

# Temporal variation in phenological and agronomic traits of some irrigated facultative/winter bread wheat (*Triticum aestivum* L.) cultivars released between 1943 and 2011 in Iran

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## ABSTRACT

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A field experiment was conducted at the Seed and Plant Improvement Institute Research Field Station in Karaj, Iran, during the 2009-10 and 2010-11 growing seasons to estimate genetic progress and the variation in phenological and agronomic characteristics in 13 irrigated facultative/winter bread wheat (*Triticum aestivum* L.) cultivars released in Iran between 1943 and 2011. Trends of temporal variation of the traits measured revealed that grain yield and some related phenological and agronomic traits have increased in the more recently released cultivars. Thousand grain weight decreased slightly compared to older cultivars. Number of days to heading and anthesis decreased in new cultivars, but grain-filling period and days to physiological maturity did not change. Spike length also increased but plant height decreased in more recently released cultivars. These changes may explain the increase in grain yield of newly released facultative/winter bread wheat cultivars.

**Keywords:** agronomic characteristics, bread wheat, days to flowering, grain filling duration, thousand grain weight

## INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is the most widely grown cereal crop worldwide and one of the central pillars of global food security. About 651 million tons of wheat was produced on 217 million hectares in 2010, with average yields of 3 t/ha (FAO, 2012). Wheat is the major crop in 43 countries and supplies food for at least 35% of the world's population (Trethowan and Pfeiffer, 1999).

World population is projected to increase to about 8.0 billion by 2025 and around 9.0 billion by 2050 (FAO, 2006). Demand for wheat is estimated to increase by 1.3% per year globally and by approximately 1.8% per year in developing countries by 2025 (Araus *et al.*, 2004). Most of the necessary increases in wheat production must come from increases in grain yield. The rate of increase in grain yield was greatest during 1964-1994 and decreased thereafter (Dixon *et al.*, 2009), though the

contribution of genetic improvement to grain yield may have been overestimated due to positive genotype × management improvement interactions (Araus *et al.*, 2004).

Genetic progress in grain yield may differ in different countries due to differences in wheat type (spring or winter), crop management, or environmental conditions, as well as the initial grain yield potential (Austin *et al.*, 1980; Austin *et al.*, 1989; Sayre *et al.*, 1997; Satorre and Slafer, 1999; Araus *et al.*, 2004). However, there is an increasing consensus that selection under optimal environmental conditions results in faster genetic progress (Richards, 1996a; Richards, 1996b; Sayre 1996; Satorre and Slafer 1999; Araus *et al.*, 2004). This is clearly indicated in the review by Araus *et al.* (2004) who demonstrated that genetic gains in wheat yields during the 1860s to the 1980s were 343.4% greater in the United Kingdom (Austin *et al.*, 1989)

than in Australia (Perry and D'Antuono, 1989), largely due to more favorable environmental conditions in the United Kingdom (Calderini and Slafer, 1998).

In various regions and environments, several morphological and physiological traits have contributed to yield gains in wheat, including reduction in days to heading (Loss and Siddique, 1994), shorter plant height (Slafer and Andrade, 1989; Stapper and Fischer, 1990; Araus *et al.*, 2004), increased grain number  $m^{-2}$  (Slafer and Andrade, 1989; Loss and Siddique, 1994; Calderini *et al.*, 1999), and higher harvest index (HI) (Calderini *et al.*, 1995; Sayre *et al.*, 1997; Calderini and Slafer, 1998). Sayre *et al.* (1997) reported that progress in spring wheat grain yield was correlated with an increase in grain number  $m^{-2}$  and HI, but not with total biomass production, grain weight, days to anthesis, spike number  $m^{-2}$  or grains per spike. They concluded that, during 1962-1988, spring wheat grain yields in northwest Mexico increased at a rate of  $64 \text{ kg ha}^{-1} \text{ year}^{-1}$  (Sayre *et al.*, 1997). Similarly,

Zand *et al.* (2002) reported that the rate of grain yield increases in some Iranian wheat cultivars over the past 50 years reached  $83 \text{ kg ha}^{-1} \text{ year}^{-1}$ .

This study investigated the genetic progress of some agronomic and phenological characteristics for a set of important facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.

## MATERIALS AND METHODS

Thirteen facultative/winter bread wheat cultivars, released in Iran between 1943 and 2011, were grown under well-watered field conditions at the Seed and Plant Improvement Institute Research Field Station, Karaj, Iran, for two consecutive growing seasons (2009-10 and 2010-11). The field station is located at  $50^{\circ} 55' \text{ E}$ ,  $35^{\circ} 50' \text{ N}$ , 1270 masl and its soil is a clay loam with  $\text{pH}=7.5$ . Meteorological information for both cropping cycles at the experimental site is shown in Table 1. A randomized complete block design with three replications was used and detailed information about the 13 facultative/winter bread wheat cultivars is given in Table 2.

Table 1. Meteorological information for the 2009-10 and 2010-11 cropping cycles at the Seed and Plant Improvement Institute Research Field Station, Karaj, Iran.

Cropping cycle	Temperature ( $^{\circ}\text{C}$ )							
	Min		Max		Mean		Precipitation (mm)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
September	10.2	3.9	32.8	31.0	21.6	19.0	13.0	0.0
November	1.6	6.6	26.6	21.8	12.9	7.5	31.1	172.0
December	-3.4	-4.2	20.0	11.8	9.9	3.6	4.1	6.4
January	-13	-5.2	13.8	13.2	1.9	3.9	41.5	30.2
February	-8.4	-8.8	11.6	11.4	2.5	1.5	28.9	39.1
March	-5.8	-7.0	21.2	18.4	6.4	5.2	67.6	6.5
April	2.2	-1.4	28.4	27.6	14.2	13.4	31.4	66.0
May	12.4	-	34.2	-	18.6	-	15.0	-
June	10.6	11.8	37.6	36.2	25.1	24.1	1.6	3.3
July	12.8	12.8	38.4	38.4	27.8	26.3	2.0	25.1

Table 2. Facultative/winter bread wheat cultivars released between 1943-2011 in Iran.

No.	Name	Pedigree/Cross name	PH (cm)	GY ( $\text{kg ha}^{-1}$ )	HI (%)	Year of release
1	Shahpasand	Local variety	114.2	2722	21.90	1943
2	Omid	Local variety	112.7	2625	26.79	1957
3	Karaj 2	Fa*Th-Mt (Omid)	119.9	2612	21.96	1974
4	Karaj 3	Drc*Mxp/Son64*Tzpp-Y54(Nai60)	93.4	3326	28.80	1977
5	Qods	Rsh/Wt/4/Nor10/K54*2//Fn/3/Ptr/6/Omid//Kal/Bb	101.0	3571	28.78	1990
6	Navid	1-39-1606 (Minhardi-Odin)	91.1	4843	34.15	1991
7	Alvand	CF1770/1-27-6275	98.7	3960	29.98	1996
8	Alamoot	Kvz/Ti71/3/Maya*s//Bb/Inia/4/Karaj2/5/Anza/3/Pi/Nar//Hys	89.6	3338	30.50	1996
9	Zarin	PK15841	94.8	4169	31.18	1996
10	Tous	Spn/Mcd//Cama/3/Nzr	91.6	3016	28.89	2003
11	Shahriyar	Kvz/Ti71/3/Maya*s//Bb/Inia/4/Karaj2/5/Anza/3/Pi/Nar//Hys	91.9	3721	30.07	2003
12	Pishgam	Bkt/90Zhong87	72.7	4148	34.97	2009
13	Zare	130L1.11/F35.70/Mo73/4/Ymh/Tob//Mcd/3/Lira	94.6	4680	33.16	2011

PH = plant height; GY = grain yield; HI = harvest index

Each experimental plot consisted of three 6 m long rows with row spacing of 20 cm and a harvested area of  $6 \text{ m}^2$ . Seeds were planted using a Winter Steiger planter with a seeding density of  $400 \text{ seed m}^{-2}$ . Basal fertilizers ( $200 \text{ kg ha}^{-1}$  ammonium de phosphate and  $100 \text{ kg ha}^{-1}$  potassium sulfate) were applied in addition to  $125 \text{ kg ha}^{-1}$  urea applied as

basal at planting and  $125 \text{ kg ha}^{-1}$  urea applied as top dressing at the commencement of stem elongation. Within each plot, 10 plants were randomly selected per replication and different traits were measured and recorded. Grain yield was harvested from  $6 \text{ m}^2$  and yield components and biological yield were determined following Sayre *et al.* (1997). SAS (SAS

institute, 2000) and SPSS (Einspruch, 2005) softwares were used for analyzing data and plotting graphs. Data from the 2009-10 and 2010-11 cropping cycles were compiled for performing combined analysis of variance.

### RESULTS AND DISCUSSION

There was considerable variation in grain yield,

yield components, and agronomic traits among cultivars, with significant genotype effects (Table 3). The main interest was the temporal variation and trends in different traits in facultative/winter bread wheat cultivars released during 1943-2011. Grain yield increased by 25kg ha<sup>-1</sup> year<sup>-1</sup> (Fig. 1a) though biological yield increased at a slower rate of 15 kg ha<sup>-1</sup> year<sup>-1</sup> (Fig. 1c).

Table 3. Combined analysis for grain yield, yield components, and agronomic traits of 13 irrigated facultative/winter bread wheat cultivars grown during 2009-10 and 2010-11.

Source of variation	d.f.	GY	BY	HI	TGW	Spike no. m <sup>-2</sup>	Grain no. m <sup>-2</sup>	Grain no.spike <sup>-1</sup>
Year	1	0.256	155.771**	882.875**	2.466	135250.05**	483485.7	379.28*
Replication(year)	4	0644	3.073	20.679	2.361	4557.74	7671962.4	28.20
Genotype	12	0.332**	7.354**	96.102	75.022**	12379.98	45288101.9**	116.36**
Genotype×Year	12	0.996	2.430	37.026*	9.411	5333.88	7090580.8	40.03
Error	48	0.577	2.777	17.478	7.970	7383.49	5298083.3	25.38
C.V.		21.14	13.499	14.259	8.674	18.972	20.481	20.049

\* and \*\* Significant at the 0.05 and 0.01 probability levels, respectively. d.f. = degrees of freedom; GY = grain yield; BY = biological yield; HI = harvest index; TGW = thousand grain weight.

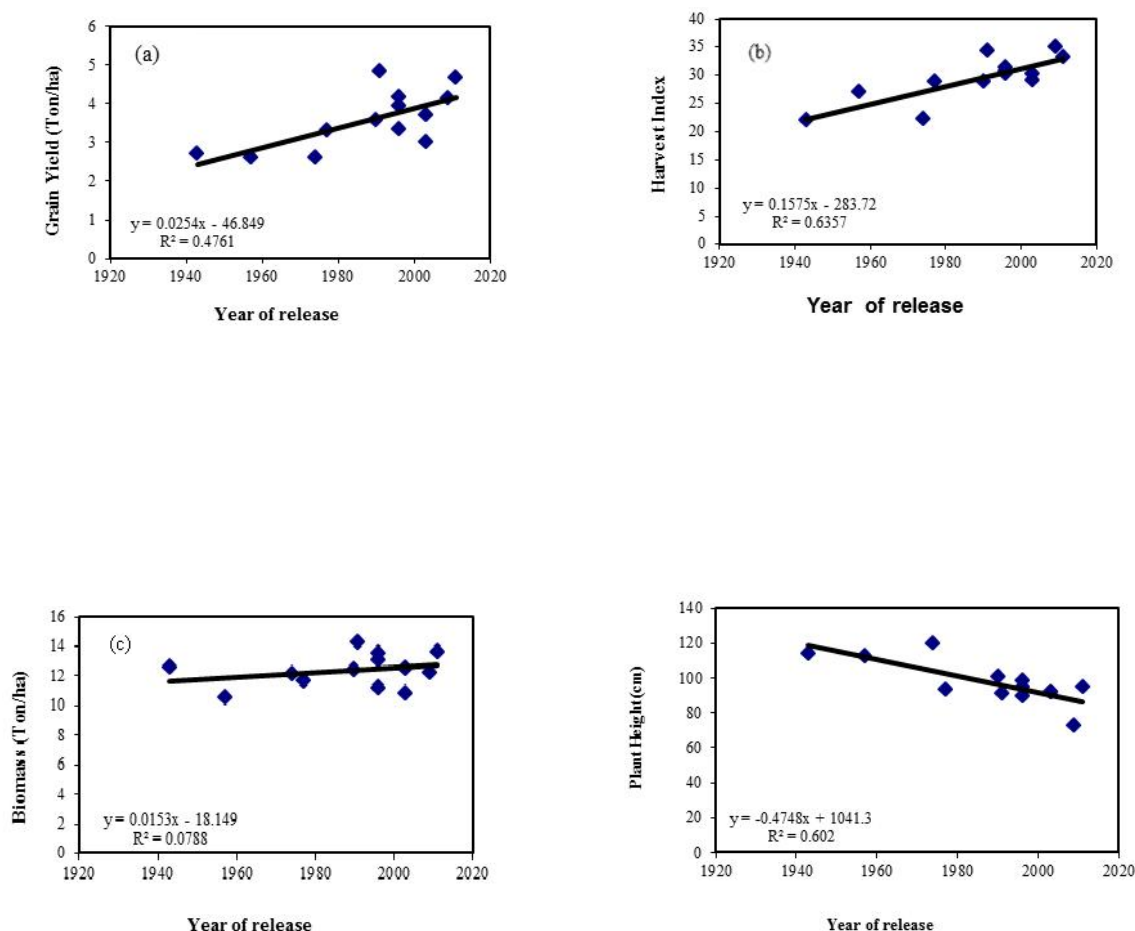


Fig. 1. Temporal variation in (a) grain yield, (b) harvest index, (c) biological yield, and (d) plant height in a set of 13 irrigated facultative/winter bread wheat cultivars released in Iran between 1943 and 2011.

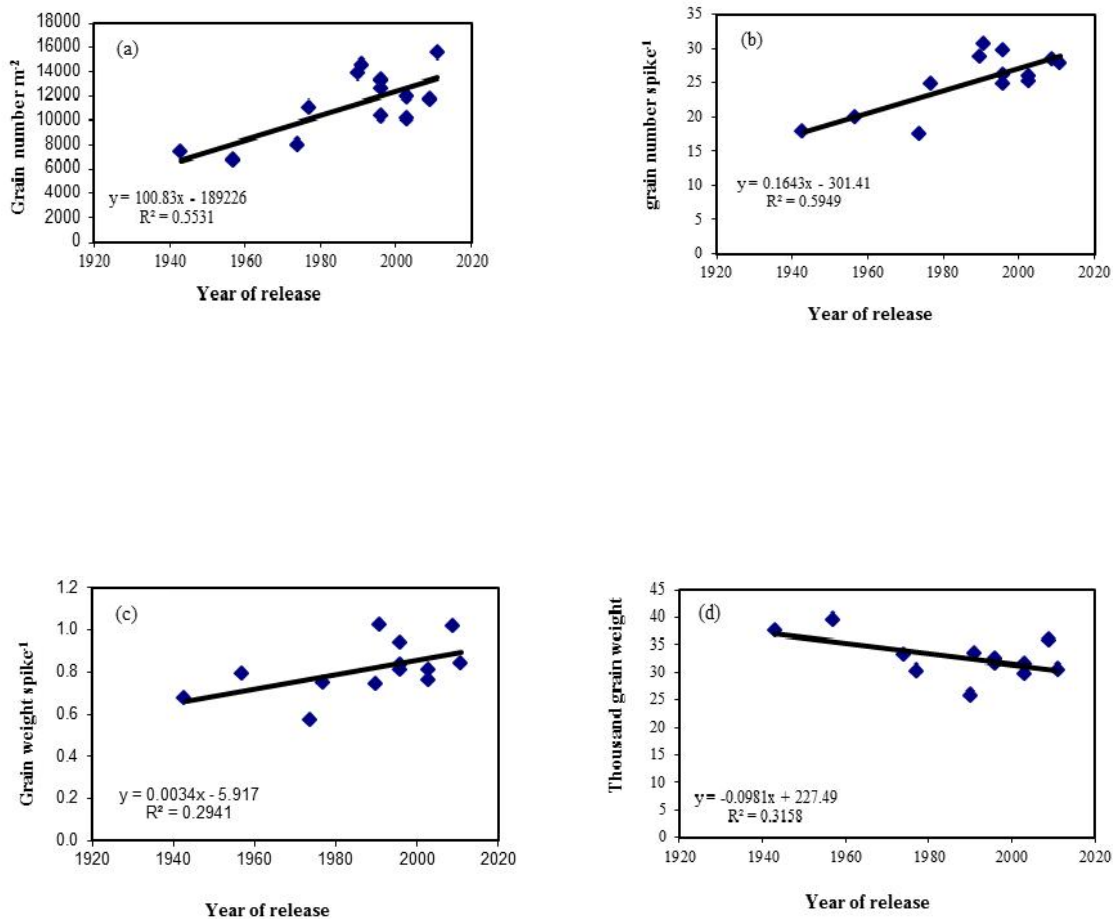
The slower rate of increase in biological yield is reflected in the rate of increase in HI (0.15%; Fig. 1b), which implies that more recent cultivars are more efficient in partitioning accumulated dry matter to the grain. This is especially interesting because plant height decreased during the same

period (Fig. 1d), thus the increase in biological yield is probably linked to yield association traits and perhaps thicker stems. Aisawi *et al.* (2010) reported no significant changes in thousand grain weight in modern bread wheat, compared to older varieties, and Zhou *et al.* (2007) reported little change in

above-ground biomass as a result of breeding. Brancourt-Hulmel *et al.* (2003) reported that –in terms of biomass production and allocation – previous genetic gains in bread wheat yields have been generally associated with increases in HI and decreases in plant height.

Grain number  $m^{-2}$ , one of the most important yield components, increased by  $100 (\pm 27)$  grains  $m^{-2}$  year $^{-1}$  (Fig. 2a) while grain number spike $^{-1}$  also increased, but at a lower rate (Fig. 2b). Grain weight spike $^{-1}$  increased at a rate of  $3.4 (\pm 2)$  g year $^{-1}$  (Fig. 2c), but thousand grain weight decreased by  $98 (\pm 44)$  mg year $^{-1}$  (Fig. 2d). This implies that the increase in grain yield and biological yield during 1943–2011 in facultative/winter wheat cultivars in Iran was mainly attributable to increases in grain weight spike $^{-1}$  due to a greater number of grains spike $^{-1}$ . Zhou *et al.* (2007) analyzed the genetic gain

in yield potential and associated agronomic traits for cultivars released from 1969 to 2000 in Shangdong province in China. Their results indicated that genetic gains in yield potential were largely associated with increases in grain number spike $^{-1}$ , grain weight spike $^{-1}$ , and HI (Zhou *et al.*, 2007). The introduction of dwarfing genes reduced the size of the vegetative organs, thus enhancing the availability of assimilates to the reproductive organs of the plant, expressed as a higher number of grains spike $^{-1}$  (Álvaro *et al.*, 2008). Singh *et al.* (2001) used data from 81 international adaptation trials to show that semi-dwarf genotypes in near-isogenic Rht lines of 10 modern bread wheat and 6 durum wheat cultivars had significantly higher numbers of grains spike $^{-1}$  and grains  $m^{-2}$ . Their results support the positive contribution of semi-dwarfing genes to yield potential.



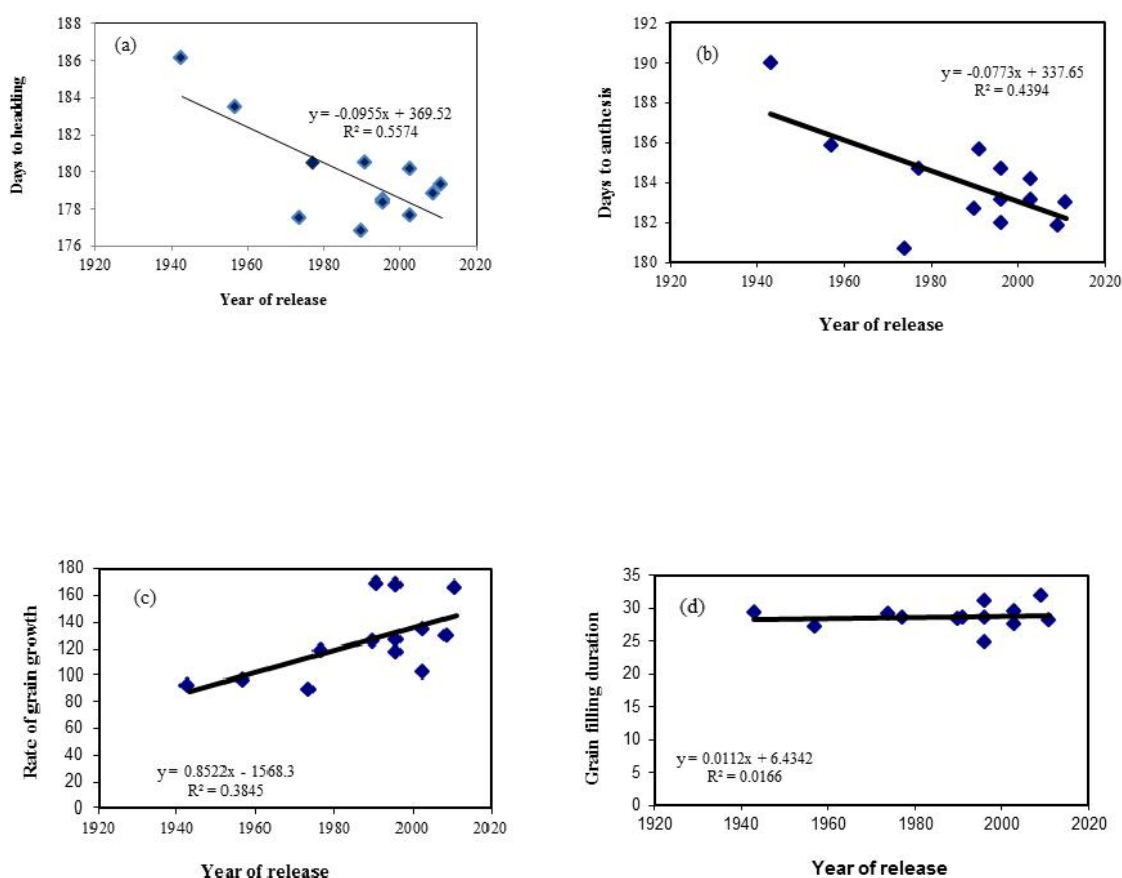
**Fig. 2.** Temporal variation in (a) grain number  $m^{-2}$ , (b) grain number spike $^{-1}$ , (c) grain weight spike $^{-1}$ , and (d) thousand kernel weight in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.

There was considerable variation in number of days to heading. Recent cultivars tended to reach the heading and anthesis stages earlier (Fig. 3a, 3b), indicating effective selection for earliness in days to heading in facultative/winter wheat breeding

programs in Iran during the last 70 years. However, the duration of the grain-filling period has not changed significantly (Fig. 3d), so the crop life cycle has not increased. The rate of grain growth has increased by  $85.2 (\pm 24.4)$  mg  $m^{-2}$  year $^{-1}$  (Fig. 3c),

which can compensate for the longer plant life cycle in the short seasons due to drought and heat. Lopes *et al.* (2012) reported that genetic yield progress in

northwest Mexico was shown to be related with earliness, increased grain size, and cooler canopies at the grain filling stage.



**Fig. 3.** Temporal variation in (a) days to heading, (b) days to anthesis, (c) rate of grain growth ( $\text{mg m}^{-2} \text{ year}^{-1}$ ), and (d) grain filling duration (days) in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.

To analyze possible causes of the grain yield increases observed during 1943–2011, we studied the relationship and contribution of some of the studied traits to grain yield. The relation between grain yield and grain number spike<sup>-1</sup> was positive and highly significant ( $r=0.76^{**}$ ) (Fig. 4d). A high positive and significant relationship between grain yield and grain number  $\text{m}^{-2}$  was also observed ( $r=0.84^{**}$ ) (Fig. 4c). The correlation coefficient between grain yield and HI was highly significant ( $r=0.85^{**}$ ) (Fig. 4b). In this study, a high and significant correlation coefficient was found between grain yield and biological yield ( $r=0.62^{**}$ ) (Fig. 4a). We therefore conclude that grain yield has increased as a result of selection for more grains spike<sup>-1</sup> and thus, selection for more grains per unit area.

Xiao *et al.* (2012) indicated that grain yield was significantly and positively associated with number

of grains  $\text{m}^{-2}$  ( $r=0.65^{**}$ ), above-ground biomass ( $r=0.67^{**}$ ), HI ( $r=0.66^{**}$ ), and was negatively correlated with plant height ( $r=-0.67^{**}$ ). They thus showed that increasing the number of grains  $\text{m}^{-2}$ , above-ground biomass, and HI, and reducing plant height would contribute to grain yield improvements. In their study, number of grains  $\text{m}^{-2}$  was significantly and positively associated with HI ( $r=0.59^*$ ), and highly negatively associated with plant height ( $r=-0.74$ ), indicating that reduced plant height had contributed to improvements in grains number  $\text{m}^{-2}$  and HI.

Days to heading and anthesis and duration of grain-filling period had no significant correlation with grain yield (Fig. 5a, 5b, and 5c). In contrast grain yield was highly correlated with the rate of grain filling (Fig. 5d).

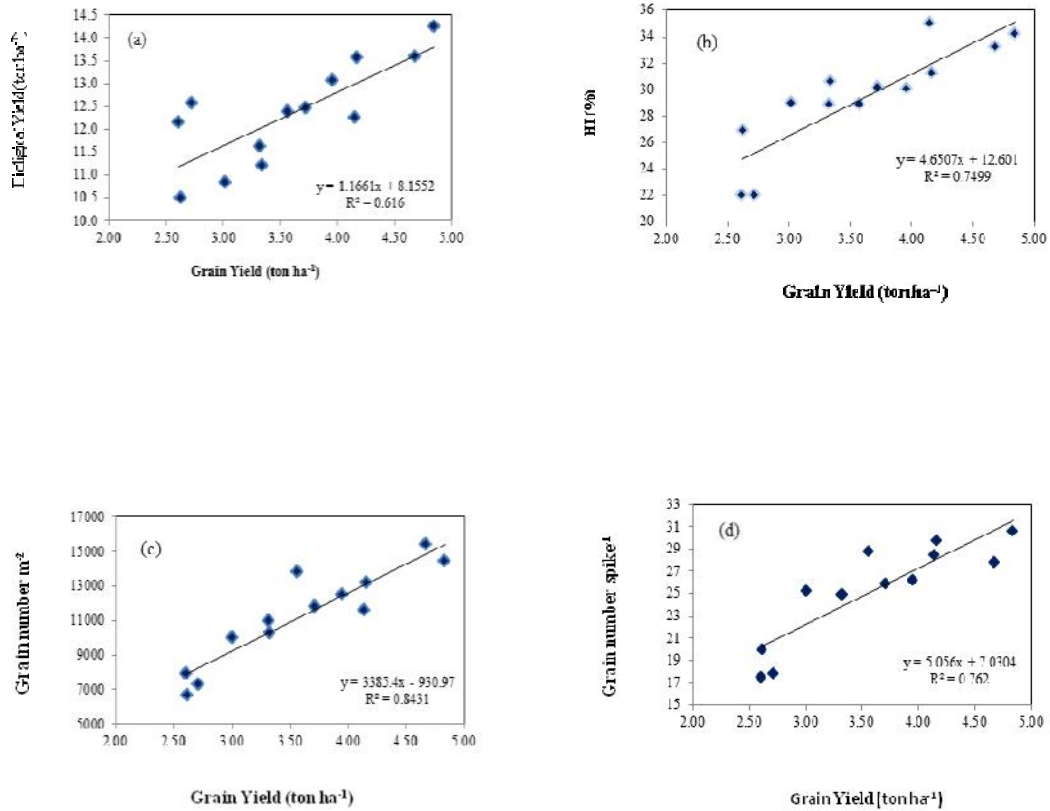


Fig. 4. The relationship between grain yield and: (a) biological yield, (b) harvest index, (c) grain number m<sup>-2</sup>, and (d) grain number spike<sup>-1</sup> in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.

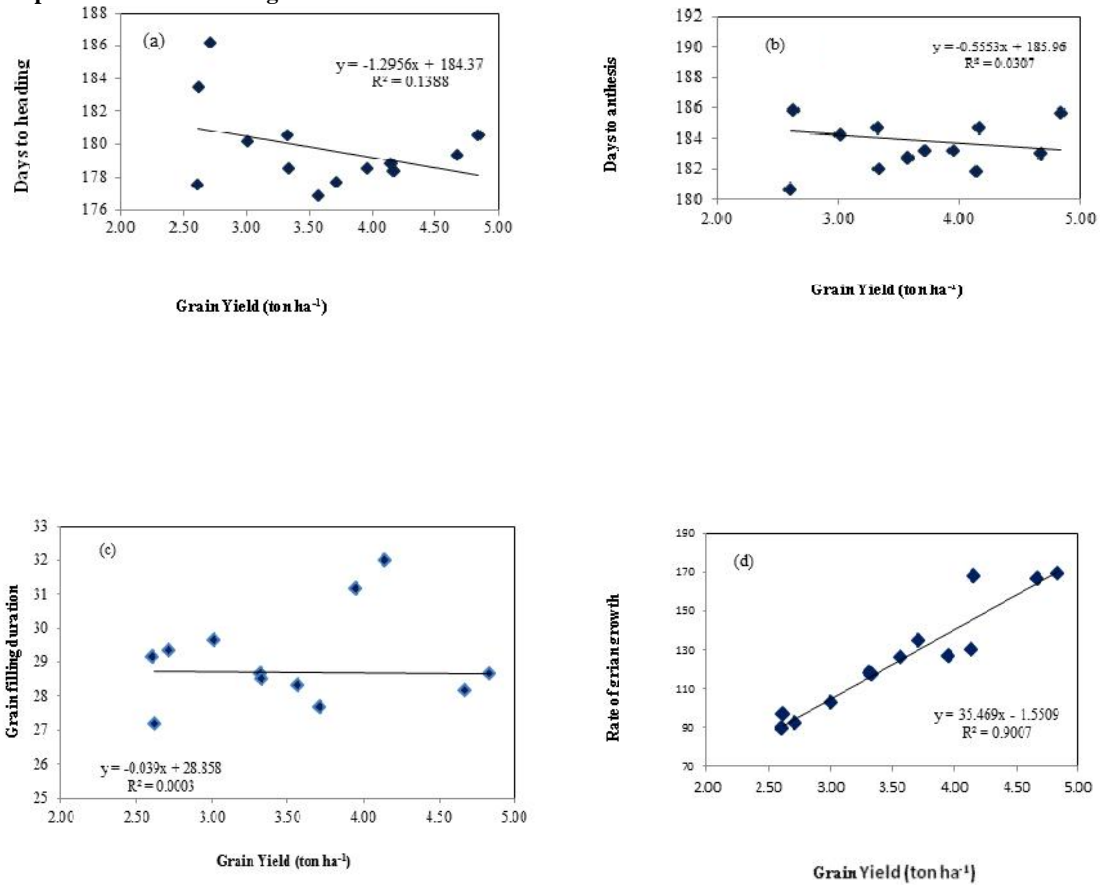


Fig. 5. Relationship between grain yield and: (a) days to heading, (b) days to anthesis, (c) grain filling duration, and (d) rate of grain growth (mg m<sup>-2</sup> year<sup>-1</sup>) in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.

## CONCLUSIONS

It appears that a combination of changes in phenological, agronomic, and physiological traits have contributed to increased grain yield of facultative/winter bread wheat during the past 70 years in Iran. A longer grain-filling period, combined with greater rates of grain growth, have contributed to greater number of grains spike<sup>-1</sup> and grains m<sup>-2</sup>, resulting in higher grain yields in recently released cultivars. A longer grain filling period in wheat could provide sufficient time for the plant to mobilize and transfer water soluble carbohydrate from stems to grains, while a greater rate of grain growth might decrease grain abortion, thus increasing the number of grains in the spike.

Winter wheat breeders in Iran should develop more genetic variation for number of days to heading and anthesis as these two phenological traits will significantly contribute to the adaptation of new facultative/winter bread wheat cultivars under a changing climate. This could be achieved by incorporating new sources of earliness into facultative/winter wheat breeding programs. Crossing adapted cultivars with introduced genotypes might provide opportunities to breed cultivars with shorter duration to heading and to anthesis, thus increasing the duration of the grain-filling period without increasing days to physiological maturity. Selection for a greater rate of grain growth seems to be another promising venue for improving the yields of facultative/winter wheat in Iran.

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