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Analysis of Yield Stability of Wheat Genotypes Using New Crop Properties Balance Index (CPBI) Method

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Abstract

The study aims at approaching some important crop characteristics in a population and the consideration of the limitations and possibilities is a general way to define suitable genotypes. Data collected over six years in the cold winter experiment stations of Iran were used to determine to optimal levels of characteristics and the stability parameters of wheat varieties under rainfed conditions. The boundary lines method allowed the determination of optimal levels of days to heading, days to physiological maturity, duration of grain filling, plant height and thousand kernel weight, which were 221.2 days, 259.6 days, 33.8 days, 62.5 centimeter and 28.3 grams, respectively. These data were closely equivalent to optimal levels determined using the averaging method. The results showed also that the released cultivars in each location had similar maximum crop properties balance index (CPBI). The maximum CPBIs in Maragheh, Kurdestan, Zanjan, Ardabil and Uromeh regions were 155, 270, 150, 182 and 440, respectively. The analysis of adaptation of commonly grown winter wheat varieties showed that 'Sardari' is more suitable for regions with cold winters and cool springs along with spring precipitation; 'Sabalan' variety is adapted to cold winters and relatively temperate spring with abundant spring precipitation; and 'Azar-2' cultivar is suitable for cold falls and temperate springs along with fall-spring precipitation and minimum winter precipitation.

Keywords: crop properties balance index, stability, wheat breeding, dryland

Introduction

The aim of any breeding program working for changing and rainfed environments is to develop varieties with high and stable yields. Breeders take advantage of the selection for several traits to achieve maximum economic yield (Koucheki *et al,* 1987; Rezaei, 1996). The selection of genotypes based on indices using yield components was used by breeders for a long time (Jensen, 1988). Smith, (1936) believed that obtaining a linear function for measurable traits could lead the selection of genotypes with better genetic values, but a need to include economic value in this function is expressed by many researchers. Simultaneous selection using characteristics with important and heritable economic values is a more effective method (Falconer, 1983; Baker, 1986; Borojevic, 1990). Crop yield is a function of multiple inter-related variables and this function can not be defined only by a single-variable equation. A scattered diagram is obtained when crop yield is plotted against one factor while considering other variables. In this case, maximum yield related to the factor will be located at the upper border of the scattered diagram (Sajjadi, 1992). By changing the growing crop properties such as the environmental conditions of the experiments, the limiting factors reach their minimum levels in contributing to maximum yield (Sumner, 1987; Walworth *et al*., 1986). Part of the population is used to determine the optimum boundary of a given trait. One of the methods for the determination of the optimum level of a trait is called "Boundary Line" which was explained by Webb (1972). Boundary lines define suitable efficiency of genotypes based on causes and effect of variables. In another way, boundary lines express the maximum restriction that each plant's trait has on yield production (Sumner, 1978; Walworth *et al*., 1986). In this paper, the "Boundary Line" method and crop properties balance index (CPBI) are used to determine optimum levels for some traits of dryland wheat as well as of their unit index in cold areas.

Materials and methods

More than 7000 data for each trait were collected from national and international trials conducted under rainfed conditions in Ardabil, Maragheh, Sanandaj, Zanjan, and Urumieh DARI experiment stations over six growing seasons (1995-2000). This information was extracted from the Iran-ICARDA annual reports prepared by the cereal group (Mahfouzi *et al*., 2000; Amiri *et al*., 1995; Amiri *et al*., 1996; Amiri *et al*., 1997; Roustaei *et al*., 1998; Roustaei *et al*., 1999) of the Dryland Agricultural Research Institute (DARI). The traits considered in the analysis are: days to heading, days to physiological maturity, grain filling period, plant height, thousand kernel weight and grain yield. The Grapher software was used to develop a scatter diagram showing the relationship between each trait with grain yield at every location except for Ardabil because of insufficient data.

Determination of "boundary lines"

The "Boundary Lines" method was used to determine the maximum limits of each crop characteristic. The scatter diagram is surrounded by two regression lines, one on the left and the other on the right called boundary lines. Maximum yield is obtained at the intersection of both boundary lines. To determine the equations for the boundary lines of each crop characteristic, all data of that characteristic along with the corresponding grain yield were sorted using Excel software, then they were considered in groups of 20 pairs as recommended by Webb (1972). For each group and starting from the lowest value of the trait considered, the value corresponding to maximum grain yield is chosen. Only pairs with increasing trend in grain yield are kept in the new database till the highest grain yield is achieved. Similarly, the data were analyzed from the maximum value of the trait until optimum yield is achieved. The outliers were discarded. These data allowed for the development of boundary lines equations using the Curve expert while the Grapher software was used to draw the two boundary lines.

Determination of optimum values for a given trait

Two methods were used to determine the optimum value for a given characteristic. First, it is based on the boundary lines method where the maximum grain yield and the optimum value for the trait considered coincide with the crossing point of the two boundary lines. The cross point was determined by means of the Qbasic software. The second approach, called averaging method, is based on subdividing the data into two groups: high and low yielding groups. The high yielding group must have a normal distribution and represents 40% of the total data as recommended by Walworth *et al* (1986). If the high yielding group does not have a normal distribution, then we choose a lower percent of high yielding group which satisfies the normality statistical condition defined by the Skewness and Kurtosis tests using MSTATC software.

Using the first method, the optimum range for a given trait can be determined by values corresponding to the intersection of optimum yield for the region with the boundary lines. For example, for a region with optimum grain yield is 3 t ha^{-1} as in cold dryland areas of Iran, a direct line from Y-axis (from 3 t ha^{-1} yield) crosses the two boundary lines in two points with the X-values correspond to the limits of the range of the optimum values for the trait (Sumner, 1977; Walworth *et al.,* 1986).

For the second method, the optimum range for the trait considered is determined as values corresponding to the upper and low limits of the average grain yield using standard deviation (Sumner, 1977; Sajjadi, 1992). The mean of each characteristic in normal high-yielding group was considered as an optimum level which by increasing the number of high-yielding group this amount will tend to the mean of the whole dataset (Letzsch and Sumner, 1984; Walworth and Sumner, 1987).

Crop properties balance index

The crop properties balance index (CPBI) is calculated on the basis of available data using the following calibration formula proposed by Beuafils (1973).

$$I_i = \left(\frac{X_i}{x_i} - 1\right)\frac{1000}{C.V.}$$

where, I_i is the index of ith characteristic, X_i is the value of ith characteristic in the database; x_i is the optimal level of the ith characteristic as obtained from the boundary lines method; and C.V. is the coefficient of variation of the high yielding group determined by the averaging method. Number of 1000 is a multiply of 10 by 100 (10 x 100) which 100 is a denominator of C.V. and 10 is used for the simplification of the calculations (Walworth and Sumner, 1987).

Then and in order to establish the relationship between crop characteristic indices and grain yield, the sum of the absolute values of the above mentioned indices is calculated and defined as crop properties balance index (CPBI) i.e.:

$$CPBI = \sum_{i=1}^{n} |I_i|$$

This index is used to characterize the stability of genotypes using all available characteristics as well as grain yield. This parameter can also be used to test the suitability of introduced varieties in a given area.

Grain yield is plotted against CPBI and the boundary line equation is determined using a Curve expert software. The high yielding genotypes have low values of CPBI. For a variety to be suitable, it should comply with the following conditions:

-it should have lower CPBI over years based and a grain yield higher than the optimum defined for each region.

-it should low curve slope of CPBI with grain yield to express stable yield in the target area.

-curve of CPBI with grain yield of suitable varieties should be closer to the boundary line of the CPBI and grain yield of all data.

This paper presents several methods which can help breeders to define the characteristics for suitable and stable genotypes of a given environment.

Results and discussion

Determination of the optimal levels of agronomic wheat characteristics

Scatter diagrams between grain yield and each of the characteristics, days to heading, days to maturity, grain filling duration, thousand kernel weight and plant height and the corresponding boundary lines and their equations are presented in Fig. 1 (A to F). The distribution trend of scatter diagrams shows that there are minimum yield levels for the lowest and highest values of each characteristic because of the bell shape of the distribution of most agronomic characteristics. Also the scatter diagram clearly indicates that the more the grain yield is approaching the optimum, the narrower the range of the values of the characteristic. Lower yields are given by varieties with highly diverse values of the characteristic considered However, the cross point of boundary lines in each figure does not indicate the genetic potential of the evaluated varieties but it shows the limitation of data used (Webb, 1972; Walworth *et al*., 1986; Sumner, 1990). The cross point in Fig. 1 showed that the optimum levels for days to heading, days to maturity, grain filling period, thousand kernel weight and plant height of wheat are 221.2 days, 259.6 days, 33.8 days, 28.3 grams and 62.5 cm respectively grown in rainfed cold winter areas of Iran.

This study showed that similar optimum levels and ranges of crop characteristics are obtained using boundary lines and averaging methods (Tab. 1). These methods could help breeders to determine the optimum and range for characteristics determining the adaptation of genotypes to a given environment. In fact, the phenology of a given crop is the most important agronomic trait to be first considered in the selection of varieties adapted to dryland and rainfed conditions. Similar analyses can be performed to determine the optimum yield components for these environments. The results show that the adapted genotypes have a long vegetative growth period and a short grain filling period.

Determination of the relationship between CPBI and grain yield

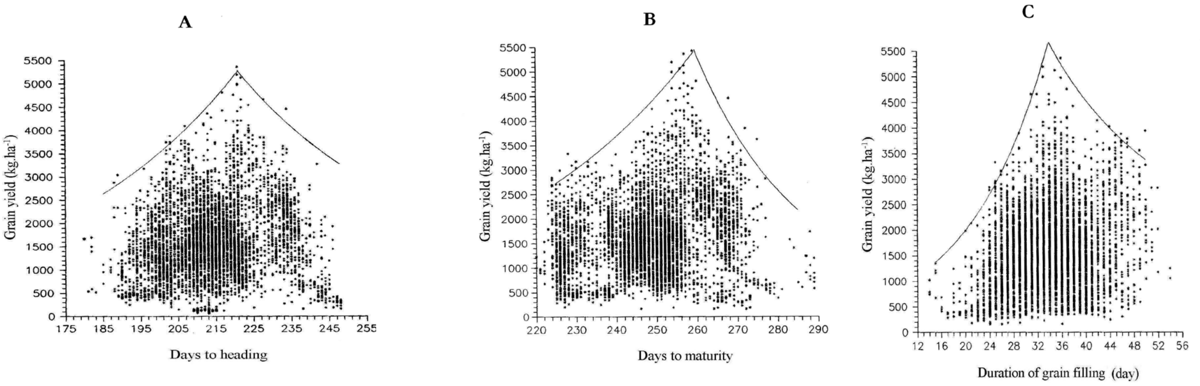
In order to use all measured crop characteristics and provide some useful recommendations, all characteristic indices were calculated by means of the calibration formula and then the relationship is drawn between absolute sum of indices and the grain yield (Fig. 2). This relation showed that by increasing CPBI, grain yield reduces rapidly and vice versa. In order to give recommendations about varieties, we can choose the expected grain yield of rainfed wheat using data set available for the region and calculate maximum CPBI for promising varieties using the boundary line equation (Fig. 2). For example if we want to choose varieties with at least 2000 kg ha^{-1}, their CPBI should not be more than 254 and by increasing grain yield to 2500 kg ha^{-1}, CPBI reduces to 161.

Comparison of adaptability of introduced varieties using CPBI

Different varieties and lines can be compared by calculating their CPBI in all regions or sub-regions where data are available and their introduction could be done in more suitable conditions. For example, 'Sardari', 'Sabalan' and 'Azar-2' are three current varieties adapted to the rainfed cold regions of Iran. The CPBIs of these varieties calculated in the Maragheh experiment station showed that the landrace 'Sardari' has special advantages compared to the two other varieties, because by increasing the CPBI or growth restriction factors its grain yield does not show more variations. 'Sardari' has a vast adaptability to the rainfed cold areas of Iran and gives high yields. It is one of the checked varieties used in national and international breeding programs for moderate and cold winter areas. Different studies concluded that 'Sardari' has some effective characteristics explaining its adaptability to cold conditions like narrow leaf blade, light color leaves which cause to reduce effect of sun radiation and transpiration, relative early maturity, complete the pollination and grain filling stages before drought and heat stress (Roustaei *et al.*, 1998; Sadeghzadeh, 2001). 'Sardari' is a multi-line which shows good buffering ability reflected in its yield stability (Ketata *et al*., 1998). For this reason, this landrace is still widely used by farmers. Additionally, the CPBI equation of 'Sardari', compared to other varieties, is closer to the boundary line (Fig. 3). The grain yield of 'Sabalan', when increasing its CPBI, was lower than that of 'Sardari' but this variety was specifically adapted to Maragheh. The grain yield of 'Azar-2' was drastically reduced when increasing its CPBI. The yield decreases of 'Azar-2' and 'Sabalan' compared to 'Sardari' were 69% and 15% respectively. Under good growing conditions (Lower CBPI), 'Azar-2' is outyielding the two varieties (Fig. 3). But the question remains on

Tab. 1. Optimal levels of wheat agronomic characteristics using averaging and boundary lines methods

	Averaging method				Boundary line method		Optimal difference of two methods
Trait	Optimal level	SD	CV %	Optimal levels	Optimal level	Optimal levels	
Days to heading	218.5	6.26	2.87	212.2-224.7	221.2	212.2-224-8	2.7
Days to maturity	257.2	3.17	1.23	254.0-260.4	259.4	253.5-260.0	2.2
Duration of grain filling (days)	36.9	5.61	15.2	31.3-42.5	33.8	32.9-44.5	3.1
1000-kernel weight (gr)	29.8	6.14	20.60	23.7-35.9	28.3	25.3-37.3	1.5
Plant height (cm)	65.3	11.85	18.15	53.4-77.1	62.8	54.2-79.8	2.5



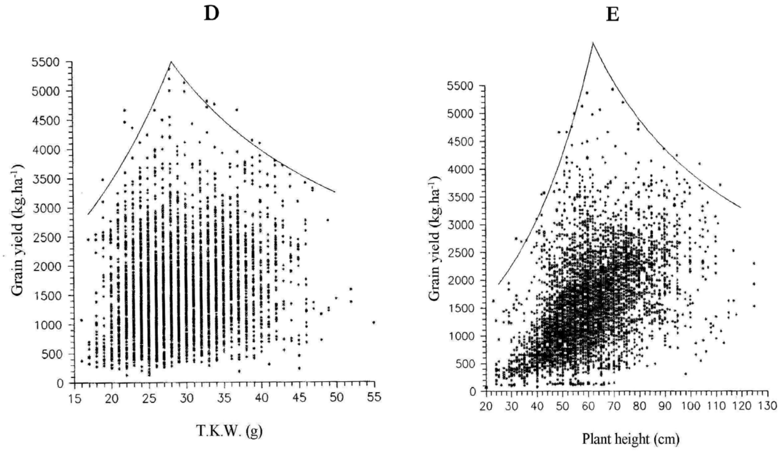


Diagram	Side	Equation	R^2
A	Left	$Y=749915 \times \exp(0.0192321X)$	0.98**
	Right	$Y=2.9799 \times 10^{13} X^{(-4.15904)}$	0.96**
B	Left	$Y=31.2921 \times \exp(0.0198687X)$	0.80*
	Right	$Y=2.19606 \times 10^{27} \times X^{(-9.7777)}$	0.94**
C	Left	$Y=445.339 \times \exp(0.0750223X)$	0.98**
	Right	$Y=64.3620 \times X^{(-1.34189)}$	0.91**
D	Left	$Y=878.881 \times \exp(0.0314205X)$	0.84*
	Right	$Y=360133 \times X^{(-0.980055)}$	0.95**
E	Left	$Y=1096.76 \times \exp(0.0569511X)$	0.90**
	Right	$Y=119681 \times X^{(-0.921811)}$	0.99**

Fig. 1. Scatter diagrams of grain yield and agronomic characteristics of wheat grown under rainfed conditions in cold winter areas of Iran

Tab. 2. Maximum and Minimum CPBI for 'Sardari', 'Sabalan' and 'Azar-2' in some cold winter areas in Iran

Locations	'Sardari'		'Sabalan'		'Azar-2'	
	Max.	Min.	Max.	Min.	Max.	Min.
Maragheh	156	43	152	38	156	57
Sanandaj	277	53	266	43	272	44
Zanjan	151	40	158	24	143	20
Ardabil	177	136	188	120	181	151
Uromia	450	160	444	153	430	157

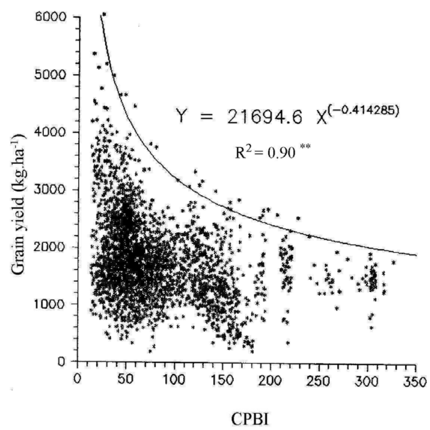


Fig. 2. Scatter diagram of rainfed wheat grain yield against crop properties balance index (CPBI)

what are the desirable growing conditions for each variety. This could be determined using the relationship between the CPBI of a given variety and the climatic or growing conditions in each region. The tree varieties showed almost similar characteristics in Zanjan and Maragheh (Fig. 3). But in Sannandaj, grain yield of 'Azar-2', by increasing CPBI, is nearly stable and is lower than that of 'Sardari' and 'Sabalan' (Fig. 3). Roustaei *et al.* (2002) studied the yield stability of different bread wheat varieties using Lin and Bins (1991) method in cold stations and concluded that 'Sardari' and 'Azar-2' are more stable than 'Sabalan' (unpublished report). The stability analysis of introduced varieties in the rainfed cold winter areas allowed for the definition of maximum CPBI for each region. The average CPBIs in Maragheh, Sannandaj, Zanjan, Ardabil and Uroumieh were 155, 270, 150, 182 and 440 respectively (Tab. 2). Different yield stability analysis methods like those of Finley and Wilkinson (1963), Eberhart and Russell (1966) and Hanson (1970) do not allow for the selection of varieties with good performance in poor and good growing conditions. Grain yield stability can be estimated using the relationship between grain yield and CPBI in different environments. According to this method yield stability is studied by considering all crop characteristics and the boundary line of yield on CPBI curve. A variety showing a lower slope of the CPBI line, has a high yield

Tab. 3. Correlation coefficient between climatic factors and CPBI in 'Sardari', 'Sabalan' and 'Azar-2' in Maragheh

cultivar	Tot. R. (mm)	Aut. R. (mm)	Win. R. (mm)	Spr. R. (mm)	Av. T. (°C)	Av. aut. T. (°C)	Av. win. T. (°C)	Av. spr. T. (°C)	Av. T min. (°C)	Av. aut. T min. (°C)	Av. win. T min. (°C)	Av. spr. T min. (°C)	Av. T max. (°C)	Av. win. T max. (°C)	Av. spr. T max. (°C)	Av. aut. T max. (°C)
'Sardari'	-0.56**	-0.13 ns	-0.22*	-0.83**	0.83**	0.62**	0.65**	0.64**	0.59**	0.67**	0.62**	-0.01 ns	0.60**	-0.23*	0.39**	0.39**
'Sabalan'	-0.67**	-0.28**	-0.13 ns	-0.94**	0.73**	0.89**	0.47**	0.29**	0.23*	0.86**	0.86**	-0.46**	0.44**	0.15 ns	0.25**	0.05 ns
'Azar-2'	-0.37**	-0.41**	0.25**	-0.71**	0.64**	0.88**	0.29**	0.30**	0.17 ns	0.62**	0.62**	-0.64**	0.39**	0.18 ns	0.12 ns	0.18 ns

cultivar	R.H. (%)	Spr. R.H. (%)	Av. E. (mm)	Av. Spr. E. (mm)	No. F.D. (day)	No. Spr. F.D. (day)
'Sardari'	-0.60**	-0.69**	0.46**	0.59**	-0.96**	-0.46**
'Sabalan'	-0.50**	-0.62**	0.52**	0.22*	-0.72**	0.06 ns
'Azar-2'	-0.28**	-0.37**	0.54**	0.18 ns	-0.68**	0.14 ns

aut.=autumn, Av.=average, E.=evaporation, F.D.=frost days, R.=rainfall, R.H.=relative humidity, spr.=spring, T.=temperature, Tot.=total, win.=winter

stability. Also according to this method, the location effect is omitted from the environmental variation and the stability of the varieties is studied in different locations separately (Fig. 3). Although it can be used in a vast region, it is not recommended to use this method since the location is a part of macro environmental variations, and it is not necessary to study variety variations in different locations. In another way, location can be considered as a fixed factor and the year as a random factor because it is not predictable. This subject had been considered by Lin and Binns's (1991) method.

Finding growth limitations of varieties

The relationship between regions climatic information and CPBI can be used to find growth limiting factors or the suitable growing conditions for introduced or promising varieties. The correlations between CBPI of 'Sardari', 'Sabalan' and 'Azar-2' and the precipitation, mean of absolute minimum temperature, mean of absolute maximum temperature, average relative humidity, number of days of frost and the evaporation were studied in Maragheh (Tab. 3). The results showed that 'Sardari' needs cold winters (r=0.65**), cold springs (r=0.64**), less number of frost days (r=-0.96**) along with spring rains (r=-0.83**) and less spring evaporation (r=0.59**) to produce optimum yield. Whereas 'Sabalan' performs better under cold winters (r=0.86**), cold autumns (r=0.86**) and relatively moderate cold springs (r=0.29**) with a rainfall of more than 120 mm. 'Azar-2' likes cold autumns (r=0.88**), moderate cold spring (r=-0.64**), good rains in autumn and spring (r=-0.41** and r=-0.71** respectively) and minimum winter precipitation (r=0.25**). The employed CPBI method to find the weaknesses and strengths of these varieties will increase by increasing the number of crop characteristics investigated. This method can be used in crop breeding programs to define ideotype characteris-

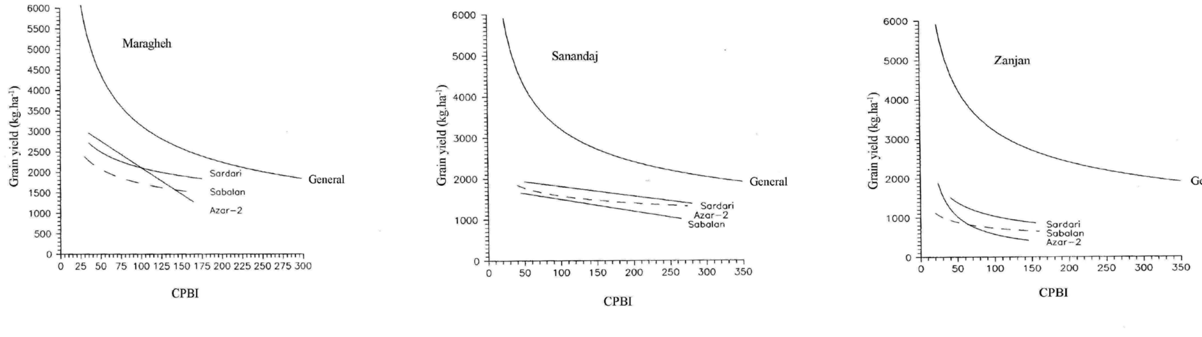


Fig. 3. Relationship between CPBI and grain yield of 'Sardari', 'Sabalan' and 'Azar-2' cultivars in Maragheh, Sanandaj and Zanjan experiment stations

tics for each environment, mainly the optimum levels for phenological traits and plant height. CPBI method can also be introduced as a complementary method to analyze the yield stability of new varieties.

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