Construction and Efficiency of Selection Indices in Wheat (*Triticum aestivum* L.) under Drought Stress and Well-Irrigated Conditions

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ABSTRACT Aggregate selection helps making selection decisions for improved profitability and permits to exploit information on correlated traits to improve accuracy. In the present study, the efficiency of trait selection was assessed by the Smith-Hazel (SHI) and the Pesek-Baker (PBI) models in 35 wheat genotypes under drought stress at heading and well-irrigated conditions at the Research Farm of Shiraz University, Iran in 2011 and 2012 years. The analysis of correlated response (CR) revealed that thousand grain weight (TGW) with CR = 24.05 (in 2011) and 9.15 (in 2012) and harvest index (HI) with CR = 18.37 (in 2011) and 9.08 (in 2012) had higher indirect effects on grain yield (GY) increase under drought stress. In both years, biological yield (BY), grain number/spike (GN), TGW, and GY had the highest genetic gain (ΔG) in SHI model. The top ten landraces in PBI for the trials in 2011 were also placed in the top rankings for grain yield under drought stress conditions. These results and estimation of the efficiency of selection (ΔH) revealed that PBI (ΔH = 19.95 and 16.5 in the first and 11.15 and 11.06 in the second year) was more efficient than SHI (ΔH = 9.58 and 8.97 in the first and 9.74 and 8.59 in the second year) in view of identifying superior genotypes based on aggregate trait selection. Overall, repeatability estimates for grain yield (33%-57.8%) was relatively low showing that individual plant selection has low efficiency for wheat improvement whilst aggregate trait selections leads to relatively high genetic gain (1.63-2.75) for grain yield.

Keywords Aggregate selection, Canopy temperature, Grain yield, Smith-Hazel, Pesek-Baker

INTRODUCTION

Prediction of the efficiency of selection on the basis of single traits is common in most studies, but less effort has been devoted to predicting responses to multiple trait selection (Blows and Brooks 2003; McGuigan 2006; Piepho *et al.* 2008; Ajala 2010). Index selection is one of the fundamental methods for the genetic improvement of traits in crop plants. A theory which introduced independently by Smith (1936) in plants and Hazel (1943) in animals is now known as Smith-Hazel index and has been demonstrated to be more reliable than independent culling levels (ICL) and tandem selection (TS) methods in terms of maximizing genetic gain in a crop population (Cotterill

1985; Costa *et al.* 2008). Hazel and Lush (1942) showed that this approach is the most effective as compared with ICL and TS selection methods for independent traits while having at least the same efficiency in the case of correlated traits (Young 1961). On the other hand, despite the availability of numerous selection methods, the best known indices in crop plants are developed by Smith (1936), Hazel and Lush (1942), Smith (1936), and Pesek and Baker (1969). This is mainly due to their advantages of taking into account of heritability, the interrelationship of traits using genetic and phenotypic correlations and the economic values of traits. Selection for an index which gives proper weight to each trait is more efficient than selection for a single trait or for several traits independently (Smith 1936).

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Breeders should make efforts to estimate reliable genetic parameters and acquire the expertise to construct selection indices and make them powerful tools for assuring satisfactory genetic gain when traits are adversely correlated (Cotterill 1985; Zhang *et al.* 2009).

In a study, Smith-Hazel and Brim-William indices were used to select the best performance in safflower (*Carthamus tinctorius* L.) in a three-year experiment in Gachsaran, Iran (Mohammadi *et al.* 2013). The results indicated that simultaneous consideration of both seed yield and oil content was better than single trait-based selection methods for the genetic improvement of seed yield (Mohammadi *et al.* 2013). In sweet corn, Smith-Hazel was found to be more efficient than Base Index (BI) and Desired Genetic Index (DSI) in improving the aggregate traits (Asghar *et al.* 2010). In a study by Cargnin *et al.* (2007), estimation of the genetic progress for selection of wheat agronomic traits illustrated that the indices Brim-William (Williams 1962) and Pesek and Baker (1969) with the economic weight of one unit were slightly superior to Smith-Hazel index. Nonetheless, in some studies (Cruz *et al.* 1993; Bertoldo *et al.* 2010; Salehi and Saeidi 2013; Jafarzadeh-Ghahdarjani *et al.* 2014) genetic gain with the Smith-Hazel has been higher than that predicted by other indices.

Reviewing literatures indicates that most studies of plant selection frequently have focused on single trait or multiple-trait selection without considering the interrelationship, heritability and the weight of traits and less effort has been devoted to index-based selection (Bertoldo *et al.* 2010; Mohammadi *et al.* 2013; Fioj *et al.* 2016). Individual plant selection based on a single trait may result in genetic variation loss in other traits of importance specifically for circumstances of low yielding environments (Hazel and Lush 1942; Falconer and Mackay 1996). Canopy temperature (CT) is one of the key criteria that has been used as indirect selection of high yielding wheat under drought stress conditions (Araus *et al.* 2003; Olivares-Villegas *et al.* 2007; Tahmasebi *et al.* 2014). This is because canopy temperature is an indirect measure of the transpiration at the whole-crop level (Araus *et al.* 2003; Reynolds *et al.* 2007). In a study on rice, the results indicated that rice mutants with reduced plant height had low yield loss due to drought stress and hence they are

promising lines for cultivation under drought condition (Ahmadikhah and Marufinia 2016). Individual plant selections based on aggregate traits such as lower canopy temperature, plant height and higher grain yield helps breeders to avoid genetic variation loss in relation to drought tolerance. Thus, the objectives of the present study were (1) to construct the Smith-Hazel and the Pesek-Baker models using aggregate traits under drought stress and normal irrigation regimes, (2) to estimate correlated response to selection and (3) to compare the efficiency of the two models in view of aggregate traits selection.

MATERIALS AND METHODS

Field experiment and plant materials

The present study was conducted in fall 2011 and 2012 at the Research Farm of Shiraz University, Shiraz, Iran. Two commercial wheat cultivars (Shiraz and CrossBulani), and thirty-three landrace varieties were selected for construction of selection indices under drought stress and water-irrigated conditions. The landrace varieties were collected from different regions of Iran and had been highly variable morphologically. Such varieties could be used as valuable resource of genes in dealing with biotic and abiotic stresses in breeding programs of commercial cultivars. These accessions are identified with a KC prefix which shows they were collected by the Seed and Plant Improvement Institute (SPII, www.spil.ir), Karaj, Iran. The soil texture was silt-loam with pH 7, EC (0.61 dS/m), CEC (0.52 dS/m), total N (0.091%), available P (21.8 mg/kg), K (600 mg/kg), OC (0.96% at 0-15 cm soil depth) and FC (28.6%). Prior to sowing, the field was fertilized with 50 kg nitrogen/ha and 110 kg/ha triple superphosphate. The meteorology data showed that total rainfall was 262.8 and 339.5 mm in 2010-2011 and 2011-2012 growing seasons, respectively. The majority of precipitations occurred between January and March. The highest rainfall occurred in January at the germination and seedling emergence stages. From April to the early heading stage there was no rainfall in both growing seasons that shows the site of study experiences severe drought stress conditions. Grain filling period occurred at temperatures exceeding

35°C in May and June. The field experiment was arranged as a split plot based on randomized complete blocks design (RCBD) with three replications. One of the main plots was allocated to the fully irrigation regime and the other assigned to drought stress condition. In plots that were allocated to drought stress, plants were fully watered (100% field capacity) until the time that 50% of genotypes headed, and then irrigation practice was stopped until harvesting time on 1-2 July in both growing seasons. Genotypes were allocated to the sub plots of 3 m × 2 m in size. In November 2011 and 2012, the seeds of the genotypes were sown at a depth of 5 cm. Weeding was performed using 40 g/ha of the herbicide Total (sulfosulfuron + metsulfuron methyl) at tillering stage and by hand pulling at all stages of wheat growth. Genotypes in the normally irrigated trial were fully watered (100% field capacity) throughout the growing season. During the growing season, 50 kg nitrogen/ha was applied at both stem elongation and heading stages.

Data collection

Days to heading (DHE) was counted from the sowing date to the time that 50% of spikes emerged from leaf sheath. Plant height (PH) was measured (in cm) from the ground level to the tip of spike during grain filling. In each plot, ten plants were selected for spikelet per spike (SPS) count and grain number (GN) per spike. Thousand grains weight (TGW) was determined by weighing the seeds. Grain yield (GY) and biological yield (BY) as per square meter were also measured after harvesting plants from the field and their ratio was considered as harvest index (HI) using the following formula:

$$HI = \frac{GY}{BY} \times 100$$

Construction of index selection models

Selection indices were constructed using the matrix of the data for plant height (PH, cm), canopy temperature (CT, °C), spike length (SL, cm), number of fertile spikes (SN), grain number per spike (GN), number of spikelets per spike (SPS), thousand grain weight (TGW, g), biological yield (BY, g/m²), grain yield (GY, g/m²) and harvest index (HI,

%). The equation was as $I = \sum b_i p_i$, where b_i is the vector of coefficients for trait based on p_i which is the phenotypic value of each trait (Falconer and McKay 1996). The Smith-Hazel index (SHI) was constructed using an equation as below (Smith 1936; Hazel 1943)

$$b = P^{-1}Ga$$

where, P^{-1} is the inverse of phenotypic variance-covariance matrix, G is the genotypic variance-covariance matrix and a is the vector of economic weight (a was +1 for all traits except CT and PH with $a = -1$).

In Pesek-Baker (1969) index (PBI), b vector was obtained using the inverse of genotypic variance-covariance matrix (G^{-1}) and the square root of phenotypic variance (g_i) as below:

$$b = G^{-1}g$$

In Pesek-Baker index, g vector was used instead of a vector of the Smith-Hazel index, because a in Smith-Hazel is limited by relative economic value of each trait. Correlated response to selection was calculated as below formula (Falconer and McKay 1996):

$$CR_i = kh_i h_j r_{gij} \sigma_{gi}$$

where, $k = 1.75$ is the selection intensity, h is the root square of heritability estimate of traits i and j , r_{gij} is genotypic correlation between traits i and j and σ_{gi} is root square of genotypic variance. The efficiency of each index was calculated as the following formula,

$$\Delta H = \sum a_i \Delta G_i$$

where, ΔG_i is the genetic gain in the i^{th} index which was calculated as below:

$$\Delta G_i = K \frac{\sigma_{I_i}}{\sigma_I}$$

where, $\sigma_{I_i} = \sum b_i \sigma_{gij}$ is correlation coefficient between the index and trait and $\sigma_I = \sqrt{b'Pb}$ is the standard error of the index. σ_{gij} is the genotypic correlation of traits i and j . Genotypic and phenotypic variances and covariance components were calculated using the expected mean squares (EMS) of genotype and experimental error in analysis of variance (ANOVA) for traits using SAS

software V.9.2. From ANOVA, the repeatability of traits (an estimation of heritability) was estimated as follow (Falconer and Mckay 1996; Mohammadi *et al.* 2013),

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_e^2}{r}}$$

where, $\sigma_g^2 = (\text{MSg} - \text{MSe})/r$ and $\sigma_e^2 = \text{MSe}$; MSg and MSe are the mean squares for genotype and experimental error in ANOVA and r is the number of replication.

RESULTS

Coefficients of traits in Smith-Hazel and Pesek-Baker models

With respect to analysis of variance for the evaluated

traits, the genotypes were divergent which allowed selection (data not shown). Coefficients of traits in the Smith-Hazel index (SHI) model for irrigation and drought stress conditions are displayed in Table 1. PH and CT had negative coefficients in the SHI model for both growing seasons. In this model, TGW, GN and SPS had the highest coefficients. These results indicated that plant selection through aggregate traits in SHI index leads to lower plant height and canopy temperature and simultaneously higher grain yield under both drought stress and normal irrigation regimes. In Pesek-Baker index, the highest coefficient was detected for BY whilst the lowest was observed for PH (Table 1).

The magnitude of grain yield in landraces and commercial cultivars and coefficients in the Smith-Hazel index are shown in Table 2. The landrace genotypes KC2165 and KC4557 had the highest grain yield in the first year under

Table 1. The coefficients of traits in the Smith-Hazel and the Pesek-Baker indices in wheat under drought stress and normal irrigation regimes in 2011 and 2012.

Trait	Smith-Hazel index			
	Irrigation		Drought	
	2011	2012	2011	2012
Plant height (cm)	−0.88	−0.99	−0.90	−0.92
Canopy temperature (°C)	−0.46	−0.63	−0.47	0.28
Spike length (cm)	0.68	0.75	0.88	0.57
Spike number (m ²)	0.84	1.0	0.87	0.78
Grain number	0.96	0.83	0.67	0.88
Number of spikelet	0.96	0.99	0.91	0.97
Thousand-grain weight (g)	0.97	1.13	0.87	0.94
Biological yield (g/m ²)	0.85	1.0	0.73	0.86
Harvest index (%)	0.64	0.24	0.48	0.91
Grain yield (g/m ²)	0.52	0.99	0.70	0.71

Trait	Pesek-Baker index			
	Irrigation		Drought	
	2011	2012	2011	2012
Plant height (cm)	0.9	1.0	1.1	1.1
Canopy temperature (°C)	1.1	1.3	1.4	1.2
Spike length (cm)	1.3	1.9	1.0	1.6
Spike number (m ²)	2.0	1.6	1.2	0.7
Grain number	1.2	1.4	1.3	1.0
Number of spikelet	1.7	1.3	1.6	1.2
Thousands-grain weight (g)	1.8	1.5	1.3	1.6
Biological yield (g/m ²)	2.3	3.6	2.5	2.2
Harvest index (%)	1.9	1.3	1.1	1.1
Grain yield (g/m ²)	1.3	1.0	1.2	0.9

Table 2. The magnitude of grain yield and the coefficients of the Smith-Hazel model for traits in wheat genotypes under normal irrigation regime and drought stress conditions in 2011 and 2012.

Genotype	Normal Irrigation				Drought			
	Grain yield (g/m ²)		Smith-Hazel Coefficient		Grain yield (g/m ²)		Smith-Hazel Coefficient	
	2011	2012	2011	2012	2011	2012	2011	2012
KC4565	673.2	534.6	653.4	723.5	504.7	549.7	738.3	532.7
KC4568	734.0	653.4	618.5	708.8	505.3	602.9	734.8	514.9
KC4818	670.0	429.0	614.5	685.2	513.2	407.8	691.6	500.3
KC4500	646.0	455.4	594.8	673.7	446.0	546.9	689.4	499.0
KC4548	640.4	551.1	593.9	669.5	446.0	527.5	688.9	485.4
KC4864	700.2	547.8	581.8	654.4	516.0	452.2	661.4	478.1
KC4617	520.6	409.2	569.3	626.8	352.0	509.8	643.0	464.9
KC2194	677.4	524.7	558.9	626.8	501.6	359.1	636.0	424.6
KC3892	660.6	478.5	550.0	618.2	596.8	416.7	622.1	424.3
KC4847	470.0	382.8	548.4	608.6	360.0	354.6	621.8	420.3
KC4567	698.6	462.0	547.8	601.2	476.8	478.8	610.3	420.2
KC2172	723.8	577.5	540.9	578.7	480.0	545.3	596.8	414.0
KC4557	864.0	716.1	536.7	572.7	726.6	660.5	589.1	413.3
KC4495	781.4	498.3	528.1	576.9	633.8	607.3	587.9	402.2
KC3893	581.0	603.9	525.4	565.5	468.0	616.2	587.5	389.8
KC4633	814.0	686.4	517.5	562.8	714.0	718.2	579.9	386.7
KC4604	516.8	405.9	514.5	562.2	494.0	443.4	572.2	384.6
KC2177	730.8	630.3	512.7	550.7	570.4	558.6	554.0	380.0
CrossBulani	644.4	594.0	507.9	534.6	586.0	563.0	552.8	376.6
KC4619	684.0	564.3	501.2	532.8	622.2	549.2	543.9	376.2
KC4618	643.2	508.2	500.3	520.8	538.6	585.2	517.4	375.6
KC4537	790.0	636.9	495.4	508.9	716.6	681.2	506.7	365.7
KC4542	739.2	749.1	493.9	496.3	519.0	775.8	489.7	357.2
KC4862	816.0	699.6	488.8	490.4	747.0	709.3	489.3	353.8
KC4543	721.2	656.7	485.0	476.9	481.4	500.9	488.4	344.8
KC3885	629.4	646.8	482.6	467.8	535.0	594.0	472.3	344.6
KC2165	917.2	603.9	482.3	439.9	540.7	598.5	440.7	328.8
KC4929	556.6	607.2	467.8	429.0	480.0	571.9	430.9	306.9
KC4595	554.0	570.9	456.9	411.8	353.5	407.8	411.4	297.8
KC3878	460.0	303.6	453.2	394.5	386.6	319.2	407.1	280.5
KC3891	845.8	696.3	439.4	384.9	792.8	731.5	385.0	273.6
Shiraz	581.2	429.0	430.8	374.0	382.3	523.1	382.0	270.2
KC4512	686.4	597.3	416.4	373.0	513.4	607.3	369.7	236.4
KC4492	680.0	594.0	392.5	346.4	526.0	549.7	347.6	233.7
KC4551	746.0	735.9	389.1	267.9	634.0	709.2	288.3	209.6

well-irrigated regime while they had intermediate values for Smith-Hazel coefficients as compared with other genotypes in the same year. KC4565 had the highest Smith-Hazel coefficient in both years and two irrigation regimes whilst its grain yield ranked 16. Under drought stress conditions, KC3891, KC4862, KC4557, KC4633 and KC4537 had top rankings for grain yield in both years.

These genotypes were not among the top rankings for Smith-Hazel coefficients. KC4565, KC4568 and KC4818 had the highest values of the Smith-Hazel model constructed for all traits in both years under drought stress conditions. These genotypes yielded 504.7, 505.3 and 513.2 g/m² in the first and 549.7, 602.9 and 407.8 g/m² in the second year, respectively.

The coefficients of genotypes in the Pesek-Baker selection index for the two growing seasons under irrigation and drought stress conditions are presented in Table 3. Under irrigation regime in the first year, KC2165, KC4557, KC3891 and KC4633 had the highest values for Pesek-Baker selection index. Of these, the genotypes KC4557 and KC3891 ranked third and fifth in the second year. In the second year, KC4542, KC4551 and KC4862 ranked first, second and fourth on the basis of coefficients

in the Pesek-Baker model. The magnitude of grain yield for these genotypes was also relatively higher than other genotypes (Table 2). This shows that genotypes with higher GY had higher coefficients in PBI under irrigation regime. Under drought stress, KC3891, KC4862 and KC4557 had the highest values for PBI in the first year. These genotypes ranked second, fourth and sixth for this index in the second year while KC4542, KC4551 and KC4537 ranked first, third and fifth in the second year. The

Table 3. The coefficients of the Pesek-Baker model for traits in wheat genotypes under normal irrigation regime and drought stress conditions in 2011 and 2012.

Genotype	Normal Irrigation		Drought	
	2011	2012	2011	2012
KC4565	925.8	805.0	831.1	734.2
KC4568	1026.7	936.4	840.7	778.8
KC4818	925.2	701.5	853.6	603.4
KC4500	876.4	720.3	755.6	720.3
KC4548	890.2	837.4	765.2	710.1
KC4864	976.4	821.0	877.3	640.1
KC4617	703.4	681.4	644.8	693.1
KC2194	935.8	797.3	844.7	551.3
KC3892	919.0	755.0	975.0	621.7
KC4847	646.2	652.6	656.3	552.0
KC4567	978.4	736.0	825.5	677.1
KC2172	1021.3	858.4	833.8	739.5
KC4557	1205.9	997.4	1144.7	853.3
KC4495	1078.3	768.4	1017.3	790.7
KC3893	802.9	879.1	810.1	801.3
KC4633	1140.9	967.4	1126.1	901.8
KC4604	710.9	674.9	831.2	642.9
KC2177	1020.2	912.0	398.4	752.6
CrossBulani	883.0	861.2	949.1	747.2
KC4619	956.2	840.1	992.4	735.2
KC4618	890.8	773.1	895.7	766.3
KC4537	1100.4	913.8	1122.5	860.5
KC4542	1033.7	1036.4	872.2	931.8
KC4862	1138.3	985.1	1159.3	876.8
KC4543	996.8	930.7	825.6	696.0
KC3885	870.6	920.7	886.5	778.2
KC2165	1283.8	889.1	905.6	794.4
KC4929	749.5	856.2	800.4	741.1
KC4595	770.0	830.6	662.2	594.3
KC3878	634.3	559.1	695.3	514.1
KC3891	1178.4	980.5	1213.6	914.3
Shiraz	790.9	678.7	676.4	699.5
KC4512	954.9	872.7	861.7	791.9
KC4492	939.7	871.2	872.4	738.5
KC4551	1045.1	1014.7	1028.2	888.2

top ten genotypes in terms of PBI coefficients in 2011 had also relatively higher grain yield under drought stress conditions (Table 2 and 3).

Prediction of genetic gain of traits and selection efficiency of models

The predicted genetic gain (ΔG) and the efficiency of trait selection (ΔH) for both SHI and PBI are displayed in Table 4. In both years, TGW, BY, GY and GN had the highest genetic gain under both irrigation regimes in the Smith-Hazel model. In spite of the reduction in SPN genetic gain under drought stress in 2011, it can be mitigated by the increase in genetic gain for GN, SPS and TGW showing the highest values in the Smith-Hazel model. For Pesek-Baker, TGW and GY had the highest genetic gain under normal irrigation regime in both years. Under drought stress, BY, GY in 2011 and BY, HI and GY in 2012 had the highest genetic gain from selection in the Pesek-Baker model. Canopy temperature had negative genetic gain in both models with the exception of irrigation regime in 2012. This implies that selection of genotypes with lower CT which is of great value in breeding programs under drought stress conditions, is feasible in the evaluated landraces. The estimation of the efficiency of selection (ΔH) revealed that PBI was more efficient than SHI.

Repeatability and correlated response

The estimated repeatability under drought and irrigation regimes in two years is shown in Table 5. The repeatability of most traits reduced under drought condition as compared with normal irrigation conditions. Lower genetic variation is expected to result in a lower reduction in repeatability; hence, the reduction in repeatability observed could be due to complex nature of traits and the influence of genotype by drought interaction. Among traits, GN, SPS, SL and TGW had higher repeatability under drought conditions in both years whilst grain yield had relatively low repeatability (33%–57.8%). The genetic correlation (r_g) and correlated response (CR) of grain yield via indirect selection for other traits are presented in Table 6. Grain yield had the highest genetic correlation with GN and TGW in both years in normal irrigation regime. Under drought stress, GY had higher correlation with TGW, HI, BY and GN in both years. The highest correlated response for increasing grain yield was obtained by GN, TGW and SN in irrigation regime in both years. Under drought stress, TGW and HI had the highest coefficients for CR, which shows selection for these traits indirectly increases grain yield under water deficit conditions.

Table 4. Efficiency of selection (ΔH) and genetic gain from selection (ΔG) in wheat genotypes under normal irrigation regime and drought stress conditions in 2011 and 2012.

Index		$\Delta G^{(2)}$									ΔH	
		PH	CT	SL	SPN	GN	SPS	TGW	BY	HI		GY
2011	Model	Irrigation										
	Smith-Hazel	0.05	−0.06	0.19	0.51	1.51	1.10	2.65	1.66	0.87	1.63	9.58
	Pesek-Baker	0.09	−0.13	0.39	−1.06	2.12	2.27	3.39	1.35	1.78	2.75	12.95
		Drought										
	Smith-Hazel	0.22	−0.22	1.00	−0.41	1.29	1.26	1.93	1.09	1.09	1.72	8.97
	Pesek-Baker	0.69	−0.37	1.46	−0.62	1.70	2.03	1.17	2.70	1.49	2.40	12.65
	2012		Irrigation									
		Smith-Hazel	0.19	0.13	−0.08	0.58	1.21	0.93	1.35	0.92	2.46	2.06
Pesek-Baker		0.48	0.19	−0.12	1.06	1.55	1.65	2.09	1.77	1.07	2.41	11.15
		Drought										
Smith-Hazel		0.16	−0.53	−0.27	0.33	1.29	1.34	1.05	0.94	2.24	2.06	8.59
Pesek-Baker		0.32	−0.75	−0.37	0.54	1.52	1.46	1.33	2.77	2.45	1.79	11.06

²⁾PH: plant height, CT: canopy temperature, SL: spike length, SPN: spike number, GN: grain number, SPS: spikelet/spike, TGW: thousand-grain weight, BY: biological yield, HI: harvest index, GY: grain yield.

Table 5. The repeatability ($h^2\%$) of agronomic traits in wheat genotypes under irrigation and drought stress conditions in two growing season.

Trait	2011		2012	
	h^2 (Irrigation)	h^2 (Drought)	h^2 (Irrigation)	h^2 (Drought)
Plant height (cm)	38.7	27.0	53.7	52.7
Spike length (cm)	53.8	58.3	76.3	69.2
Days to heading (day)	64.6	56.5	75.5	45.02
Spike number	24.1	16.3	40.8	53.5
Grain number/spike	78.4	73.0	89.2	53.5
Spikelet number/spike	72.1	62.6	88.0	66.2
Thousand grain weight (g)	84.8	52.2	83.3	84.2
Biological yield (g/m ²)	38.5	31.6	44.0	56.0
Grain yield (g/m ²)	34.5	33.0	44.8	57.8
Harvest index (%)	54.0	54.8	43.5	45.6

Table 6. Genotypic correlation (r_g) and correlated response (CR) of grain yield via indirect selection in wheat under drought stress and irrigated conditions in 2011 and 2012.

Trait	Irrigation				Drought			
	r_g		CR		r_g		CR	
	2011	2012	2011	2012	2011	2012	2011	2012
Spike length (cm)	0.11	-0.17	1.73	-1.11	0.51	-0.10	8.57	-1.47
Spike number	-0.27	0.61	-6.05	5.52	-0.21	0.36	-3.52	10.5
Grain number/spike	0.98	0.69	23.80	9.82	0.76	0.43	15.80	4.84
Spikelet number/spike	0.64	0.35	11.07	9.95	0.64	0.45	13.02	5.05
Thousand grain weight (g)	0.97	0.59	20.95	7.91	1.00	0.50	24.05	9.15
Biological yield (g/m ²)	0.34	0.24	5.54	2.93	0.85	0.63	13.18	10.32
Harvest index (%)	0.52	0.22	8.80	3.6	0.85	0.63	18.37	9.08
Days to heading (day)	0.91	0.27	6.09	4.22	0.53	0.21	3.61	1.14

DISCUSSION

The results indicated that the Pesek-Baker model was more efficient than the Smith-Hazel model in both years and two irrigation regimes in terms of plant selection based on aggregate traits and predicted genetic gain. In both years, TGW, BY, GY and GN had the highest genetic gain under both irrigation regimes in the Smith-Hazel model. Under drought stress, BY, GY in 2011 and BY, HI and GY in 2012 had the highest genetic gain from selection in the Pesek-Baker model. Overall, coefficients for both indices indicated that index-based selection results in grain yield increase and decrease in plant height and canopy temperature. In wheat, canopy temperature (CT) is associated with components of grain yield (GY) and can be routinely measured (Reynolds and Langridge 2016). Canopy

temperature is an indicator of evaporative cooling from the canopy surface. Cooler CT is associated with greater stomatal conductance and increased gas exchange rate under irrigated conditions and better hydration status under drought (Pinto *et al.* 2010). Blum *et al.* (1989) and Blum (2014) found a positive correlation between drought susceptibility and canopy temperature in stressed environments and genotypes with higher yield losses under drought had warmer canopies. In a study on rice, Ahmadikhah and Marufinia (2016) revealed that in severe water deficit, the rice mutant line MT85 (a rice mutant line which was 18 cm shorter than its wild type cv Neda) showed lower loss (19%) in yield as compared to Neda (31%) with high yield loss. The problem of selection for drought tolerance is how to select the best individuals or how to rank them with respect to some related traits (Ajala 2010; Mohammadi *et*

al. 2013). It can be concluded that selection via an index which gives proper weight to each trait is more efficient than selection for individual traits at a time or for several traits with an independent culling level for each trait (Hazel 1943; Mohammadi *et al.* 2013). In addition, simultaneous selection for multiple traits in wheat genotypes increases the success of drought breeding programs (Cargnin *et al.* 2007). In the present study, the results showed due to the interrelationship between traits, genotypes with higher grain yield may not necessarily be among the top rankings based on the Smith-Hazel model. A practical selection method allows time and cost savings and favors the identification of the best genotypes which is a fundamental step towards development of new cultivars for specific targets such as drought tolerance (Kurek *et al.* 2001).

In the present study, the consistency between the magnitude of genotypes' coefficient in PBI and grain yield was more evident than those in SHI. In a study on S1 families of sweet corn, Entringer *et al.* (2016) found higher coincidence between Pesek-Baker (1969) and restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) indices (0.75) compared with Smith-Hazel and REML/BLUP (0.70) in terms of 20 superior progenies selected when six traits were simultaneously were selected. The results obtained by Costa *et al.* (2008) indicated that the use of the Smith-Hazel and Pesek-Baker indices was advantageous over direct selection for grain yield in soybean, since the gains were distributed among all traits and classical index of Smith-Hazel had a slight advantage over Pesek-Baker.

The relative efficiency of index selection depends upon the estimate of heritability and genetic and phenotypic correlations between traits (Lin 1978). Estimated repeatability indicated that grain yield had low heritability compared to other traits i.e. grain number and thousands grain weight. Repeatability for grain yield (33%-57.8%) was relatively low showing that individual plant selection has low efficiency for wheat improvement whilst construction of an index comprising aggregate traits such as thousands grain weight and grain number led to relatively high genetic gain (1.63-2.75) for grain yield.

REFERENCES

- Ahmadikhah A, Marufinia A. 2016. Effect of reduced plant height on drought tolerance in rice. 3 Biotech. 6: 221.
- Ajala SO. 2010. Expected responses to aggregate trait selection in maize (*Zea mays* L.). J. Food Agr. Env. 8: 185-189.
- Araus JL. 2003. Breeding cereals for mediterranean conditions: ecophysiological clues for biotechnology applications. Ann. Appl. Biol. 142: 129-141.
- Asghar MJ, Mehdi SS. 2010. Selection indices for yield and quality traits in sweet corns. Pak. J. Bot. 42: 775-789.
- Bertoldo JG, Barili LD, de Vale NM, Coimbra JLM, Stahelin D, Guidolin AF. 2010. Genetic gain in agronomic traits of common bean in the region of *Planalto Catarinense*. Euphytica. 171: 381-388.
- Blows MW, Brooks R. 2003. Measuring nonlinear selection. Am. Nat. 162: 815-820.
- Blum A, Shipiler L, Golan G, Mayer J. 1989. Yield stability and canopy temperature of wheat genotypes under drought stress. Field Crop. Res. 22: 289-296.
- Blum A. 2014. The abiotic stress response and adaptation of triticale-a review. Cereal Res. Comm. 42: 359-375.
- Cargnin A, de Souza MA, Machado CG, Pimentel AJB. 2007. Genetic gain prediction for wheat with different selection criteria. Crop Breed. Appl. Biot. 7: 334-339.
- Costa MM, Di Mauro AO, Uneda-Trevisoli SH, Arriel NHC, Barbo IM, da Silveira GD *et al.* 2008. Analysis of direct and indirect selection and indices in soybean segregating population. Crop Breed. Appl. Biot. 8: 47-55.
- Cotterill PP. 1985. On index selection: II. Simple indices which require no genetic parameters of special expertise to construct. Silvae Genet. 34: 2-3.
- Cruz CD, Vencovsky, R, Silva So, Tosello GA. 1993. Comparison of gains from selection among progenies, based on different criteria. Rev. Bras. Genet. 16: 79-89.
- Entringer GC, Vettorazzi JCF, Santos A, Pereira MG, Viana AP. 2016. Genetic gain estimates and selection of S1 progenies based on selection indices and REML/BLUP in super sweet corn. Aust. J. Crop Sci. 10: 411-417.
- Falconer DS, Mackay TFC. 1996. Introduction to Quantitative Genetics, Ed 4. Longmans Green, Harlow, Essex, UK.
- Fjoj R, Heidari B, Dadkhodaie A. 2016. Investigation of triticale and wheat performance under dry land

- conditions on the basis of variations in agronomic and morphological traits. *J. Adv. Biol. Biot.* 4: 1-9.
- Hazel LN, Lush JL. 1942. The efficiency of three methods of selection. *J. Hered.* 33: 393-399.
- Hazel LN. 1943. The genetic basis for constructing selection indexes. *Genetics*. 28: 476-490.
- Jafarzadeh-Ghahdarijani M, Majidi M, Mirlohi A, Ebrahimi M. 2014. Response of direct and indirect selection of grain yield, oil and yield components in canola varieties under normal and soil moisture stress. *The Plant Prod. (Scient. J. Agric.)* 37: 129-141.
- Kurek AJ, Carvalho FIF, Assmann IC, Marchioro VS, Cruz PJ. 2001. Path analysis as an indirect selection criterion for bean grain yield. *Rev. Bras. Agron.* 7: 29-32.
- Lin CY. 1978. Index selection for genetic improvement of quantitative characters. *Theor. Appl. Genet.* 52: 49-56.
- McGuigan K. 2006. Studying phenotypic and evolution using multivariate quantitative genetics. *Mol. Ecol.* 15: 883-896.
- Mohammadi M, Karimzadeh R, Youseiazar M. 2013. Investigation of selection efficiency in safflower (*Carthamus tinctorius* L.) genotypes. *Nat. Mont. Pod.* 12: 165-180.
- Olivares-Villegas JJ, Reynolds MP, McDonald GK. 2007. Drought adaptive attributes in the Seri/Babaxhexaploid wheat population. *Funct. Plant Biol.* 34: 189-203.
- Pesek J, Baker RJ. 1969. Desired improvement in relation to selection indices. *Can. J. Plant Sci.* 49: 803-804.
- Piepho HP, Mohring J, Melchinger AE, Buchse A. 2008. BLUP for phenotypic selection in plant breeding and variety testing. *Euphytica*. 161: 209-228.
- Pinto RS, Reynolds MP, Mathews KL, McIntyre CL, Olivares-Villegas JJ, Chapman SC. 2010. Heat and drought adaptive QTL in a wheat population designed to minimize confounding agronomic effects. *Theor. Appl. Genet.* 121: 1001-1021.
- Reynolds MP, Trethowan RM. 2007. Physiological interventions in breeding for adaptation to abiotic stress, p. 129-146. In: JHJ. Spiertz, PC. Struik, HH. Van Laar (eds). *Scale and Complexity in Plant Systems Research: Gene-Plant-Crop Relations*. Wageningen UR Frontis Series, Springer.
- Reynolds M, P. Langridge. 2016. Physiological breeding. *Curr. Opin. Plant Biol.* 31: 162-171.
- Salehi M, Saeidi GA. 2013. Selection indices for seed yield improvement in sesame (*Sesamum indicum* L.). *Iranian J. Field Crops Res.* 10: 667-673.
- Smith HF. 1936. A discriminant function of plant selection. *Ann. Eugen.* 7: 240-250.
- Tahmasebi S, Heidari B, Pakniyat H, Jalal Kamali MR. 2014. Independent and combined effects of heat and drought stress in the SeriM82 × Babax bread wheat population. *Plant Breed.* 133: 701-711.
- Williams JS. 1962. The evaluation of a selection index. *Biometrics*. 18: 375-393.
- Young SSY. 1961. A further examination of the relative efficiency of three methods of selection for genetic gains under less restricted conditions. *Genet. Res. Camb.* 2: 106.
- Zhang W, Xu H, Zhu J. 2009. Index selection on seed traits under direct, cytoplasmic and maternal effects in multiple environments. *J. Genet. Genomics*. 36: 41-49.