DOI: http://dx.doi.org/10.22092/cbj.2016.107103

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

M. Esmaeilzadeh Moghaddam[1], M. R. Jalal Kamali[2], N. Soda[3], S. Sadre Jahani[4], and M. Ghodsi[5]

[1]Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran.
[2]Internatioanl Maize and Wheat Improvement Cenetr (CIMMYT), Karaj, Iran.
[3]Islamic Azad University, Karaj, Iran.
[4]Agriculture faculty of Varamin, Islamic Azad University, Varamin, Iran.
[5]Khorasan-e-Razavi Agriculture and Natural Research Center, Agricultural Research, Education and Extension Organization (AREEO), Mashhad, Iran.
* Corresponding author E-mail address:esmaeilzadehmohsen@ymail.com

Received: July 2016
Accepted: August 2016

## ABSTRACT

**Esmaeilzadeh Moghaddam, M., Jalal Kamali, M. R., Soda, N., Sadre Jahani, S., and Ghodsi, M. 2016.** 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. **Crop Breeding Journal 4, 5 and 6 (2; 1 and 2): 9-16.**

**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 penological 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 phonological 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, butgrain-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 forat 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 there after (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 Salfer 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; Stapperand Fischer, 1990; Araus *et al.*, 2004), increased grain numberm$^{-2}$ (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 kgha$^{-1}$ 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 kgha$^{-1}$ year$^{-1}$.

This study investigated the genetic progress of some agronomic and phonological 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 50º 55' E, 35º 50' N, 1270 masl and its soil is a clay loam with pH=7.5. Meteorological information for both cropping cyclesat 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.**

| | Temperature (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | Mean | | Precipitation (mm) | |
| Cropping cycle | 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 (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 m$^2$. Seeds were planted using a Winter Steiger planter with a seeding density of 400 seed m$^{-2}$. Basal fertilizers (200 kg ha$^{-1}$ ammonium de phosphate and 100 kg ha$^{-1}$ potassium sulfate) were applied in addition to 125kg ha$^{-1}$urea applied as basal at planting and 125 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 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 thetemporal variation and trends in different traits in facultative/winter bread wheat cultivars released during 1943-2011. Grain yield increased by 25kg ha$^{-1}$ year$^{-1}$ (Fig. 1a) though biological yield increased at a slower rate of 15 kg ha$^{-1}$ year$^{-1}$ (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$^{-2}$ | Grain no. m$^{-2}$ | Grain no.spike$^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| 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.**

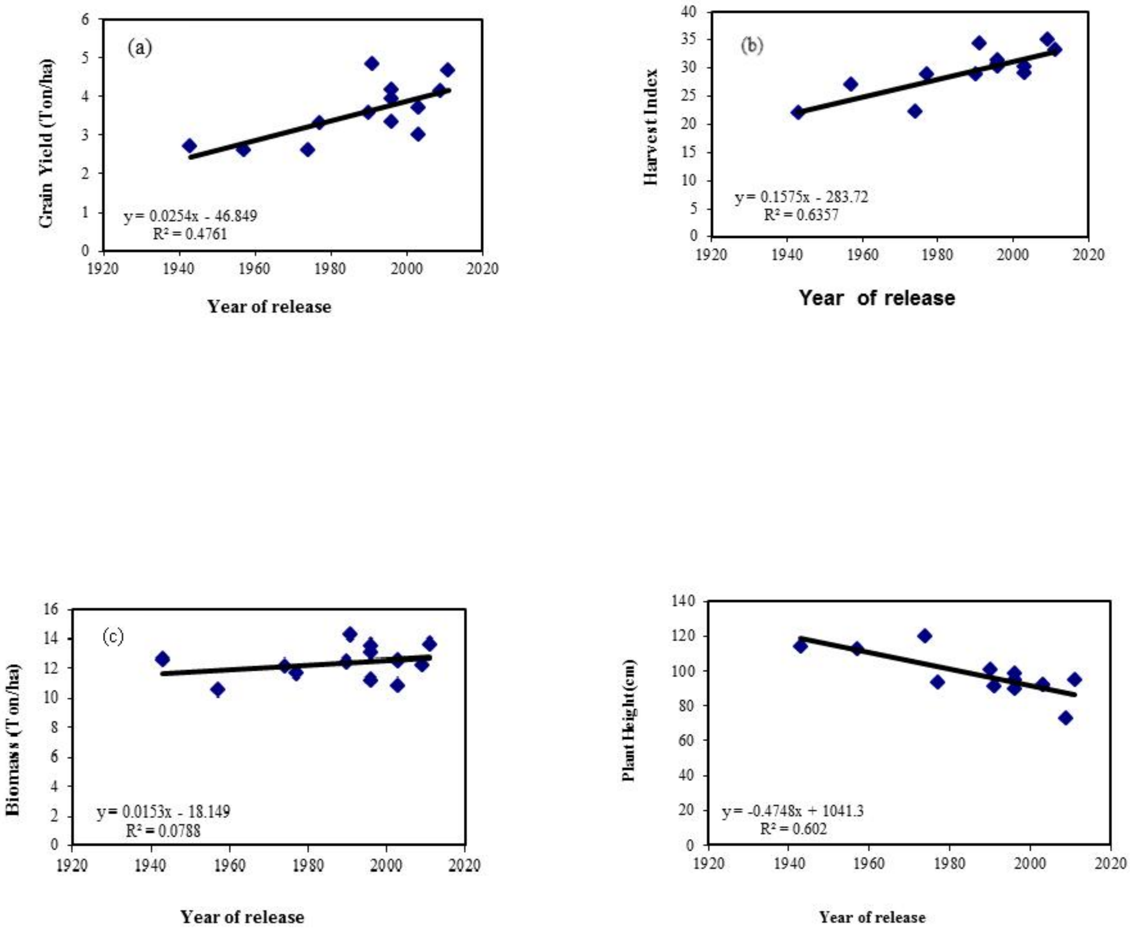


**Fig. 1. Temporal variation in (a) grain yield, (b) harvest index, (c) biological yield, and (d) plant height in a set of 13 irrigated facultative/winter bread wheat cultivars released in Iran between 1943 and 2011.**

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 (±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(±2) g $year^{-1}$ (Fig. 2c), but thousand grain weight decreased by 98 (±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.

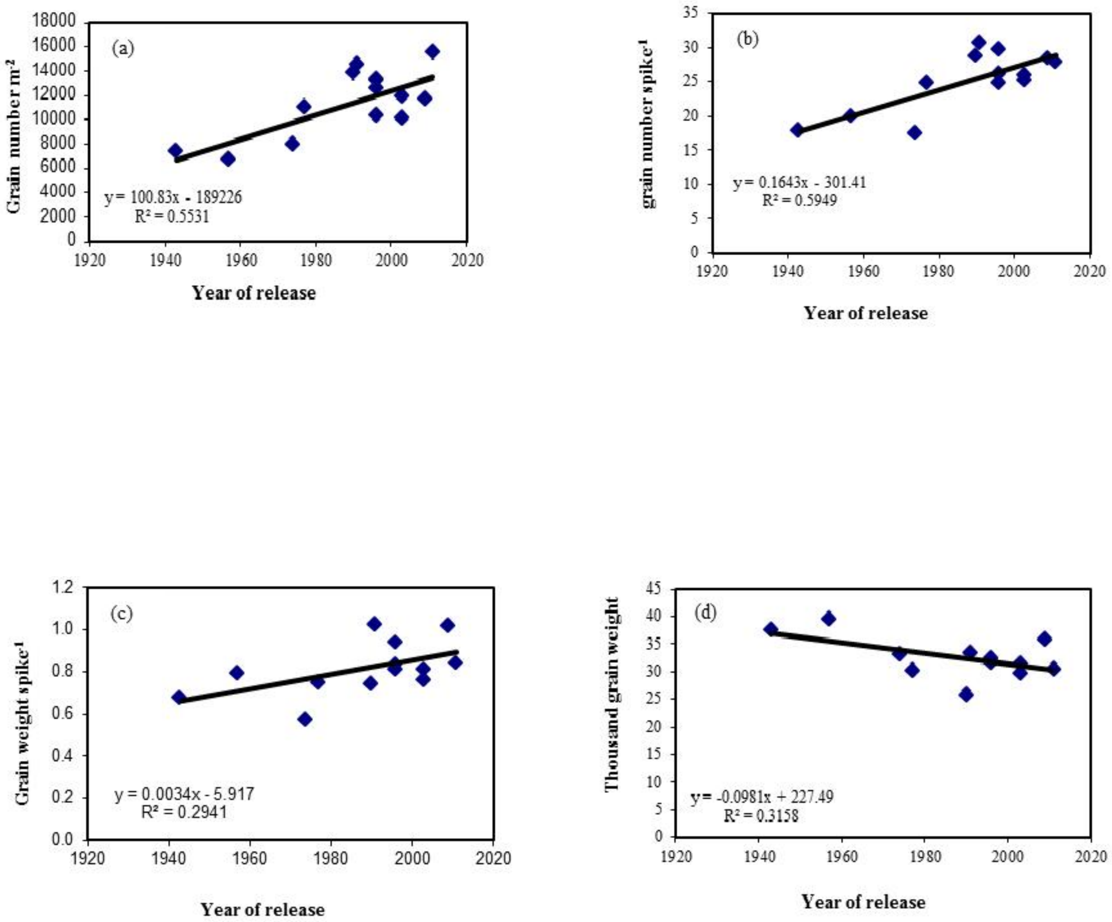


**Fig. 2. Temporal variation in (a) grain number $m^{-2}$, (b) grain number $spike^{-1}$, (c) grain weight $spike^{-1}$, and (d) thousand kernel weight in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.**

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 thelast 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 (±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.

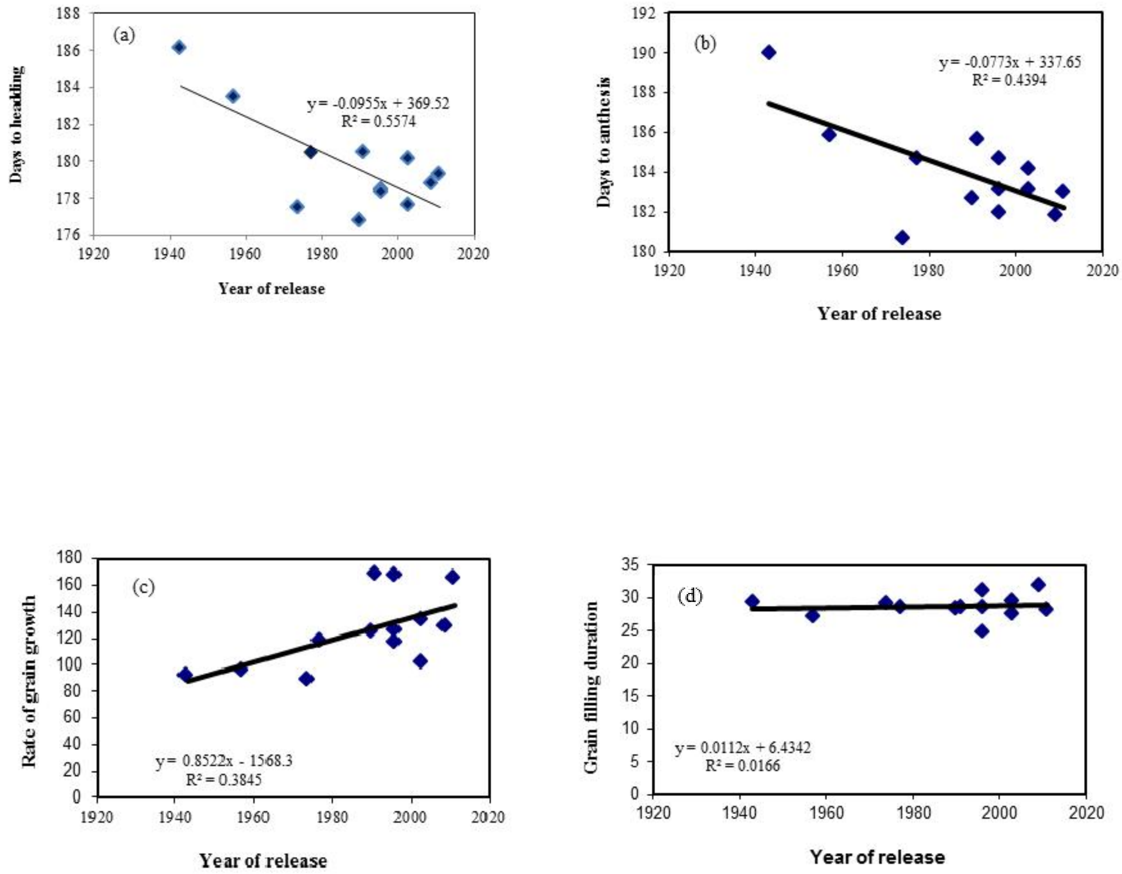


**Fig. 3. Temporal variation in (a) days to heading, (b) days to anthesis, (c) rate of grain growth (mg m$^{-2}$ year$^{-1}$), and (d) grain filling duration (days) in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.**

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$^{-1}$ was positive and highly significant (r=0.76$^{**}$) (Fig. 4d). Ahigh positive and significant relationship between grain yield and grain number 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$^{-1}$ 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 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 m$^{-2}$, above-ground biomass, and HI, and reducing plant height would contribute to grain yield improvements. In their study, number of grains 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 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).

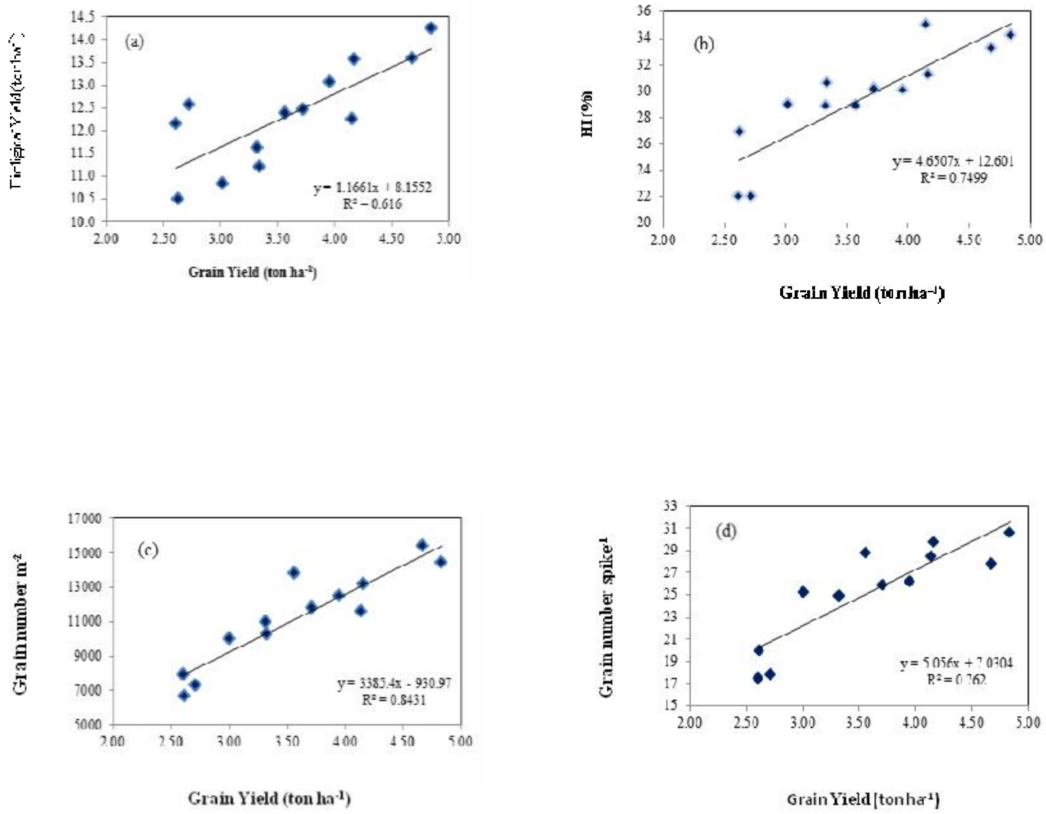


**Fig. 4. The relationship between grain yield and: (a) biological yield, (b) harvest index, (c) grain number m$^{-2}$, and (d) grain number spike$^{-1}$ in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.**

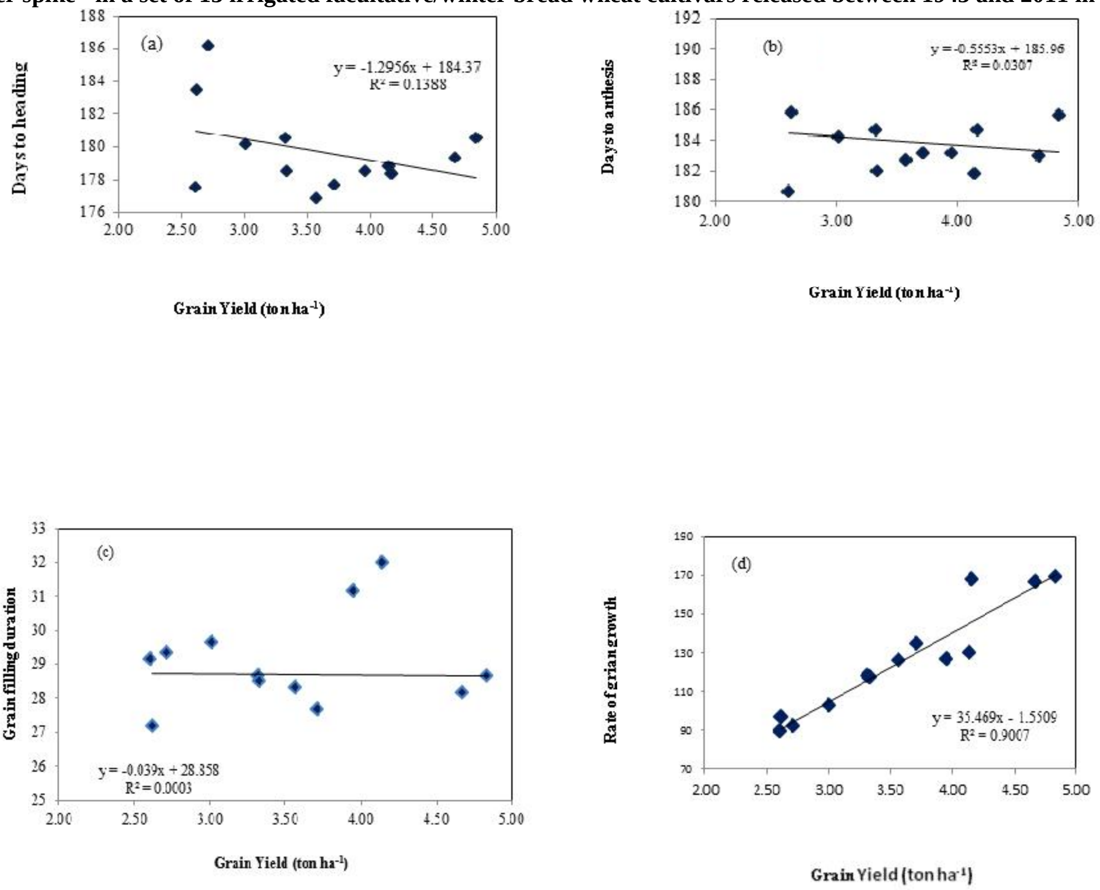


**Fig. 5. Relationship between grain yield and: (a) days to heading, (b) days to anthesis, (c) grain filling duration, and (d) rate of grain growth (mg m$^{-2}$ year$^{-1}$) in a set of 13 irrigated facultative/winter bread wheat cultivars released between 1943 and 2011 in Iran.**

## 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$^{-1}$and grains m$^{-2}$, 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 agreater 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.

## REFERENCES

Alvaro, F., J. Isidro, D. Villegas, L. F. Garcia-Delmoral, and C. Royo. 2008. Old and modern durum wheat varieties from Italy and Spain differ in main spike components. Field Crops Res.106: 86–93.

Araus, J., G. A. Slafer, M. P. Reynolds, and C. Royo. 2004. Physiology of yield and adaptation in wheat and barley. Pp. 1-49. *In* Nguyen H. T., and A. Blum (eds.). Physiology and Biotechnology Integration for Plant Breeding. CRC Press. Taylor and Francis Group.

Aisawi, K., M. J. Foulkes, M. P. Reynolds, and S. Mayes. 2010. The physiological basis of genetic progress in yield potential of CIMMYT wheat varieties from 1966 to 2009. Pp. 349. *In* Dzyubenko, N. I. (ed.). Proceedings of 8th International. Wheat Conference. St. Petersburg, Russia.

Austin, R. B., J. Bingham, R. D. Blackwell, L. T. Evans, M. A. Ford, C. L. Morgan, and M. Taylor. 1980. Genetic improvements in winter wheat yields since 1900 and associated physiological changes. J. Agric. Sci. Camb. 112: 295-301.

Austin, R. B., M. A. Ford, and C. L. Morgan. 1989. Genetic improvement in yield of winter wheat: A further evaluation. J. Agric. Sci.Camb. 112: 295-301.

Brancourt-Hulmel, M., G. Doussinault, C. Lecomte, P. Berard, B. LeBuanec, M. Trottet. 2003. Genetic improvement of agronomic traits of winter wheat cultivars released in France from 1946 to 1992. Crop Sci. 43: 37–45.

Calderini, D. F., and G. A. Slafer. 1998. Changes in yield and yield stability in wheat during the 20th century. Field Crops Res. 57(3): 335-347.

Calderini, D. F., M. P. Reynolds, and G. A. Slafer.1999. Genetic gains in wheat yield and associated physiological changes during the twenty century. Pp. 351-377. *In* Satorre, E. H., and G. A. Slafer (eds.). Wheat: ecology and physiology of yield determination. Food Product Press.

Dixon, J., H. J. Braun, P. Kosina, J. Crouch. 2009. Wheat facts and figures 2009. Mexico, D. F.: CIMMYT. 95 pp.

Einspruch, E. L. 2005. An introductory guide to SPSS for windows. Stage Publication Inc. Thousand Oaks, CA.

FAO. 2006. World agriculture: Towards 2030/2050. Interim Report. Global Perspective Studies Unit. FAO, Rome, Italy.

FAO. 2012. FAOSTAT agriculture data. Agricultural production 2009. FAO, Rome. Available at: http://faostat.fao.org.

Lopes, M. S., M. P. Reynolds, Y. Manes, R. P. Singh, J. Crossa, and H. J. Braun.2012. Genetic yield gains and changes in associated traits of CIMMYT spring bread wheat in a “Historic” set representing 30 years of breeding. Crop Sci. 52: 1123–1131.

Loss, S. P., and K. H. M. Siddique. 1994. Morphological and physiological traits associated with wheat yield increases in Mediterranean environments. Adv. Agron. 52: 229-276.

Perry, M.W., and M.F. d'Antuono. 1989. Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. Crop Pasture Sci. 40(3): 457-72.

Richards, R. A. 1996a. Defining selection criteria to improve yield under drought. Plant Growth Regul. 20: 57-166.

Richards, R. A. 1996b. Increasing yield potential in wheat-source and sink limitations. pp.134-149. *In:* Reynolds, M. P., S. Rajaram, and A. McNab (eds). Increasing yield potential in wheat: Breaking the barriers. Mexico, D. F.: CIMMYT.

SAS Institute. 2000. The SAS system for windows. Release 8.01, SAS InstInc, Cary, New York City.

Satorre, E. H., and G. A. Slafer. 1999.Wheat: ecology and physiology of yield determination. Food Product Press. 503 pp.

Sayre, K. D. 1996.The role of crop management research in CIMMYT in addressing bread wheat yield potential issues. Pp. 203-208. *In* Reynolds, M. P., S. Rajaram, and A. McNab (eds.). Increasing yield potential in wheat: Breaking the barriers. Mexico, D. F.: CIMMYT.

Sayre, K. D., S. Rajaram, and R. A. Fischer. 1997. Yield potential progress in short bread wheats in North Mexico. Crop Sci. 37: 36-42.

Singh, R. P., J. Huerta-Espino, S. Rajaram, and J. Crossa. 2001. Grain yield and other traits of tall and dwarf isolines ofmodern bread and durum wheats. Euphytica. 119:241–244.

Slafer, G. A., and F. H. Andrade. 1989. Genetic improvement in bread wheat (*Triticum aestivum*) yield in Argentina. Field Crops Res. 21(3): 289-296.

Trethowan, R., and W. H. Pfeiffer.1999. Challenges and future strategies in breeding wheat for adaptation to drought stressed environments: A CIMMYT wheat program perspective. Pp. 45-48. *In* Ribaut, J. M., and D. Poland (eds.). Molecular approaches for the genetic improvement of cereals for stable production in water-limited environments. Mexico, D F: CIMMYT.

Xiao, Y. G., Z. G. Qian, K. Wu, J. J. Liu, X. C. Xia, W. Q. Ji, and Z. H. He. 2012. Genetic gains in grain yield and physiological traits of winter wheat in Shandong province, China, from 1969 to 2006. Crop Sci. 52: 44–56.

Zand, E., A. Koocheki, H. Rahimian, and M. Nasiri Mahalti. 2002. Study of the trend of morphological and physiological characteristics in some Iranian wheat cultivars over 50 years. J. Sci. Agric. Indust. 16(1): 116-171.

Zhou, Y., Z. H. He, X. X. Sui, X. C. Xia, X. K. Zhang, and G. S. Zhang. 2007. Genetic improvement of grain yield and associated with traits in the northern China winter wheat region from 1960 to 2000. Crop Sci. 47: 245–253.