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Full Length Research Paper

Genetic improvement of agronomic and quality traits of wheat cultivars introduced to temperate regions of Iran during 1942 - 2007

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Wheat is an important food crop to mankind. In order to assess the effects of plant breeding on yield and other characteristics of wheat cultivars released by Iran Seed and Plant Improvement Institute during the period of 1942 to 2007, 21 spring wheat cultivars recommended for temperate regions were evaluated for two successive years for yield, agronomic traits and quality attributes . Results showed that plant breeding has increased the grain yield through the decrease of plant height and the increase of harvest index. Number of grains per spike was higher in modern varieties than older ones. Contrary to grain yield and its components, protein content and majority of other quality parameters either did not change or decreased significantly during the same period. Evidence supported the hypothesis that breeding efforts have led to reduction in baking quality of Iranian wheat cultivars. Cluster analysis divided the cultivars into three main groups of old, medium and modern varieties. Factor analysis showed that quality parameters and phenological traits, while not following time-trends, accounted for most of the variations among the cultivars.

Key words: Wheat, breeding, genetic gain, grain quality, Iran.

INTRODUCTION

Wheat (*Triticum aestivum* L.), as the most important food crop worldwide, has experienced significant improvements in its yield, quality and architecture during the last few decades, following the Green Revolution. Improving yield, industrial quality, resistance to lodging, resistance to diseases and pests, tolerance to drought, heat, cold, salinity and acidity, tolerance to soil micronutrient imbalances, photoperiod sensitivity, change of grain color, resistance to pre-harvest sprouting, nitrogen use efficiency and rapid grain filling are examples of achievements in wheat breeding (Feil, 1992; Slafer and Peltonen-Sainio, 2001; Heisey et al., 2002; Soufizadeh et al., 2006). Also, changes have been made in the architecture towards a plant with robust stem, long head, multiple spikelets and florets, large leaf area, and broad leaves, by the final aim of increasing seed set abilities through higher harvest index (Rajaram and Borlaug, 1997). The increase of world's wheat production is attributed to the enlargement of harvested area, optimization of crop management and development of high yielding varieties (Feil, 1992).

Wheat breeding has started its impact on yield and yield potential by the introduction of semi dwarf wheat varieties at the beginning of the Green Revolution. Since then, wheat yield potential has continuously increased (Evans and Fischer, 1999; Hafner, 2003; Ewert et al., 2005). However, cautions have been made regarding possible wheat yield leveling-off in recent years (Slafer and Peltoen-Sainio, 2001).

In experiments which aim to assess the impact of wheat breeding on wheat yield, attempts are often made to supply nutrients and water at non-limiting levels, and sometimes, to control the effects of foliar diseases and lodging. However, these treatments may bias the results. For example, supporting genotypes against diseases and

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Table 1. Varieties released for temperate regions by the Wheat Breeding Department, SPII in Iran during 1942 and 2007 period.

Cultivar	Year of release	Cultivar	Year of release
Shapasnd	1942	Alvand	1995
Tabasi	1951	Mahdavi	1995
Roshan	1958	Kavir	1997
Deihim	1968	Chamran	1997
Karaj1	1973	Zagros	1997
Karaj2	1973	Marvdast	1999
Azadi	1979	Shiraz	2002
Ghods	1989	Pishtaz	2002
Navid	1990	Bahar	2007
Falat	1990	M796	2007
Backrshn	1992		

lodging discards the improvements for these traits and therefore will underestimate the genetic component of grain yield progress (Feil, 1992). Generally, methods applied to estimate progress can be classified into direct and indirect methods (Krzymuski et al., 1997; Brancourt - Hulmel et al., 2003). In indirect methods, the results obtained from experimental stations, official statistical data etc. are used. Direct methods need field experi-ments to be run for several years and in a number of locations. Then, the coefficients of regression of the variety mean yields (or other components of yield) on the years of their release are used to estimate annual genetic progress (Hesselbach, 1985; Cox et al., 1988). Usually, the regression is linear and gains are expressed as the increase in kilograms per hectare per year. However, yield gains by themselves are imperfect measures of research performance, as yield data may not reflect differences in market classes and value (Heisey et al., 2002). Besides, selection for grain yield would have modified certain morphological and physiological traits which are linked to yielding ability. Corporation of such traits which show directional trends among old and modern varieties might accelerate breeding progress (Feil, 1992). Many studies have shown the importance of wheat breeding in increasing yield, its quality and plant architecture (Feyerherm et al., 1984; Byerlee and Moya, 1993; Van Lill and Purchase, 1995; McCaig and DePauw, 1995). Lantican et al. (2001) reported that the annual increase in grain yield of irrigated wheat during 1964 and 1995 ranged between 1.22 and 1.72%, while from 1979 to 1995, in less favorable environments, percentage yield grains increased annually between 2.53 and 2.75%.

Grain protein content is the most important quality crite-rion in wheat (Feil, 1997); however, there is still doubt about correlations between grain protein content and baking quality (Wrigley et al., 1994; Stone and Savin, 1999; Acuna et al., 2005; Soufizadeh et al., 2006). Generally, modern cultivars present less protein content than their predecessors, suggesting that breeding may have reduced baking quality while improving yield. While it is tempting to attribute this reduction in protein content to a large increase in grain biomass together with a usually negligible increase in nitrogen accumulation (Acuna et al., 2005; Soufizadeh et al., 2006), some studies have reported higher nitrogen use efficiency for modern wheat cultivars, which could result from either an improved nitrogen uptake efficiency or a greater nitrogen use efficiency (Ortiz-Monasterio et al., 1997; Brancourt-Hulmel et al., 2003). In Iran, irrigated wheat is grown in four different mega agro-ecological zones, namely warm and humid zone, warm and dry zone, temperate zone and cold zone. Among them, the temperate zone spans over 30.7% of the total wheat cultivation area and includes spring and facultative wheat cultivars (Jalal Kamali and Duveiller, 2008). The current study aimed to assess the variations among Iranian wheat cultivars bred for the temperate zone during 1942 and 2007 period, to find directional changes in yield and other agronomic and quality traits during the breeding process and to deter-mine the most important factors accounting for these variations.

MATERIALS AND METHODS

Plant material and field trials

Among the wheat cultivars released in Iran by the Seed and Plant Improvement Institute (SPII), 21 spring varieties which have been recommended for temperate regions were chosen for this study (Table 1). These varieties include the most successful cultivars introduced to the temperate zone and some of them are still used in Iran. The varieties were planted under a randomized complete block design arrangement with 4 replications at Karaj experiment station, Iran, for two successive years 2004 and 2005. Sowing date in both years was the same (November 1st), and at the time of sowing, soil was fertilized with potassium sulfate (50 kg/ha), ammo-nium phosphate (100 kg/ha) and urea (100 kg/ha), and another 75 kg/ha urea was applied at stem elongation initiation. Each plot comprised 6 lines of 4 m long, with a line spacing of 20 cm, and a density of 400 seeds/m^2. The field was irrigated twice in autumn and four times in spring using furrow method. Rust and foliar diseases were controlled using Tilt (2000 ppm), while broad - and

Table 2. Analysis of variances for traits measured in wheat cultivars released between 1942 And 2007 in Iran and grown at Karaj station during 2004 and 2005 cropping seasons.

S.O.V.	d.f.	Heading (days)	Anthesis (days)	Maturity (days)	Plant height (cm)	Number of spikes (m^{-2})	Length of spike (cm)	Length of peduncle (cm)	Biomass (Kg/ha)	Seed weight (g)	Yield (Kg/ha)	Flag leaf area (mm^2)	Harvest index
Year	1	350.29**	144.18**	32.02**	38.92	2910797**	6.76	2.06	310460815**	10830*	18295826**	10651134**	51.94
Error	6	4.50	1.67	12.13	58.76	2709	1.84	15.28	20449451	1190	71800	169833	18.68
Rly[a]	13	158.01**	91.27**	71.19**	1503.85**	21039**	2.64**	351.66**	18334712**	7360**	1043205**	545331**	169.06**
Rly x year	12	6.64	6.09	5.63	15.47	10390*	0.39	19.36	9201395	865	180365**	79284*	17.81**
Error	131	6.56	3.90	8.79	18.10	5179	0.52	10.65	9169332	804	50255	44969	6.83
Total	163												
CV%		2.06	1.51	1.72	4.08	11.78	7.99	8.28	17.27	16.02	9.70	11.30	7.70

[a] Rly=year of cultivar release.

narrow-leaved weeds were controlled using Puma Super (1.9 lit/ha) and Granstar (20 g/ha), respectively. Plants were prevented from lodging using wood-stands and ropes.

Morphological measurements and quality analysis

During the growing seasons of both years, records were made on phenological stages including days to heading, to anthesis and to maturity, plant height, area of flag leaf, flag leaf dry weight (g), length of peduncle and length of spikes. At harvest, plot margins were discarded and an area of 3.6 m^2 was harvested. Biomass (kg ha^{-1}), grain yield (kg ha^{-1}), harvest index, number of spikes (per meter square), grains per spike and grain test weight (g) were measured. Seed samples from each plot were sent to laboratory to determine their quality parameters. Sampling was performed based on ICC no. 101, protein content was determined based on ICC no. 105, Hectoliter weight (test weight) by ISO-7970, sedimentation index by ICC no. 116, gluten percentage by ICC no. 137, SDS (sodium dodecyl sulfate) sedimentation by ICC no. 151, falling number by ICC no. 107, hardness index by AACC-55-30, bread volume (BV) and water absorption using small bowl Brabender-E pharinograph by ICC no. 115/1 (ICC, 2005; AACC, 1995). Also gluten index and dry and wet glutens were determined using ICC standards. Sun pest damage was also scored.

Statistical analysis

Analysis of variations was performed for cultivars, in years using SAS statistical program (SAS institute, 1997). Regression analysis was performed to estimate the gain per year for each trait. Factor analysis was performed with standardized data and varimax rotation. The latter analyses were carried out using SPSS version. 16.

RESULTS

Combined analysis of variance revealed significant differences among wheat varieties for all the studied traits (results not shown). Environment had significant effects on days to heading, anthesis and maturity, number of spikes, length of spikes, seeds per spike, seed weight per spike, biomass, 1000-seed weight, plot yield, flag leaf size, hectoliter weight, Zeleni index, BV, water absorption, wet gluten, gluten index and Sunn pest damage(SD).

There were significant genotype-year interactions for days to heading, anthesis and maturity, length of peduncle, number of spikes, number of seeds per spike, seed weight per spike, leaf area, plot yield, harvest index, kernel test weight (TKW), hectoliter weight (HLW), hardness index, wet gluten, gluten index, and SDS (SDS sedimentation volume). Regression analysis revealed significant trends in many of the traits in response to the release years (Table 2). The most prominent changes were documented for harvest index, 1000-seed weight, plant height and plot yield.

Contrary to the increase in yield, quality related traits either stayed unchanged or decreased significantly along the years of breeding efforts. Actually, none of Iranian wheat cultivars presented a good baking quality. During the breeding process, SDS decreased from relatively high (over 50 ml) to medium class (about 45 ml).

Higher SDS sedimentation values correspond to higher gluten strength (Triboi and Martre, 2004). While gluten index was not affected by the breeding efforts, wet gluten and dry gluten indices moved from medium quality class to low quality group. The bread volume (BV, loaf volume) test supports the above decreasing trends, with a dropped from about 500 to 430. Zeleni test suggests that quality has reduced from good

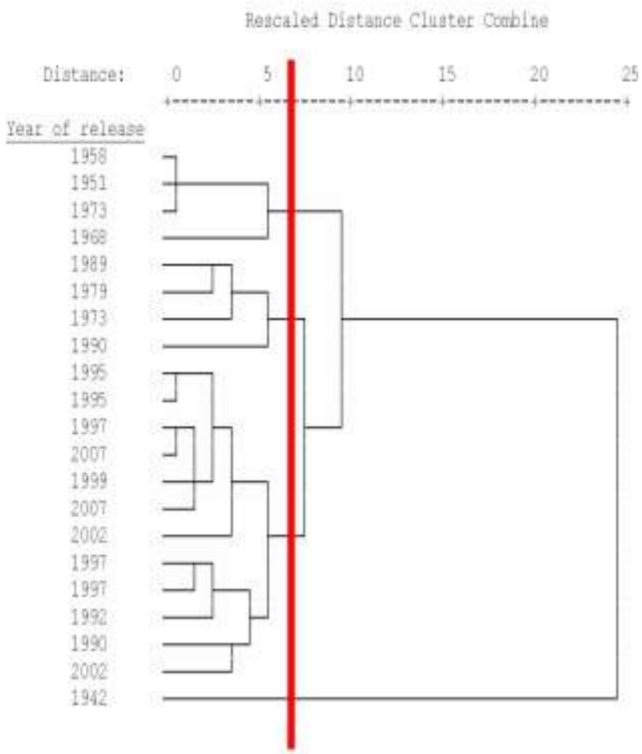

Figure 1. Dendrogram of Iranian wheat cultivars released between 1942 and 2007 based on studied traits.

(more than 30 ml) to medium class (about 27 ml). Based on hector-liter weight, Iranian wheat cultivars were classified to very heavy and very highly heavy classes, and the shift has been towards higher HLW values. When considering the 1000 grain weight, it is obvious that wheat lines with very small grains have been replaced by cultivars with medium weight grains. In order to show if there are enough differences in the overall structures between new and old cultivars to divide them into different time-classes, cluster analysis was performed using standardized morphological data. The resulting dendrogram (Figure 1), divided the wheat cultivars into 3 groups, namely old cultivars released before 1973, medium cultivars released between 1973 and 1990 and modern cultivars released after 1990. Shapasand, the oldest cultivar had quite different characteristics and constituted a separate group with a large distance with others (Table 3).

Factor analysis was implemented to concentrate original data in fewer axes, to detect important underlying factors responsible for the variation among the varieties and also to group them in a two dimensional space. Factor analysis with Varimax rotation resulted in six significant factors (Table not presented). The first factor with the most importance accounted for more than 38% of the phenotypic variation among the cultivars, while the second factor accounted for about 17% of this variation (Table 4).

DISCUSSION

Analysis of variance revealed significant differences among the wheat cultivars used. Almost all previous studies have reported such significant genetic diversities for morphological, phenological and grain quality traits among commercial wheat cultivars (Panozzo and Eagles, 1998; Ames et al., 1999; Mladenov et al., 2001; Bechere et al., 2002; Zhang et al., 2006). However, molecular analysis have shown that although the genome-wide reduction of crop genetic diversity due to plant breeding over time has been minor, the allelic reduction at individual chromosomal segments has been substantial (Fu, 2006).

Environment and its interaction with genotype have had significant effects on most of the studied traits. Zhang et al. (2006) reported that environmental factors such as temperature, photoperiod and water availability may influence the ranking of cultivars for grain quality. Calderini and Slafer (1999) suggested that wheat breeding has diminished the yield stability. It should be the case, as there has been an interaction between cultivars and crop management, and introduction of new cultivars has changed crop management. For instance, modern wheat varieties are short and resistant to lodging and more responsive to heavy N-fertilizer application (Feil, 1992; Soufizadeh et al., 2006). Williams et al. (2008) reviewed papers from four major international databases had reported that relative contributions of G (genotype), E (environment) and G x E varied across studies. However, traits associated with protein content were more influenced by E and G x E than those associated with protein quality, where G effects were more important. Considering the magnitude of variance components, it is evident that for quality traits, the additive effects of environment and genotype have been more important than the genotype-environment interact-tion. These findings are similar with those of Ames et al. (1999). Studies in Australia also suggest a lack of G x E effect for quality traits, with G and E having similar effects (Williams et al., 2008). Investigation of the plant height clearly shows that reducing this trait has been of great importance to Iranian wheat breeders. The studied wheat cultivars can be divided into tall and semi-dwarf varieties. All tall varieties being released before 1979 while all short ones have been released after that time. As shown in Figure 2, all new cultivars are gathered in the right-bottom corner of the graph. Therefore, it seems that unless incorporating additional dwarfing genes, there would not be Slafer and Araus (2007) believe that this trait is not anymore useful as modern cultivars possess already the optimum height for high yield potential. Some researchers have suggested that a moderate culm length of 70 cm would be more suitable for achieving high yield potential under favorable conditions (Borojevic, 1986; Fischer and Quail, 1990). However, shorter plant height would not be appropriate, as farmers usually use the hay for animal feeding. For further wheat plant height

Table 3. Means of the traits which showed significant trends during wheat breeding process.

Year of release	Heading (Days)	Maturity(Days)	Height (cm)	Length of peduncle (cm)	1000 seed weight	Harvest index	Grain yield(kg ha^{-1})	Seeds per spike	Seed weight per spike (g)	HLW (g)	Protein (%)	ZEL (%)	BV	Water absorption (%)	Wet glutenin	Dry glutenin	SDS(ml)
1942	134.5	183.0	132.8	39.5	40.2	22.0	4639	28.6	1.12	76.2	11.8	32.3	531.0	64.3	31.5	10.3	55.5
1951	126.0	174.5	125.4	46.92	42.1	27.6	5294	27.47	1.45	80.9	11.3	30.0	452.0	63.8	31.6	10.4	52.8
1958	122.5	172.5	124.6	48.8	45.12	29.7	5183	27.5	1.5	80.7	11.4	29.5	465.8	63.7	31.1	10.6	50.3
1968	131.0	173.5	120.3	31.31	33.17	27.3	4472	30.93	1.27	80.9	11.2	28.9	472.9	63.7	27.9	9.5	50.5
1973	126.0	172.5	125.8	49.3	37.78	26.5	5033	30.47	1.34	78.6	11.0	27.9	444.7	63.4	28.6	9.5	47.8
1979	125.5	172.0	104.6	42.4	29.17	29.7	5869	41.27	1.46	77.5	10.8	26.1	439.3	63.1	24.4	7.1	43.6
1989	123.5	172.5	103.1	41.28	28.9	34.6	5989	40.96	1.46	78.4	10.9	28.0	430.1	63.6	27.3	8.5	49.7
1990	126.5	172.0	94.4	32.62	37.33	37.3	6658	38.33	1.63	81.5	10.8	26.4	416.5	63.4	25.3	7.8	44.4
1992	120.5	172.0	100.3	38.43	39.7	33.2	7192	30.65	1.49	80.6	11.0	27.5	421.3	63.2	27.5	8.8	48.4
1995	124.5	173.0	106.8	40.61	41.01	35.3	7147	37.21	1.75	81.0	10.8	27.1	418.8	63.5	27.2	8.9	45.6
1997	117.5	168.0	89.6	36.43	40.32	38.1	6653	33.6	1.57	83.6	11.0	28.0	449.5	63.6	27.6	9.1	46.8
1999	124.5	171.5	94.8	36.37	36.05	38.4	6850	36.87	1.56	81.8	11.1	28.0	440.1	63.5	27.5	9.0	47.3
2002	125.0	176.0	94.9	37.21	42.7	39.2	7553	31.95	1.58	82.1	11.0	28.1	439.9	63.4	28.3	9.3	47.7
2007	124.0	172.0	95.3	36.98	41.08	38.1	7769	38.15	1.81	83.7	10.9	27.3	428.0	63.7	26.2	8.3	47.7

reduction, extremely dwarf germplasm is already available (Jain and Kulshrestha, 1976; Law et al., 1978). Austin et al. (1989) reported that the height of winter wheat cultivars in the U.K. was reduced from 150 cm in the 19th century to about 80 cm in the 1980s. Despite the outstanding reduction in plant height, biomass of the cultivars has remained nearly unchanged. Shorter straw implies less susceptibility to lodging, and increases the harvest index. The ability to produce more kernels from a given total above-ground biomass has been an important factor in increasing the yield of modern cultivars (Brancourt-Hulmel et al., 2003; De Vita et al., 2007; Giunta et al., 2007). The kernel number per unit of area increased while keeping constant kernel weight shifted the negative correlation between 1000 kernel weight and kernel number/m^2. In this study, biomass and number of spikes remained unchanged, while number of seeds per kernel and kernel weight increased. Therefore, modern cultivars have been more efficient in translocating nutrients from the straw to the grain. On the other hand, in a study on six Iranian wheat genotypes released within the last five decades, Soufizadeh et al. (2006) reported that more recent varieties had higher biomass and grain yield.

Based on the means presented in Table 3, all the Iranian wheat cultivars have had about 10 - 11% protein, which classifies them into weak

Table 4. The results of factor analysis.

Component	Initial Eigenvalues		
	Total	% of variance	Cumulative (%)
1	10.692	38.187	38.187
2	4.744	16.943	55.130
3	3.338	11.923	67.053
4	2.129	7.603	74.657
5	1.947	6.953	81.610
6	1.327	4.740	86.350

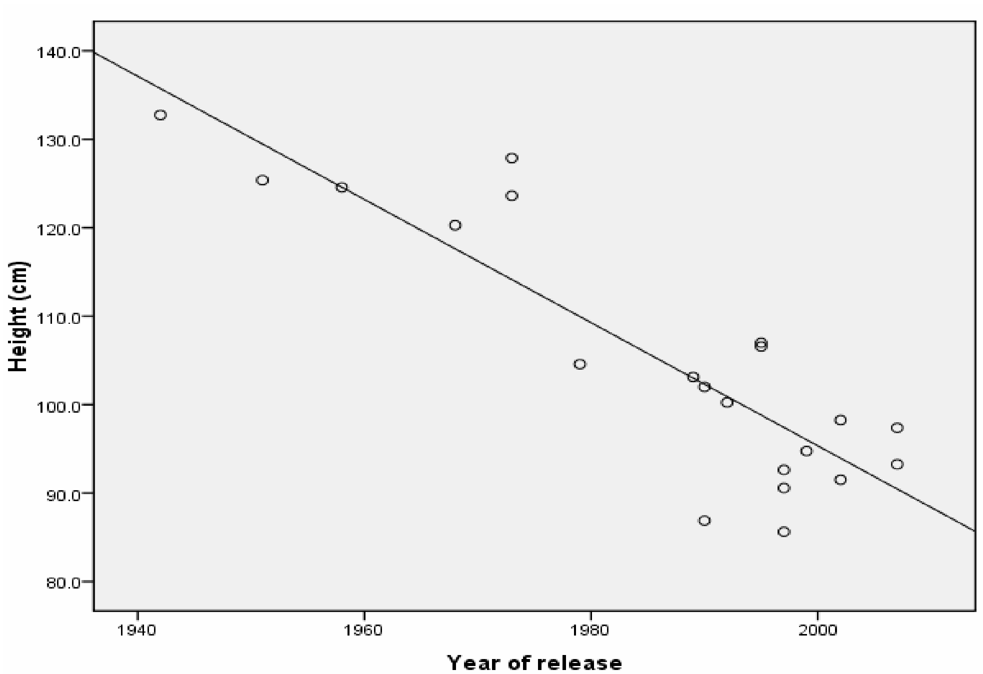

Figure 2. Reduction in plant height through development of modern varieties.

quality wheats. Also breeding process has aggravated the situation since the new cultivars have shifted towards very weak class. Soufizadeh et al. (2006), also, reported that recent Iranian wheat varieties had lower grain protein concentrations. Our results revealed that grain quality has been to some extent neglected by the Iranian wheat breeding programs. Previous studies have suggested a negative correlation between grain yield and protein content, which indicates breeding, has decreased the grain quality (Kibite and Evans, 1984; Ortiz-Monasterio et al., 1997; Brancourt-Hulmel et al., 2003; Acuna et al., 2005; Soufizadeh et al., 2006). Beside protein content, baking quality seems to be strongly affected by the balance between the different types of gliadins and glutenins largely influencing strength and elasticity of the dough (Stone and Savin, 1999). Wheat storage proteins are inherited by multigene families (Gale, 2005), and managing all these genes and components needs labor and money. As a result, it reduces the money for breeding high yielding varieties and therefore slow downs the progress in grain yield (Mesdag, 1985). Recently, molecular markers applications for efficient, rapid and cost effective quality breeding have become a popular approach (Devos et al., 1995; Gale, 2005). It is believed that among factors contributing to yield improvement of modern cultivars, reduction of height has been of most importance (Brancourt-Hulmel et al., 2003). Reducing height does not alter the ability to capture resources, but improves the efficiency with which resources are used to produce yield (Slafer and Araus, 2007). Factor analysis is usually implemented for concentrating the data and drawing a clear two-dimensional picture from the long list of different traits. To that end, we extracted the first four important factors which, considering factor loadings should be named Quality, Earliness, Biomass and Plant Height factors, respectively. Biplot diagram of the

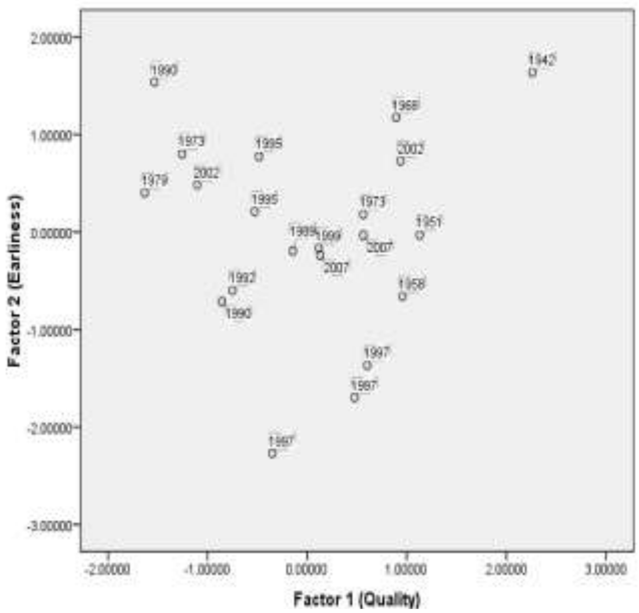

Figure 3. Biplot of wheat cultivars by using two most important factors; namely quality (X axis) and earliness (Y axis).

cultivars using the first two factors is presented in Figure 3. In this figure random dispersion of cultivars released in different years suggests that while harboring high genetic variability, neither quality nor earliness has been an important determinant for the introduction of new wheat cultivars. It would therefore be concluded that improving grain yield has been the main target for Iranian wheat breeders. Among the traits potentially related to wheat grain yield, many did not show any trends in the Iranian wheat breeding history, and some of them have not been studied in our experiment. Traits such as number of spikes, early maturity and area of flag leaf were not apparently considered in wheat breeding programs, and important traits such as disease resistance, green leaf duration, carbon isotope discrimination (Δ13C) and a lengthened stem elongation phase (Slafer and Araus, 2007) were not included in the current study. Implementation of these traits would help breeders to improve current genetic materials. Until now, all the wheat cultivars released in Iran have been developed through conventional methods. The inclusion of more sophisticated methods, such as development and application of DNA markers, especially locus-specific markers, and gene transformation would assist future increases in grain yield and quality. Naturally, traits such as resistance to diseases and some quality traits will be first candidates for these methods.

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