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Temporal variation in phenological characteristics, grain yield, and yield components of spring bread wheat (*Triticum aestivum* L.) cultivars released in Iran between 1952 and 2009

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ABSTRACT

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To estimate genetic progress and the variation in agronomic characteristics and phenology in 15 bread wheat (*Triticum aestivum* L.) cultivars released in Iran between 1952 and 2009, a field experiment was conducted at the Seed and Plant Improvement Institute's Research Field Station in Karaj, Iran, in the 2009-2010 and 2010-2011 growing seasons. Temporal variation trends of the measured traits revealed that grain yield and related traits have increased in more recently released cultivars, though thousand-grain weight has changed only slightly compared with older cultivars released during 1952-2009. Number of days to heading and to anthesis did not change in modern cultivars, but grain-filling period and days to physiological maturity did increase. Grain number spike^{-1} and rate of grain growth increased but plant height decreased in more recently released cultivars.

Keywords: anthesis, grain growth rate, physiological maturity, thousand-grain weight

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is the most widely grown field crop in the world. It is currently sown on about 218 million hectares worldwide with a total annual production of about 650 million tons (Anonymous, 2009). Wheat is a major crop in 43 countries, supplying food for at least 35% of the world population (Trethowan and Pfeiffer, 1999).

World population is reached 7.2 billion in 2014 and is estimated to increase to by more than 2.0 billion by 2050 (Anon., 2014). Global demand for wheat is estimated to increase 1.3% year^{-1} and approximately 1.8% year^{-1} in developing countries by 2025 (Araus *et al.*, 2004). Most of the necessary increases in wheat production must come from increases in grain yield productivity. 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 gains in grain yield may differ in different countries; this may be due to differences in wheat type (spring or winter), crop management or environmental conditions, as well as initial grain yield potential (Austin *et al.*, 1980, 1989; Sayre *et al.*, 1996; 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,b; 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 yield from 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). This is 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^{-1} (Slafer and Andrade 1989; Loss and Siddique, 1994; Calderini *et al*., 1999), and higher harvest index (HI) (Calderini *et al*., 1999; Sayre *et al*., 1996; Calderini and Slafer, 1998).

Sayre *et al.* (1997) reported that progress in spring wheat grain yield was correlated with an increase in grain number per m^{-2} and HI, but not with total biomass production, grain weight, days to anthesis, spike number per m^{-2}, or grains per spike. They concluded that during 1962-1988, spring wheat grain yield in northwest Mexico increased at a rate of 64 kg ha^{-1} $year^{-1}$ (Sayre *et al*., 1996). 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 kg/ha/year. This study investigated the genetic progress in grain yield and several phenological characteristics of a set of important spring bread wheat cultivars released in Iran during 1952-2009.

MATERIALS AND METHODS

To evaluate grain yield, yield components, and some agronomic characteristics, we grew 15 bread wheat (*Triticum aestivum* L.) cultivars, released in Iran between 1952 and 2009, under well-watered field conditions using a randomized complete block design with three replications, at the Seed and Plant Improvement Institute's Research Field Station in the 2009-10 and 2010-11 growing seasons. The field station is located at Karaj (50º55' E, 35º 50' N and 1270 masl). The soil was a clay loam with pH = 7.5. Meteorological data during the study are shown in Table 1. Detailed information on the bread wheat cultivars evaluated in this study is given in Table 2.

Each experimental plot consisted of three rows, each 6 m long, with 20 cm row spacing and a harvested area of 6 m^2. Seeds were sown with a planter at a density of 400 seeds per m^{-2}. We applied 250 kg ha^{-1} of urea: 50% as basal application at planting and 50% as top dressing at the beginning of stem elongation. Basal application of 200 kg ha^{-1} phosphorus from diammonium phosphate and 100 kg ha^{-1} potassium from potassium sulfate were also applied. Within each plot, 10 plants per replication were randomly selected and different traits were measured and recorded. Grain yield, yield components, and biological yield were determined following Sayre *et al.* (1996). We used SAS (SAS Institute, 2000) and SPSS (Einspruch, 2005) software for analyzing data and plotting graphs.

Table 1. Meteorological conditions at the experimental site in the 2009-10 and 2010-11 growing seasons.

Growing season	Temperature (ºC)						Precipitation (mm)	
	Min.		Max.		Mean			
	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	-13.0	-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. Information on spring bread wheat cultivars evaluated for phenological and grain yield changes in Iran during 1952-2009.

	Name	Pedigree/Cross name	Plant height (cm)	Grain yield (kg/ha)	Harvest index (%)	Year of release
1	Tabasi	local variety	122.6	3157	25	1952
2	Sholeh	local variety	120.4	3317	25	1958
3	Roshan	local variety	124.5	3964	31	1958
4	Khalij	local variety	110.4	3391	30	1961
5	Inia	Lr64/Sn64	98.9	4971	38	1969
6	Karaj1	200H/Vfn//Rsh	120.6	3617	28	1974
7	Moghan2	Choti Lerma	113.8	4080	30	1975
8	Adl	Shahpasand/Turky	93.9	5427	41	1977
9	Azadi	4820/1-32-15409//Mxp	99.2	4490	38	1980
10	Golestan	Alandora"s"	95.9	5130	39	1987
11	Darab 2	Maya"s'/Nac	89.8	5220	40	1996
12	Chamran	Attila	89.0	5238	42	1998
13	Pishtaz	Alvand//Aldan/Ias58	90.7	5231	40	2003
14	Darya	SHA4/CHIL	93.2	5646	44	2008
15	Parsi	Dove"s"/ Buc"s"//2*Darab	92.5	5654	40	2009

Data from two growing seasons (2009-2010 and 2010-2011) were compiled and a combined analysis of variance was performed.

RESULTS AND DISCUSSIONS

Considerable variation in grain yield, yield components, and agronomic traits was observed among cultivars. We were mostly interested in studying the variation and trends shown by different traits from 1952 to 2009. Grain yield increased by 40 kg ha^{-1} $year^{-1}$ (Fig. 1a), while biological yield increased at a slower rate of 13 kg ha^{-1} $year^{-1}$ (Fig. 1c). This is reflected in the rate of increase in HI (0.28%; Fig. 1b), which implies progress in partitioning accumulated dry matter to the grain in more recent cultivars. 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-associated traits and perhaps thicker stems. Aisawi *et al*. (2010) reported no significant changes in thousand-grain weight in modern bread wheat cultivars as compared to older varieties, and Zhou *et al.* (2007) reported little change in above-ground biomass as a result of breeding efforts.

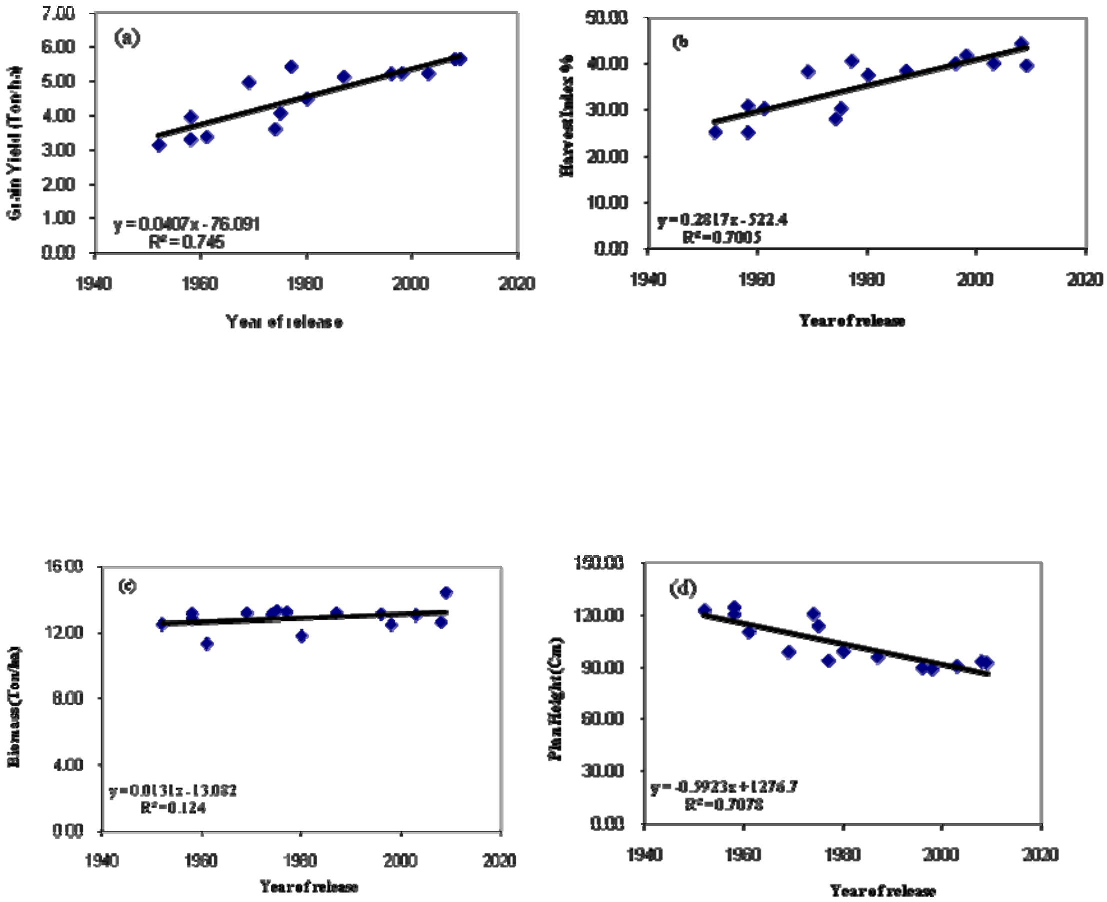

Fig. 1. Temporal variation in (a) grain yield, (b) harvest index, (c) biological yield, and (d) plant height in a set of 15 spring bread wheat cultivars released between 1952 and 2009 in Iran.

Grain number per m^{-2}, one of the most important yield components, increased by 122 (± 28) grains m^{-2} $year^{-1}$ (Fig. 2a); grain number $spike^{-1}$ also increased, but at a lower rate (Fig. 2b). Grain weight $spike^{-1}$ increased at a rate of 5.6 (± 1.1) mg $year^{-1}$ (Fig. 2c), but with no change in thousand-grain weight (Fig. 2d). This leads us to conclude that the increase in grain yield and biological yield during 1952-2009 in Iran is attributable mainly 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 grains $spike^{-1}$, grain weight $spike^{-1}$, and HI. Sanchez-Garcia *et al.* (2012) reported that from 1930 to 2000, grain yield increased at a rate of 35.1 kg ha^{-1} $year^{-1}$, or 0.88%

year^{-1}, in Spain. They also showed that grain number spike^{-1} and spike number per m^{-2} increased at a rate of 0.60% year^{-1} and 0.30% year^{-1}, respectively, while grain weight remained unchanged. Sadras and Lawson (2007) compared 13 South Australian wheat varieties released between 1958 and 2007 and reported that grain yield increased linearly with year of cultivar release at a rate of 25 ± 3.4 kg ha^{-1} year^{-1}.

Singh *et al*. (2001) used data from 81 international adaptation trials to show that semidwarf wheat 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 per m^{-2}. Their results support the positive contribution of semi-dwarfing genes to yield potential.

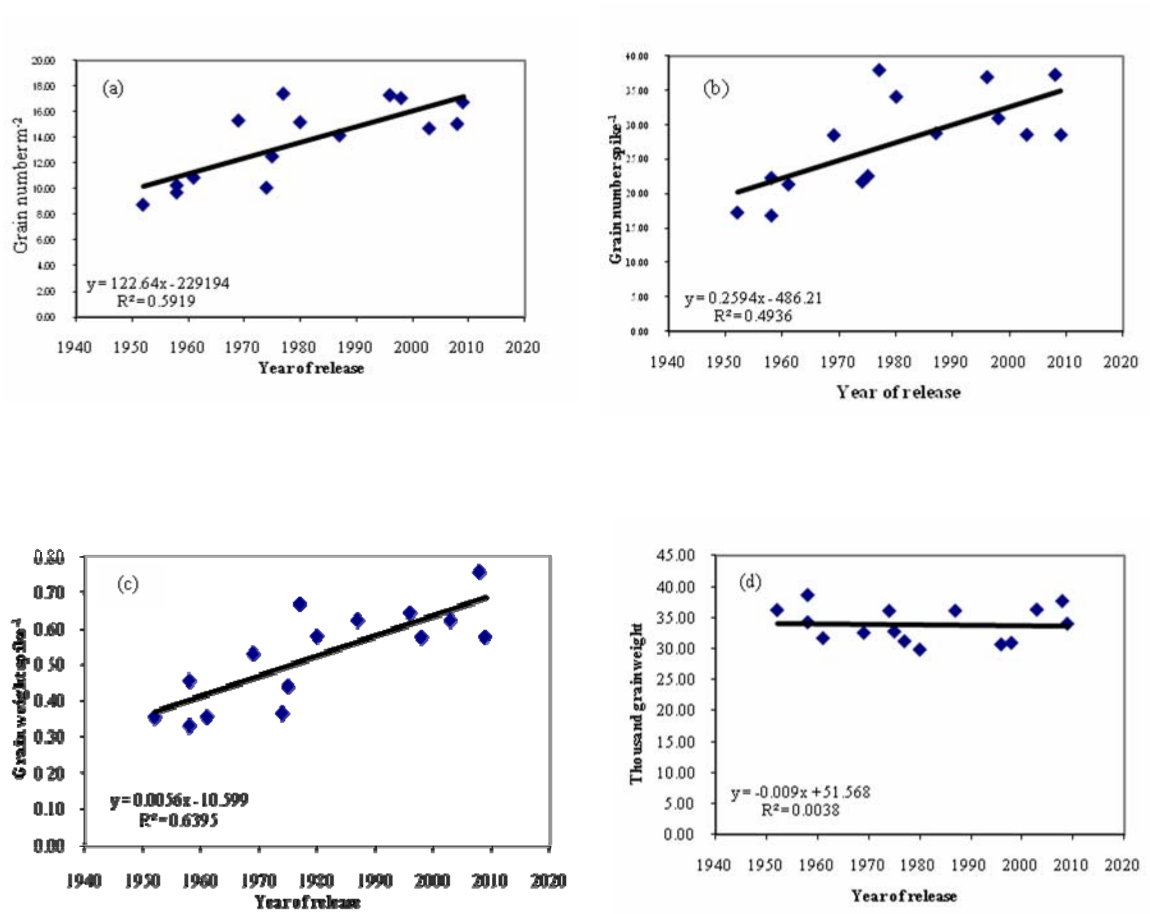

Fig. 2. Temporal variation in (a) grain number per m^{-2}, (b) grain number spike^{-1}, (c) grain weight spike^{-1}, and (d) thousand-grain weight in a set of 15 spring bread wheat cultivars released between 1952 and 2009 in Iran.

Considerable variation was not observed in the number of days to heading. Recent cultivars tended to reach heading and anthesis at the same time as the older ones (Fig. 3a). This implies that selection for earliness in heading by Iranian wheat breeding programs over the last 59 years was not effective. However, duration of grain-filling period and days to maturity increased (Figs. 3b and 3d, respectively); hence, the crop life cycle increased slightly. The rate of grain growth increased by 123 (± 2) mg m^{-2} year^{-1} (Fig. 3c), which could compensate for the longer plant life cycle in the short seasons due to terminal drought and heat stresses.

To analyze possible causes of the grain yield increases observed during 1952-2009, we studied the relationship and contribution of several traits to grain yield. The relationship between grain yield and grain number spike^{-1} was positive and highly significant ($r = 0.86^{**}$) (Fig. 4d). A high positive correlation between grain yield and grain number m^{-2} was also observed ($r = 0.92^{**}$) (Fig. 4c). The correlation coefficient between grain yield and HI was highly significant ($r = 0.96^{**}$) (Fig. 4b), but we did not find a significant correlation between grain

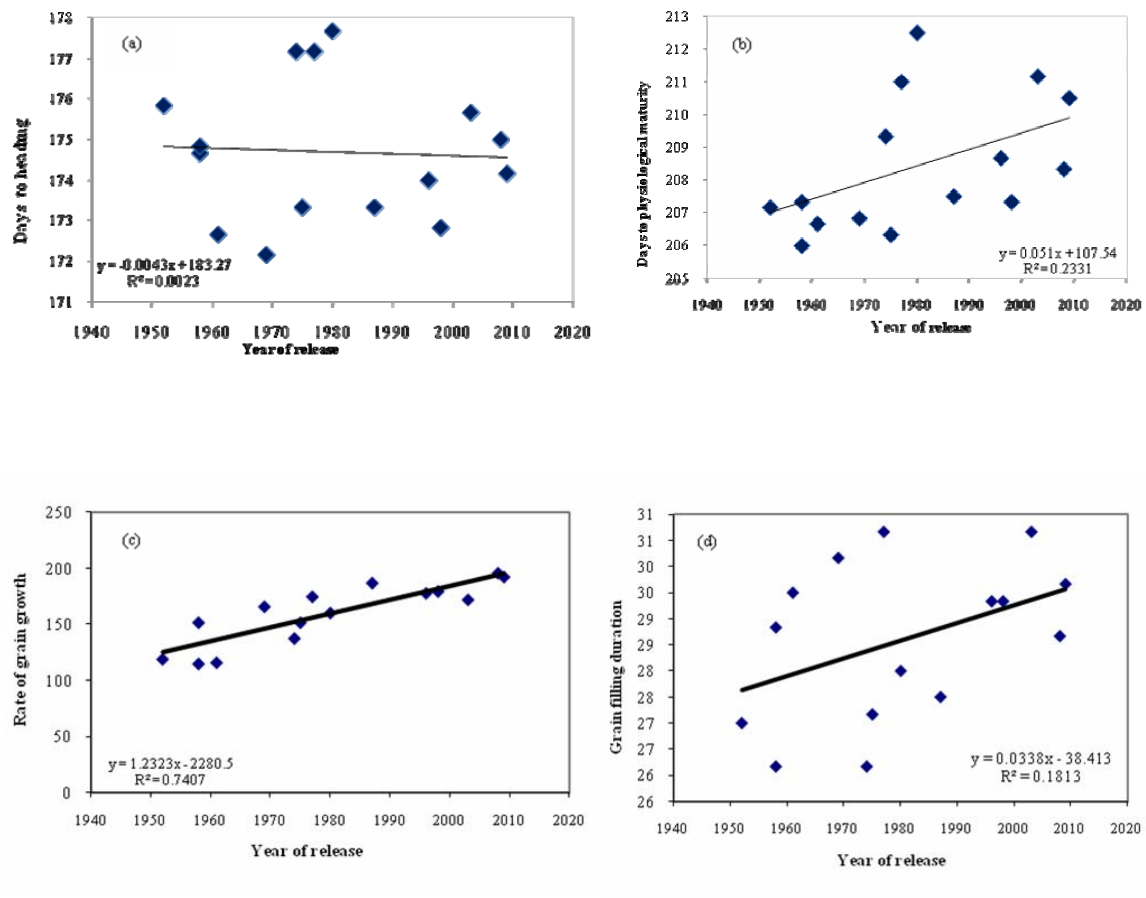

Fig. 3. Temporal variation in (a) days to heading, (b) days to physiological maturity, (c) rate of grain growth, and (d) grain-filling period in a set of 15 spring bread wheat cultivars released between 1930 and 2007 in Iran.

yield and biological yield (r = 0.4) in this study (Fig. 4a). Therefore, we conclude that grain yield has increased as a result of selection for more grains spike^{-1} and thus, selection for more grains per unit area.

Xiao *et al*. (2012) indicated that grain yield was significantly and positively associated with grains per m^{-2} (r = 0.65**), aboveground biomass (r = 0.67**), and HI (r = 0.66**), and negatively correlated with plant height (r = −0.67**). They showed that increased grains per m^{-2}, above-ground biomass, and HI, and reduced plant height contributed to grain yield improvement. In their study, grains per m^{-2} was significantly and positively associated with HI (r = 0.59*5), and highly significant and negatively associated with plant height (r = −0.74**), indicating that reduced plant height contributed to improving grains per m^{-2} and HI. Sadras and Lawson (2007) showed that yield improvement in 13 South Australian wheat varieties released between 1958 and 2007 was associated with a linear increase in HI during that same period and with increased shoot biomass in varieties released after the early 1980s.

Days to heading had no significant correlation with grain yield (Fig. 5a). In contrast, an intermediate positive correlation was found between grain yield and days to physiological maturity (Fig. 5b). A positive correlation, although not significant, was found between grain yield and duration of grain-filling period (Fig. 5c) and grain yield was highly correlated with grain growth rate (Fig. 5d).

CONCLUSIONS

It appears that a combination of changes in phenological and physiological traits along with changes in number of grains spike^{-1} have contributed to improving grain yield in spring bread wheat during the last 59 years in Iran. A longer grain-filling period combined with a higher rate of grain growth has contributed to increasing the number of grains spike^{-1} or grains per m^{-2} and resulted in higher grain yield in recently released cultivars. A longer grain-filling period may give wheat plants enough time to mobilize and transfer water soluble carbohydrates from stems to grains, under irrigated conditions. Higher grain growth rate may reduce grain abortion, thus increasing the number of grains spike^{-1}. It appears that the greater number of days to physiological maturity was due to the longer grain-

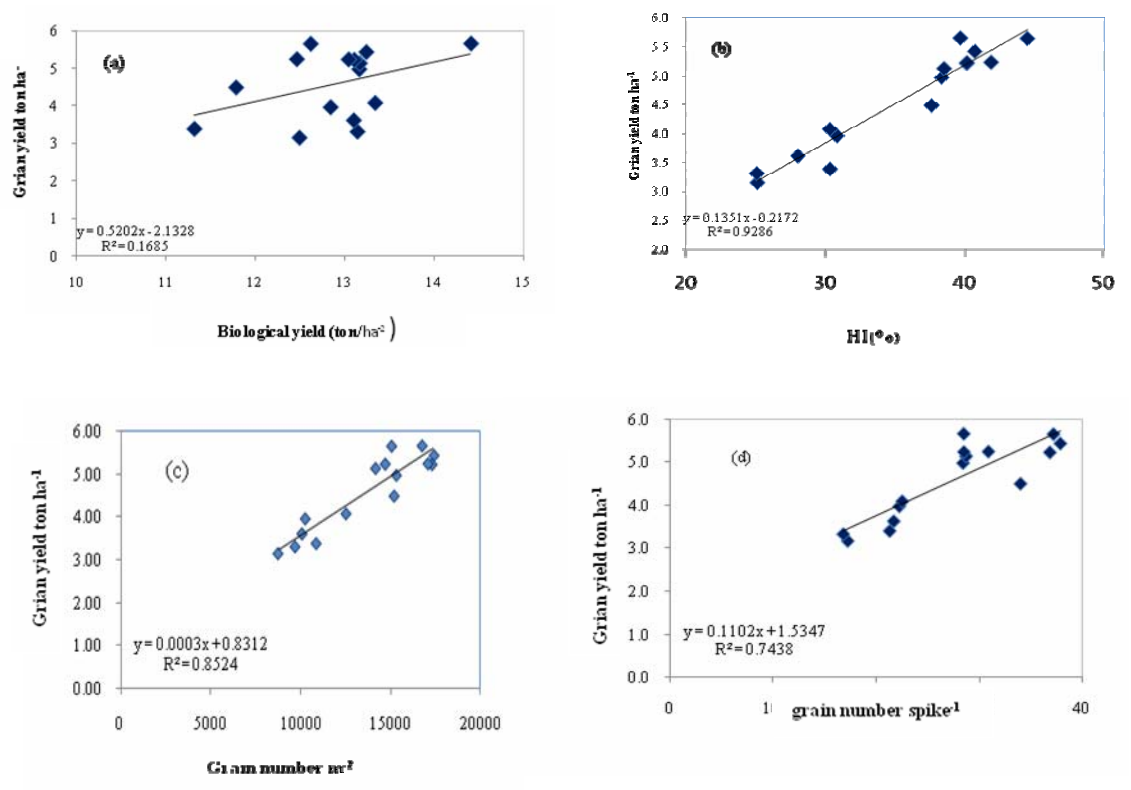

Fig. 4. Relationship between grain yield and biological yield (a), harvest index (b), grain number per m^{-2} (c), and grain number spike^{-1} (d) in a set of 15 spring bread wheat cultivars released between 1952 and 2009 in Iran.

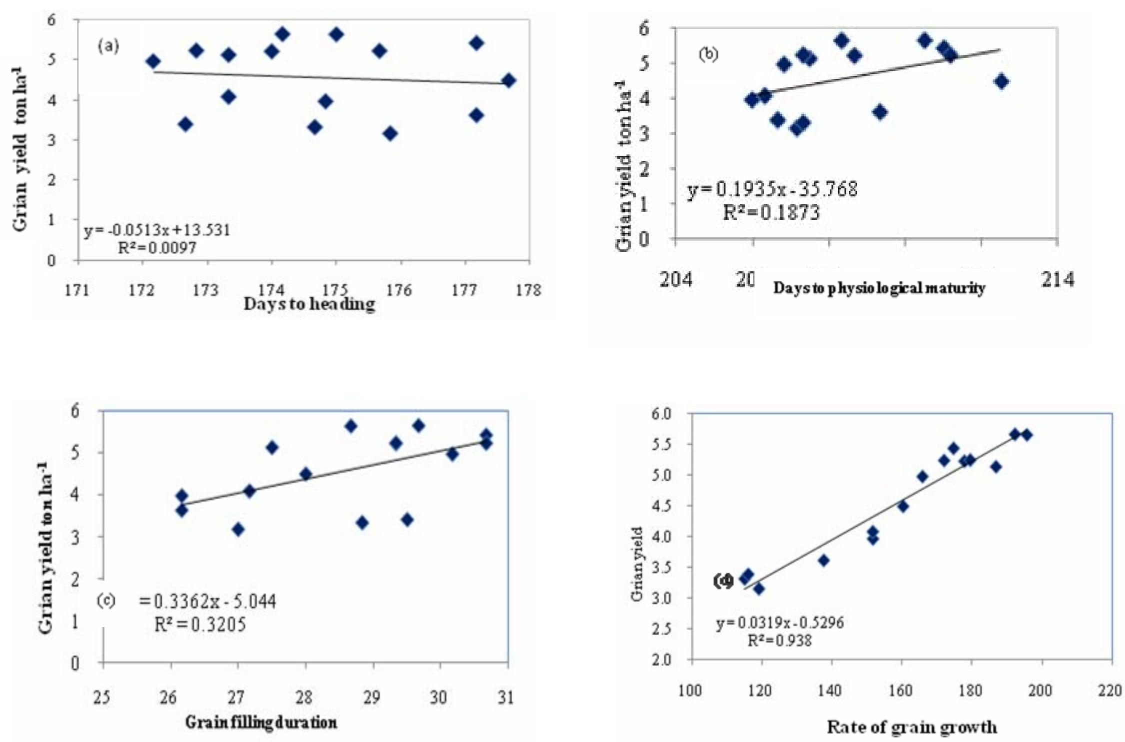

Fig. 5. Relationship between grain yield and days to heading (a), days to physiological maturity (b), grain-filling duration (c) and rate of grain growth (d) in a set of 15 spring bread wheat cultivars released between 1952 and 2009 in Iran.

filling period observed in late cultivars as compared with early cultivars.

Wheat breeders in Iran should focus on developing genetic variation for number of days to heading and to anthesis, as these two phenological traits have not changed significantly in Iranian wheat cultivars over the past 59 years. This could be achieved by introducing new early-maturing germplasm in Iranian spring bread wheat breeding programs. Crossing adapted cultivars with introduced earlier-maturing germplasm may provide opportunities to breed cultivars with fewer days to heading and anthesis, thus further increasing the duration of grain-filling without increasing days to physiological maturity. Selection for greater rate of grain growth may be another way of improving grain yield in the future.

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