index (Fischer and Maurer 1978). Now, with objective of finding genotypes to be better than the mean of the population in terms of stress tolerance, the border line for SSI value should be placed at any value less than 1.0, e.g. 0.9, 0.8, etc. up to 0.0. The lower the value of the SSI border line, the higher is the chance to retain more drought-tolerant genotypes. At the same time, the main question is: which value between 1.0 and 0.0 should be considered as the SSI cut off line? As has been introduced by Fischer and Maurer (1978), SI, which is calculated in the denominator of the SSI calculation formula, shows the severity of the stress applied. The cut-off line for the SSI value could be chosen by considering the value of the SI index and also circumstances of the targeted environment. It is clear from SI formula that the higher the severity of the stress, the closer the value of SI index is to 1.0, because under sever stress, the yield of a stressed environment will be reduced significantly and its ratio to yield under a normal environment will be less than 1.0 and nearer 0.0; subtraction of that ratio from 1.0 gives a figure near to 1.0. In this study, the SI value was 0.27, meaning that for all studied genotypes an average of 27% of normal environment grain yield was lost in the stressed environment. The severity of this study's stress could be considered as a mild. The stress in our study targeted the environment and confirms that, because the aim of this study within the context of a breeding program was to release adapted varieties under terminal water deficit, one or two final irrigations would not be applied to irrigated wheat. Consequently, the value of the SSI cut-off line was considered to be 0.8. When the SI index value increases from 0.2 toward 1.0 for each unit increased, i.e. 0.1, a breeder can reduce the SSI cut-off value accordingly by one unit, i.e. 0.1. This will lead to a relationship between SI index value and SSI cut off line value to be 0.2 and 0.8 (i.e. 1.0-0.2); 0.3 and 0.7; 0.4 and 0.6; 0.5 and 0.5; 0.6 and 0.4, etc. The reason for starting from 0.2 for SI is that a values less than 0.2 shows extremely low severity and perhaps neglectful effect in proper screening for stress tolerance. Choosing a higher value of SSI than 1.0 for the cut-off line will lead to the selection of less tolerant and even stress-susceptible genotypes. And a value of the SI index of more than 0.6 (meaning a loss of more than 60% yield from a normal environment to a stressed one) shows higher extremes of stress and a destructive severity in such a way that might not be manageable through breeding practices. The logic for following the above-mentioned relationship between SI and the cut-off line value of SSI in screening practices is that when the stress impact is very severe in a particular target environment, and accordingly in its concerned breeding program as well, the selection pressure for stress tolerance screening should be increased so that the more tolerant genotypes which can succeed in that target environment get a chance of release. Therefore in the 2nd step of this study, out of 50 genotypes, 33 were eligible to be considered as final selected lines (**Table 4**, indicated by S2). Drought tolerance indices and grain yield of the rejected lines are shown in **Table 5**. This two step strategy appears to combine yield potential (as it is based on STI and grain yield in both conditions) and drought tolerance (as it is also based on SSI values) in the process of screening.

Table 5 Normal and stressed conditions grain yield along with values of drought tolerance indices for rejected lines of the study in step 2.

Line №	Normal conditions grain yield (g/plot)	Stressed conditions grain yield (g/plot)	SSI	TOL (g)	MP (g)	STI	GMP (g)
24	5125	3144	1.43	1980	4135	0.93	4014
71	3919	2704	1.15	1216	3311	0.61	3255
83	4436	2849	1.32	1587	3642	0.73	3555
84	4740	3229	1.18	1511	3985	0.88	3912
107	4207	3256	0.84	951	3732	0.79	3701
108	4062	3163	0.82	899	3613	0.74	3585
111	4209	3046	1.02	1162	3628	0.74	3581
144	3917	3016	0.85	901	3466	0.68	3437
145	4797	2883	1.48	1914	3840	0.80	3719
146	4124	3105	0.91	1019	3615	0.74	3579
173	4167	3254	0.81	913	3710	0.78	3682
189	4523	3047	1.21	1475	3785	0.79	3713
190	5054	3850	0.88	1204	4452	1.12	4411
195	4832	3324	1.16	1507	4078	0.92	4008
237	3777	2939	0.82	838	3358	0.64	3332
301	3409	2462	1.03	948	2936	0.48	2897
302	3223	2433	0.91	790	2828	0.45	2800

Plot size: 6 m^2

The improvement obtained in yield and 1000-kernel weight mean of selected lines over two steps in comparison to all 291 entries is shown in **Table 6**. It can be seen that under the normal condition yield has been reduced from 4168 to 3856 g/plot in step 1 and to 3645 g/plot in step 2, but under the stressed condition it was increased from 3036 to 3371 g/plot in step 1 and to 3541 g/plot in step 2, respectively for all entries and selected lines. The mean STI value increased from 0.73 to 0.75 in both steps for grain yield. The mean SSI value decreased from 0.92 for all genotypes to 0.39 for selected lines in step 1 and 0.04 in step 2. Improvements in other indices for grain yield have also been made. 1000-kernel weight increased from 42 to 43 g for step 1 and to 44 g for step 2 selections respectively, in normal conditions and from 35 to 37 g in step 1 and to 38 g in step 2 selections in stressed conditions. The mean STI value for this trait has improved from 0.83 to 0.91 in step 1 and to 0.93 in step 2 of selection. Other indices have also been improved for test weight in the selected lines. These figures show that in step 1 mostly yield potential has been effective and in step 2 drought tolerance has been more effective.

In this trial four irrigated wheat cultivars were used which were replicated several times throughout each experiment and also some of the materials under investigation were other varieties or land races whose performance has been presented in **Table 7**. The four cultivars 'Mahdavi', 'Marvdasht', 'Pishtaz' and 'Shiraz' are released varieties for irrigated farms of the temperate zone of Iran. Among these only 'Pishtaz' was slightly better for late season drought tolerance. As can be seen in **Table 7**, most of the cultivars

Table 6 Mean for grain yield and 1000 kernel weight in two conditions and also drought tolerance indices for all 291 investigated entries compared to the selected lines in step 1 and 2.

Kernel yield (g/plot)	**Normal**	**Stressed**	**SSI**	**TOL (g)**	**MP (g)**	**STI**	**GMP (g)**
All genotypes	4168	3036	0.92	1132	3602	0.73	3527
Selected lines (step 1)	3856	3371	0.39	485	3614	0.75	3590
Selected lines (step 2)	3645	3541	0.04	104	3593	0.75	3585
1000-kernel weight (g)	**Normal**	**Stressed**	**SSI**	**TOL (g)**	**MP (g)**	**STI**	**GMP (g)**
All genotypes	42	35	0.93	7	38	0.83	38
Selected lines (step 1)	43	37	0.71	5	40	0.91	40
Selected lines (step 2)	44	38	0.75	6	41	0.93	41

Plot size : 6 m^2

Table 7 Normal and stressed conditions grain yield and values of drought tolerance indices for checks and other varieties included in the study.

Variety	**Normal conditions grain yield (g/plot)**	**Stressed conditions grain yield (g/plot)**	**SSI**	**TOL (g)**	**MP (g)**	**STI**	**GMP (g)**
Mahdavi	3807	2581	1.14	1232	3198	0.57	3122
Marvdasht	4899	2742	1.58	2157	3820	0.77	3643
Pishtaz	4871	3088	1.36	1783	3979	0.87	3875
Shiraz	4673	2408	1.79	2265	3540	0.64	3348
S.B. Of Roshan	4670	2472	1.74	2198	3571	0.66	3398
Alborz	3938	2551	1.30	1387	3245	0.58	3170
W.B. Of Roshan	3626	2094	1.56	1532	2860	0.44	2756
Roshan	3930	1684	1.57	1246	2307	0.28	2221
Chamran	4039	2436	1.47	1602	3238	0.57	3137
Zagross	3777	2939	0.82	838	3358	0.64	3332
Niknejad	3694	3222	0.47	471	3458	0.69	3450
D. Cross of Shahi	3409	2462	1.03	948	2936	0.48	2897
Cross Alborz	3223	2433	0.91	790	2828	0.45	2800

Plot size: 6 m^2

showed a considerable SSI value. If we consider both SSI and STI figures to screen these genotypes only few cultivars may look acceptable. 'Zagross', a variety released for high land rain fed farms whose STI and SSI indices were 0.64 and 0.82, respectively, appeared to be adapted to water scarcity conditions. Likewise, 'Niknejad', with STI and SSI values of 0.69 and 0.47, respectively appears good for supplementary irrigation. This study showed that cluster analysis based on "STI along with grain yield in both normal and stressed conditions" followed by a further screening with SSI index could be used perfectly for screening large nurseries for drought tolerance and yield responsiveness. This strategy is a complementary suggestion to the proposal of using STI or GMP *per se*, which was done by Fernandez (1992) and it is proposed to be tested further with replicated trials by others and proposed to be applied in breeding programs.

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REFERENCES

Babaei F, Maleki A, Chahar-Soghi-Amin H (2008) Evaluation of drought tolerance indices in bread wheat genotypes under normal irrigation and drought stress conditions. In: *10th Iranian Congress of Crop Sciences*, 18-20 August, 2008, Karaj, Iran, p 184 (Abstract, in Farsi)

Banziger M, Setimela PS, Hodson D, Vivek B (2004) Breeding for improved drought tolerance in Maize adapted to southern Africa. In: Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borrell A, Lloyd D (Eds) *New Directions for a Diverse Planet: 4th International Crop Science Congress,* 26 September-1 October, 2004, Brisbane, Australia, published on the CD-ROM

Bramel-Cox PJ, Barker T, Zavala-Garcia F, Eastin JD (1991) Selection and testing environments for improved performance under reduced-input conditions. In: *Plant Breeding and Sustainable Agriculture: Considerations for Objectives and Methods*, CSSA Special Publication No 18, CSSA and ASA, Madison, USA, pp 29-56

Byerlee D, Moya P (1993) *Impacts of International Wheat Breeding Research in the Developing World*, 1969-90, CIMMYT, Mexico, 135 pp

Cooper M, Byth DE, Woodruff DR (1994) An investigation of the grain yield adaptation of CIMMYT wheat lines to water stress environments in Queensland. II. Classification analysis. *Australian Journal of Agricultural Research* **45**, 985-1002

Denic M, Mariote D, Chauqe P, Fato D, Senete C, Haag W (2006) Breeding approaches in simultaneous selection for multiple stress tolerance of quality protein maize. In: Higman S (Ed) *Proceedings of International Plant Breeding Symposium, Honoring John W. Dudley,* 20-25 August, 2006, Mexico City, p 116 (Abstract)

Duvick DN (1992) Genetic contributions to advances in yield of U.S. maize. *Maydica* **37**, 69-79

Ehdaie B, Waines JG, Hall AE (1988) Differential responses of landrace and improved spring wheat genotypes to stress environments. *Crop Science* **28**, 838-842

Fernandez GCJ (1992) Effective selection criteria for assessing plant stress tolerance. In: Kuo CG (Ed) *Adaptation of Food Crops to Temperature and Water Stress, Proceedings of International Symposium*, 13-18 August, 1992, Taipei, Taiwan, Publ. No 93-410, Asian Vegetable Research and Development Center, Shanhua, Taiwan, pp 257-270

Fischer RA, Maurer R (1978) Drought resistance in spring wheat cultivars. 1. Grain yield responses. *Australian Journal of Agricultural Research* **29**, 897-912

Ghodsi M, Jalal-Kamali MR, Mazaheri D, Chaichi MR (2008) Water and radiation use efficiency in different developmental stages in four bread wheat cultivars under moisture stress conditions. *Desert* **12**, 129-137

Jalal-Kamali MR (2000) Cereal Research Department. In: Saidi A, Choukan R (Eds) *A Summary of Research Achievements at Seed and Plant Improvement Research Institute of Iran (SPII)*, Seed and Plant Improvement Research Institute, Karaj, Iran, pp 12-40 (in Farsi)

Jongdee B, Pantuwan G, Fukai S, Fischer K (2004) Improving drought tolerance in rainfed lowland rice: an example from Thailand. In: Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borrell A, Lloyd D (Eds) *New Directions for a Diverse Planet: 4th International Crop Science Congress,* 26 September-1 October, 2004, Brisbane, Australia, published on CD-ROM

Khezri-Afravi M, Hossain-Zadeh AH, Mohammadi V, Ahmadi A (2008) Evaluation of drought tolerance indices in durum wheat (*Triticum turgidum* var. Durum). *Proceedings of 10th Iranian Congress of Crop Sciences*, 18-20 August, 2008, Karaj, Iran, p 192 (Abstract, in Farsi)

Moosavi SS, Yazdi-Samadi B, Naghavi MR, Zali AA, Dashti H, Pourshahbazi A (2008) Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert* **12**, 165-178

Morris ML, Belaid A, Byerlee D (1991) *Wheat and Barley Production in Rainfed Marginal Environments of Developing World.* Part I of 1990-91, CIMMYT World Wheat Facts and Trends, CIMMYT, Mexico, 51 pp

Muasya WNP, Diallo AO (2006) Strategies for developing high yielding maize varieties for the dry mid-altitude ecology of Kenya. In: Higman S (Ed) *Proceedings of International Plant Breeding Symposium, Honoring John W. Dudley*, 20-25 August, 2006, Mexico City, p 134 (Abstract)

Naderi A, Majidi-Hervan E, Hashemi-Dezfuli A, Rezai A, Normohamadi GH (1999) Efficiency analysis of indices for tolerance to environmental stress in field crops and introduction of a new index. *Iranian Journal of Agri-*

cultural Sciences **15 (4)**, 390-402

Najafian G (2003) Screening of high volume breeding lines of hexaploid wheat for drought tolerance using cluster analysis based on kernel yield and STI. In: *Proceedings of 10th International Wheat Genetics Symposium* (Vol II), 1-6 September, Paestum, Italy pp 783-785

Najafian G, Ghandi A, Abdi H (2004) Screening for late season drought tolerance in wheat genotypes grown in Iran. In: Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borrell A, Lloyd D (Eds) *New Directions for a Diverse Planet: 4th International Crop Science Congress,* 26 September-1 October, 2004, Brisbane, Australia, published on CD-ROM

Najafian G, Jalal-Kamali M (2004) Wide adaptation of '*Veery*' genotype and its descendants, a clear sample of wheat homeostasis. *Key Papers of the 8th Iranian Crop Production and Breeding Congress*, August 25-27, 2004, Rasht, Iran, pp 175-191 (in Farsi)

Najafian G, Jafar-Nejad A, Ghandi A, Abdi H, Nikooseresht R (2005) Yield stability and morphological characteristics of promising hexaploid wheat (*T. Aestivum* L.) lines grown under water scarcity conditions in temperate areas of Iran. In: *Proceedings of 7th International Wheat Conference*, November 27-December 2, 2005, Mardel Plata, Argentina, p 42 (Abstract)

Normand-Moayed F, Rostami MA, Ghanadha MR (2001) Study of drought resistance indices in bread wheat. *Iranian Journal of Agricultural Sciences* **32**, 795-805 (in Farsi)

Parvizi-Almani M, **Sadeghian SY, Taleghani DF, Mohammadian R** (1998) Study of drought tolerance indices for important traits in sugar beet. In: *Proceedings of 5th Iranian Congress of Crop Sciences*, August 31-September 4, 1998, Karaj, Iran, p 285 (Abstract, in Farsi)

Rajaram S (2000) International wheat breeding: past and present achievements and future directions. In: Karow R, Reed B (Eds) *Warren E. Kronstad Honorary Symposium*, Corvallis, OR, Oregon State University Extension Service, Special Report 1017, June 2000, pp 49-79

Rajaram S, Van-Ginkel M (1995) Wheat breeding methodology: International perspectives. In: *Proceedings of 20th Hard Red Winter Wheat Workers Workshop*, 25-27 January, 1995, Oklahoma City, OK, USA, pp 1-15

Reynolds MP, Saint-Pierre C, Vargas M (2007) Evaluating potential genetic gain in wheat associated with stress-adaptive trait expression in elite genetic resources under drought and heat stress. In: Albrecht B, Bernardo R, Godshalk EB, Lamkey KR, Rodomiro O (Eds) *International Plant Breeding Symposium, Honoring John W. Dudley*, A Supplement to Crop Science, December 2007, CSSA, USA, **47(S3)**, 172-189

Rosielle AA, Hamblin J (1981) Theoretical aspect of selection for yield in stress and non stress environment, *Crop Science* **21**, 943-946

Uddin N, Carver BF, Clutter AC (1992) Genetic analysis and selection for wheat yield in drought-stressed and irrigated environments. *Euphytica* **62**, 89-96

Zavala-Garcia F, Bramel-Cox PJ, Eastin JD, Witt MD, Andrews DJ (1992) Increasing the efficiency of crop selection for unpredictable environments. *Crop Science* **32**, 51-57