

ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
<http://ansijournals.com/ja>

JOURNAL OF AGRONOMY



ANSI*net*

Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan



Research Article

Fruiting Efficiency in Iranian Wheat Cultivars: Genetic Changes Over Time and Associations with Agronomic Traits

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Abstract

Fruiting efficiency (grain set per unit of spike dry weight at anthesis) could be considered as a promising trait for further improvement in wheat grain yield. The aims of this research were to study genotypic variations for Fruiting Efficiency (FE) among Iranian wheat cultivars, its change during past breeding activity as well as its association with main stem grain yield and its component. Eighty-one wheat cultivars released from 1930-2006 were examined under well watered conditions at Parsabad-Moghan during 2013-2014 growing season. Considerable variations were found for FE where this trait ranged from 30.9-105.5 grains per gram spike. Linear regression analysis of FE against the year of release revealed that this trait did not change significantly from old to modern cultivars. Although, correlation analysis showed no significant associations between FE and main stem grain yield, but the differences among cultivars with respect to grain number per spike and hence, main stem grain yield were partly related to cultivars differences in FE, emphasizing the potential values of FE for future breeding. It could be concluded that there are substantial variations in FE among Iranian wheat cultivars, suggesting that this trait could be changed in breeding programs.

Key words: Fruiting efficiency, grain yield, grain number, modern and old cultivars, wheat

Received: September 29, 2015

Accepted: November 11, 2015

Published: December 15, 2015

Citation : Mehdi Joudi, Manochehr Shiri and Morteza Kamrani, 2016. Fruiting Efficiency in Iranian Wheat Cultivars: Genetic Changes over Time and Associations with Agronomic Traits. J. Agron., 15: 19-25.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Wheat is grown on 219 million hectares throughout the world producing approximately 716 million tons of grain. In Iran, the area under wheat cultivation during 2012-13 was 7 million hectares with a production of 14 million tones (FAO., 2013).

Grain yield of wheat has increased noticeably from the beginning of the twentieth century. It is well known that during past breeding activities and progresses in wheat yield, different plant characters have been changed (Feil, 1992; De Vita *et al.*, 2007). Fischer (2011) stated that in most cases variations in grain yield of wheat as well as its improvement is related to changes in grain number. Therefore, understanding agronomical, phenological and physiological traits associated with grain number, among wheat cultivars grown in semi-arid condition such as in Iran can help wheat breeders to accelerate genetic improvement in grain yield potential.

Researchers have found some avenues for improving grain number and increased grain yield. Fischer (2011) stated that grain number in wheat has been linked to dry weight accumulation in spike (g m^{-2}) at flowering which in turn is determined by the duration of spike growth, the rate of dry matter accumulation in the crop and the fraction of this dry matter partitioned to the spike during spike growth period. Miralles and Slafer (2007) reported that the phase of rapid spike growth period is critical for grain number determination and increasing spike growth so that lengthening the duration of this phase (without altering flowering time) would result in an increased grain number per spike. Increasing fruiting efficiency, the number of grains per unit of spike chaff dry weight is another alternative to enhance grain number per spike (Fischer, 1984, 2011; Slafer *et al.*, 2015; Mirabella *et al.*, 2015). This trait shows the efficiency with which the photoassimilates partitioned to the spikes are used to produce a certain number of grains (Abbate *et al.*, 1997, 2013; Garcia *et al.*, 2014; Slafer *et al.*, 2015).

Although, the history of fruiting efficiency goes back as far as 30 years (Fischer, 1984), but very few studies have been conducted about this character. It has been reported that there are genetic variations for fruiting efficiency among wheat cultivars. Mirabella *et al.* (2015) studied variations for fruiting efficiency in six datasets combining commercial cultivars under different environmental conditions and reported large variations among studied population and revealing that this variation was consistently larger than genotype $\times$ environment interaction. The estimated narrow sense heritability for fruiting efficiency in their work was 0.63, suggesting that fruiting efficiency is a heritable trait with predominantly additive effects.

The numbers of studies that have investigated the impacts of past breeding effects on fruiting efficiency are limited. Additionally, the retrospective studies performed this area do not show clear trend with respect to breeding effects on FE during past decades. Working with one landrace, seven cultivars released since, 1950 and two advanced breeding lines in the Mediterranean area of Spain during three consecutive growing seasons. Acreche *et al.* (2008) reported that the increase in number of grains per meter square from old cultivars to modern ones was associated with both fruiting efficiency and spike dry weight at anthesis. They proposed that the increases in fruiting efficiency could be attributed to a higher allocation of photoassimilates to the growing florets instead of to structural components of the spike (rachis, glumes and awns) in modern cultivars. In contrast, no clear associations were found between year of cultivar release and fruiting efficiency in Argentina and England (Slafer *et al.*, 2015; Shearman *et al.*, 2005). All these observations suggest that further studies in needed to get clear trend of breeding effects on FE during past decades.

To the best knowledge, there is no information on genetic variations and genetic gains for fruiting efficiency among wheat cultivars grown in semi-arid condition such as in Iran where, wheat growth takes place under high temperature and high radiation conditions. Given this, genetic variation for fruiting efficiency was studied among Iranian wheat cultivars released from 1930-2006. The association between fruiting efficiency and year of cultivar release was also explored.

MATERIALS AND METHODS

Seventy five Iranian bread wheat, two foreign bread wheat and four durum cultivars released from 1930-2006 were considered in the current study (Table 1). They were commonly grown in Iran during this period and covered up to 90% of the total area of cultivation (Joudi *et al.*, 2014). Experiments were performed at Parsabad, located in the Moghan region in Northwest Iran ($39^{\circ}36'N$, $47^{\circ}57'E$ and 45 masl). Parsabad has a warm Mediterranean climate with cold winters, humid spring and summers with average annual precipitation of 271 mm.

Experiment was conducted over crop season 2013-2014 under well-watered conditions at the agriculture research farm of Moghan College of Agriculture and Natural Resources, University of Mohaghegh Ardabili. The cultivars were planted on 11 December, 2013. Seeding rates were adjusted by cultivar according to thousand grain weight to achieve a target plant number of 300 m^{-2} . The experimental design was a simple lattice (9×9) with two replications. There were four rows in each plot in a North-South direction, rows were 2 m

Table 1: Wheat cultivars used in the Parsabad-Moghan experiment during 2013-2014 growing season

Cultivars	Origins	Year of release in Iran	Cultivars	Origins	Year of release in Iran
Arta	Iran	2006	Gholestan	CIMMYT	1986
Akbari	Iran	2006	Sabalan	Iran	1981
Bam	Iran	2006	Bistun	Iran	1980
Daria	CIMMYT	2006	Kaveh	Mexico	1980
Sepahan	Iran	2006	Azadi	Iran	1979
Sistan	ICARDA	2006	Alborz	CIMMYT	1978
Moghan 3	Iran	2006	Naz	CIMMYT	1978
Stark	CIMMYT	2005	Baiat	Iran	1976
Shovamald	CIMMYT	2003	Karaj 3	Iran	1976
Pishtaz	Iran	2002	Chenab	Pakistan	1975
Dez	CIMMYT	2002	Moghan 2	CIMMYT	1974
Shahriar	Iran	2002	Arvand	Iran	1973
Shiraz	Iran	2002	Khazar 1	Mexico	1973
Crossed Falat Hamun	Iran	2002	Karaj 1	Iran	1973
Hamun	Iran	2002	Karaj 2	Iran	1973
Azar2	Iran	1999	Moghan 1	Mexico	1973
Marvdasht	Iran	1999	Inia	CIMMYT	1968
Spring BC Roshan	Iran	1998	Navid	Iran	1968
Winter BC Roshan	Iran	1998	Shahi	Iran	1967
Chamran	CIMMYT	1997	Adl	Iran	1962
Simine	Iran	1997	Khalij	Iran	1960
Shirodi	CIMMYT	1997	Roshan	Iran	1958
Kavir	Iran	1997	Sorkhtokhm	Iran	1957
Durum Yavarus	CIMMYT	1996	Shole	Iraq	1957
Zakros	ICARDA	1996	Azar 1	Iran	1956
Atrak	CIMMYT	1995	Omid	Iran	1956
Estar	CIMMYT	1995	Tabasi	Iran	1951
Alvand	Iran	1995	Shahpasand	Iran	1942
Alamut	Iran	1995	Sardari	Iran	1930
Darab 2	CIMMYT	1995	Bulani	Iran	-
Zarrin	-	1995	Somaye 3	China	-
Mahdavi	Iran	1995	Frontana	Brazil	-
Niknazhad	ICARDA	1995	Fongh	China	-
Soissons	France	1994	Crossed Alborz	Iran	-
Gascogne	France	1994	Crossed Shahi	Iran	-
Gaspard	France	1994	Verinak	CIMMYT	-
Rasul	CIMMYT	1992	DN-11	CIMMYT	-
Marun	Iran	1991	WS-82-9	-	-
Hirmand	Iran	1991	Kauz	-	-
Falat	CIMMYT	1990	Montana	-	-
Ghods	Iran	1989			

:- Unknown

long with 0.2 m spacing. Fertilizers applied were diammonium phosphate (200 kg ha⁻¹) and urea (100 kg ha⁻¹) before planting and 50 kg ha⁻¹ of urea top-dressed at jointing Zadoks GS 31 (Zadoks *et al.*, 1974). Herbicides and insecticide were sprayed to prevent or control weeds and insects. The plants were irrigated four times from sowing to maturity. Approximately 55 mm of irrigation water was applied each time. The dates of anthesis and physiological maturity were recorded. To achieve this, the plots were monitored every two days. Anthesis was recorded when half of the main shoot spikes had visible anthers. Dates of physiological maturity were recorded when peduncles on half of the plants in plots were completely yellow. In each plot, ten main stem's spikes from the two middle rows were harvested at random at anthesis and physiological maturity. They immediately dried

in a forced air dryer at 70°C for 48 h to minimize respiration and weight losses. The spikes were weighted and their average was obtained. Main stem grain yield was measured by threshing the obtained spikes at physiologic maturity. To achieve this, the spikes threshed and their average was obtained as well. The number of grains per spike was also measured. Individual grain weight was obtained as the ratio of main stem grain yield to grain number per spike. Fruiting Efficiency (FE) was calculated as the ratio between grain number per spike and spike dry weight at anthesis (Ferrante *et al.*, 2015).

Analyses of variance (ANOVA) were carried out using SAS statistical software (SAS Institute, 1994). Data was analyzed according to a lattice design and adjusted means were considered. Measured parameters were regressed against year

of cultivar release to obtain genetic gain and to study changes in different plant characteristic over time using linear equations that were fitted to the data. Among tested cultivars, the years of release for 11 cultivars were unknown; they were not, therefore, considered in regression analysis. Relationships between traits were studied by correlation analysis. Regression and correlation analyses were performed using SPSS statistical software Version 17.0 (SPSS., 2009).

RESULTS AND DISCUSSION

At anthesis, mean spike dry weight was 0.86 g. The lowest and the highest values of this trait were 0.32 and 1.35 g, respectively (Table 2). There was no significant association between spike dry weight at anthesis and year of release (Fig. 1a). Large variations were found among cultivars for main stem grain yield; main stem grain yields ranged from 1.02-2.5 g (Table 2). Overall, new wheat cultivars produced more grain yield than old ones. Linear regression analysis of grain yield against year of release indicated that annual gain in main stem grain yield was 8 mg per spike per year (Fig. 1b). Sener *et al.* (2009) worked on 16 bread wheat cultivars in the Mediterranean region of Turkey and reported that national bread wheat yields increased by an average of 20.8 kg ha⁻¹ year⁻¹ from 1925-2006. They also stated that grain yield components such as grain number/spike, grain weight/spike and 1000-seed weight tended to increase in newer cultivars.

Average grain number per spike was 44.7. Numbers of grains per spike increased linearly with year of release in tested cultivars (Fig. 1c). Similar results were reported by Royo *et al.* (2007). Shearman *et al.* (2005) reported that genetic gains in number of grains per meter square were associated with changes over time in both number of spikes per square meter and number of grains per spike. Improvement in the grain number per spike during past decades suggests that the total amount of available assimilates was sufficient to support the development of higher numbers of grains per meter square in modern cultivars (De Vita *et al.*, 2007).

Considerable variations were found for individual grain weight per spike where, this trait ranged from 19-52 mg. Individual grain weight per spike tended to increase from old to modern cultivars (Fig. 1d). In most cases researchers have reported that thousand grain weight in wheat has not changed significantly during the past decades (Joudi *et al.*, 2014; Sadras, 2007; Sanchez-Garcia *et al.*, 2013). That is to say yield variation and yield progress is controlled more by changes in grain number than grain weight (Fischer, 2011).

Examined cultivars showed significant differences with respect to FE. The values of this trait ranged from 30.9-105.6 grain per gram spike. Karaj 3, Arta and Sabalan showed the highest amount of FE, while Shirodi, Adl and Zagros exhibited the opposite (Fig. 1e). The values of spike fertility or FE ranged from 56-113 grain per gram in the works of Mirabella *et al.* (2015) which performed under different environmental conditions. Differences in the floret developmental rate and the proportion of grain set per fertile floret are possible explanations for observed variations in the FE. Slafer *et al.* (2015) believe that by increasing allocation of assimilates for the florets developing during spike growth before anthesis and by reducing demand of the florets for maintaining their normal development and therefore, leaving more resources for distal florets it could be possible to improve the values of FE in breeding programs.

Linear regression analysis of FE against the year of release indicated that this trait did not change significantly from old to modern cultivars (Fig. 1e). It was reported that huge gains in wheat grain yield were achieved simply in the past decades by selecting for reduced height and increasing partitioning to the spikes before anthesis and therefore, FE was not considered as a possibility. It was proposed, however, it may be more relevant in the future as a trait to be considered in wheat breeding programs (Slafer *et al.*, 2015).

Correlation analysis revealed no significant associations between main stem grain yield and FE. A lack of significant association between main stem grain yield and FE does not imply that FE is not related to grain yield improvement, because there is a positive and significant correlation between FE and grain number per spike (Table 3). Individual grain

Table 2: Basic statistics for measured traits of 81 wheat cultivars grown at Parsabad-Moghan during 2013-2014 growing season

Parameters	Spike weight at anthesis (g)	Main stem grain yield (g)	Grain No. per spike	Individual grain weight (mg)	Fruiting efficiency (grains per gram spike)
Minimum	0.32	1.02	26.00	19.00	30.90
Maximum	1.35	2.50	60.00	52.00	105.50
Mean	0.86	1.78	44.70	40.30	54.20
SD	0.19	0.33	7.08	6.09	13.24
CV	22.00	18.00	16.00	15.00	24.00

SD: Standard deviation, CV: Coefficient of variation

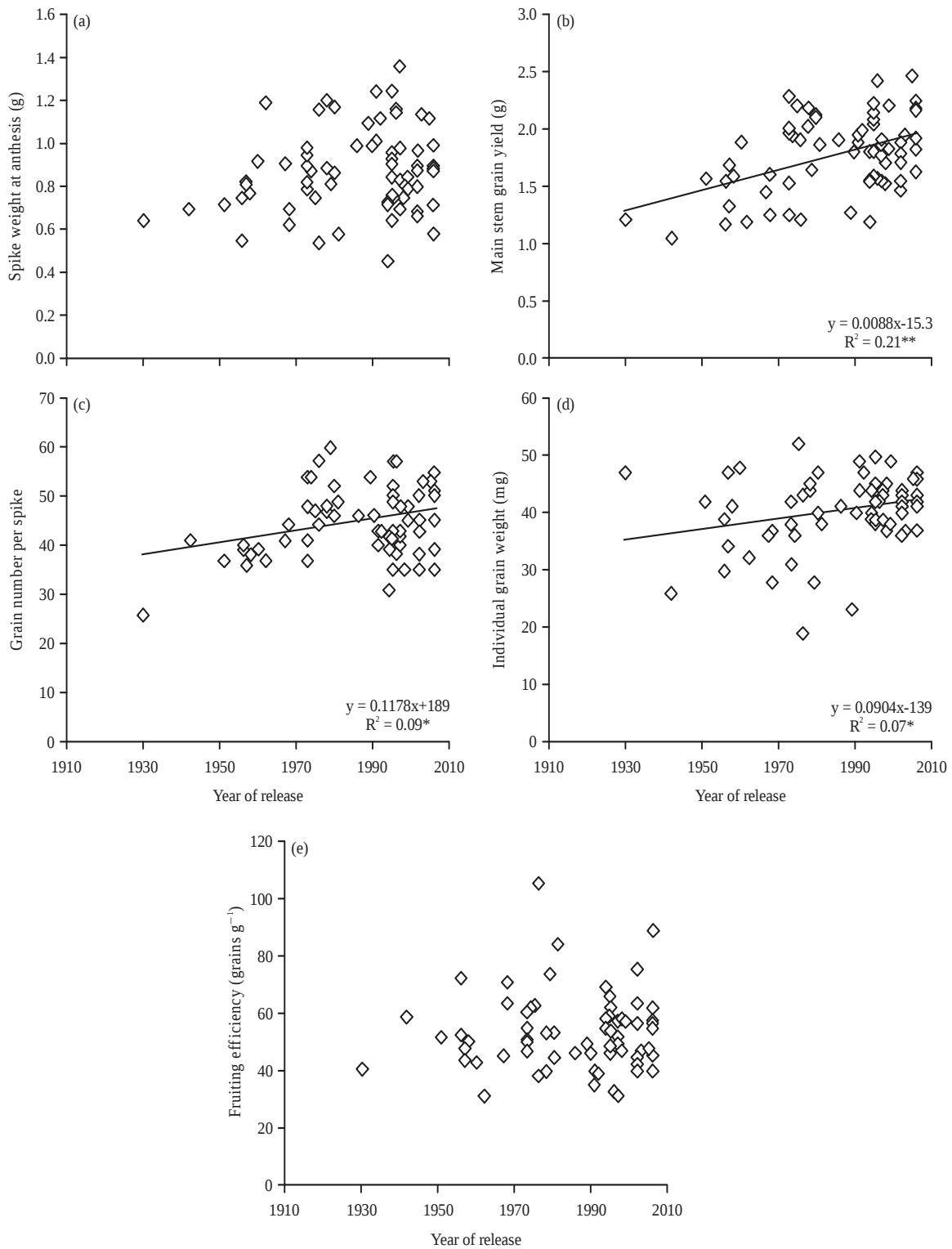


Fig. 1(a-e): Relationships between year of cultivar release and (a) Spike weight at anthesis, (b) Main stem grain yield, (c) Grain number per spike, (d) Individual grain weight and (e) Fruiting efficiency in Iranian wheat cultivars released from 1930-2006. Each lozenge represents the mean value of one cultivar. Only significant linear regressions were plotted

Table 3: Correlation coefficients among measured traits of 81 wheat cultivars grown at Parsabad-Moghan during 2013-2014 growing season

Parameters	Main stem grain yield	Fruiting efficiency	Grain number per spike	Individual grain weight	Spike weight at anthesis
Main stem grain yield	1				
Fruiting efficiency	-0.08 ^{ns}	1			
Grain number per spike	0.62**	0.32**	1		
Individual grain weight	0.57**	-0.42**	-0.27*	1	
Spike weight at anthesis	0.43**	-0.74**	0.32**	0.18 ^{ns}	1

ns: Non significant, *Significant at $p = 0.05$, **Significant at $p = 0.01$

weight correlated negatively and significantly with FE (Table 3). Ferrante *et al.* (2015) stated that as in wheat grain growth is mostly sink limited, the trade-off between FE and average grain weight would not be related to an increased competition for limited assimilates during post anthesis. It is possible that in cultivars with higher FE values, the numbers of distal grains have been increased which in turn resulted in decreased individual grain weight.

CONCLUSION

In conclusion, the results showed that there are substantial variations in FE among Iranian wheat cultivars, suggesting that this trait could be changed in breeding programs. Although, there was no difference between old and modern cultivars regarding the FE, but the differences among cultivars in terms of grain number per spike was related to cultivars differences in FE, emphasizing the potential values of FE for future breeding.

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