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Research Article

Analysis of grain yield in ten Iranian wheat cultivars grown under semi-arid conditions

Maryam Jahani Doghozlou and Yahya Emam*

Department of Plant Production and Genetics, School of Agriculture, Shiraz University, Shiraz, Iran

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****Corresponding author:***
E-mail: Yaemam@shirazu.ac.ir

Abstract

Increased wheat yields are an urgent priority for global food security. Phenological performance in relation to yield of tenmodern wheat varieties including Bayat, Azadi, Falat, Navid, Chamran, Marvdasht, Pishtaz, Shiraz, Sirvan and Baharan, which were released during the last five decades wasevaluated at Shiraz University, Shiraz, Iran. The superior cultivars in terms of grain yield (Sirvan, Baharan and Chamran), had also higher grains/m² as well as higherbiological yield. Sirvan and Baharan also showed greater harvest indices(43.38% and 41.77% respectively). Booting stage was longer in cultivars with lower grain number (Navid, Bayat and Shiraz).The high yielding cultivars, (Sirvan, Baharan and Chamran)entered the stem elongation phase (SEP) earlier than others. It wasconcluded thatlonger duration of SEPwithout change in the anthesis timecan increase grain yieldin semi-arid regions.

Key words: Anthesis time, Grain Yield components, Phenology, Stem elongation phase, *Triticum aestivum*

1. Introduction

Wheat(*Triticumaestivum*L.) was one of the first plants to be domesticated by humans and has been cultivated as a staple food in European countries, West Asia and North Africa for 8000 years. Today, it is grown on more than 240 million ha as the most important source of nourishment for humans than any other food source (Curtis *et al.*, 2002). Therefore a substantial improvementin wheat yield is essential to ensure food security in the future(Reynolds et al., 2009). However, it appears that further increase in wheat yield potential,particularly in semi-arid regions with late season water stress might not be simply possible(González *et al.*, 2011). For better understanding of the yield-limiting factors,survey of the physiological changes associated with genetic gains is essential(Aisawi *et al.*, 2015). The number of grains set per m^2 and the average weight of these grains are the two main components of wheat grain yield. It seems that to achieve relevant genetic gains in yield potential, further improvement in sink-strength is essential, it means that identification of traits affecting the grain number seems necessary(Acreche & Slafer, 2006; Cartelle *et al.*, 2006; Fischer, 2011; Kumar *et al.,* 2019;Pedro *et al.*, 2012; PirastehAnosheh *et al.*, 2016; Reynolds *et al.*, 2009; Sadras & Slafer, 2012; Slafer *et al.*, 2014).Since it has been reported in a wide range of previous studies that the plant has enough capacity to provide assimilates to fill the grains (Borrás *et al.*, 2004; Gonzalez-Navarro *et al.*, 2016; Serrago *et al.*, 2013) even under Mediterranean conditions (Acreche & Slafer, 2006; Cartelle *et al.*, 2006).

It is known that there is genetic variation within well-adapted modern wheat cultivars in grain number determination due to differences in spike growth during pre-anthesis period (i.e. between terminal spikelet and anthesis) (Pedro *et al.*, 2011). Grain number in wheat is determined over time that the juvenile spike is growing rapidly, during the stem elongation phase (SEP)(Fischer, 1985; Slafer & Rawson, 1994). The number of grains per m^2 is influenced by the number of spikes per m^2, the number of spikelets per spike and the number of florets per spikelet.During the floret developmental processes, many floret primordia(6-12) are generatedand then - a rather large proportion of those – degenerate, so that not more than usually five to six fertile florets can be found at anthesis(Kirby, 1974). At anthesis, the ovaries of these florets fertilize and then immediately after anthesis, a proportion of these fertilized ovaries abort during the lag phase, and the rest set grains and finally determines the grain yield at maturity (Guo *et al.*, 2016). Fischer (2011) summarized that spike and stem compete for assimilates during SEP, thus extending this growth period could be a way to increase the fertile floret numberand, subsequently, final grain number. Adaptation of spike growth stage to environmental conditions can improve grain yield. Since inMediterranean region, with short growing seasons, drought and high temperature stresses at post flowering stage limit yield formation, delay in flowering, usually results toa lower yield. Nevertheless, early flowering could improve pollination and thus increase grain set and finally grain yield (Motzo & Giunta, 2007).Therefore, the objective of this work was firstly, to compare the yield and yield components of mostly adopted wheat cultivars in the region. Secondly, to examine how the different phenological stage duration could affect grain number and yield of recently released wheat cultivars under semi-arid conditions.

2. Materials and methods

2.1 General conditions

The experiment was carried out in a research field of School of Agriculture, Shiraz University (located at 29° 50´ N and 52° 46´ E, with a geographical altitude of 1810 m above sea level) during 2019-2020 growing season. The soil had a loamy-silty-clay texture, with clay, silt, and sand contents of 39%, 46%, and 15%, respectively, and the acidity (pH) of the soil extract was 7.7. Ten wheat cultivars(Bayat, Azadi, Falat, Navid, Chamran, Marvdasht, Pishtaz, Shiraz,Sirvan andBaharan)which were released during the last five decades,were carefully chosen to be well-adapted to Shiraz, Iran, where this study took place.

The experimental design was RCBD (Randomized CompleteBlock Design) with three replications. Plant density was set to 250plants/m^2. Based on the local practices, the planting date was 20 November 2019 and irrigation interval was set at ten days using a tape irrigation system.Uniform seeds were hand sown in 1.6*2.5 m plots. Each plot consistedof eight rows of20 cm apart. Soil was fertilized by application of urea at a rate of 150 kg ha^{-1} (before sowing, at mid tillering and anthesis). No pesticide was used and the plots were hand-weeded.The meteorological statistics are presentedin Table 1.

Table 1: Rainfall, mean temperature and relative humidity for 2019-20 cropping season

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Temp. (°c)	6.0	5.5	3.3	6.5	8.5	13.0	18.4	23.6
Rainfall (mm)	65.0	85.0	69.5	54	25	72.0	56	0
RH (%)	47.5	56.5	57.2	44.5	46	51.7	45.5	34.4

2.2 Measurements

Duration of the sowing to onset of stem elongation (SE, ZG31), booting (B, ZG41), anthesis (AN, ZG61) and physiological maturity (PM) were recorded(Zadoks *et al.*, 1974) in thermal time (TT) units. Thermal time (°Cd) was calculated as the summation of daily average temperature, with a base temperature of 0 °C (McMaster & Wilhelm, 1997).It is worth mentioning that phenological stages and accurate monitoring of spike development was examined in the form of a greenhouse experiment whose data is being published (JahaniDoghozlou&Emam, 2021).At harvest,plants of 1m^2 area in center of each plot were hand harvested from the ground level.The spikes harvested from one square meter, were counted.Thenthe grains per spike was determined in 20 randomly selected spikes.The number of grains/m^2 was also calculated by multiplying the spikes/m^2 and mean grains/spike.To determine the 1000-grain weight, 500 grains were randomly selected and weighed. Finally, dry weight of the aboveground biomass from 1m^2 area was weighed after drying for 48 h at 75°C and considered as biological yield. The spikes were threshed and weighed after drying for 48 h at 75°C, to determine grain yield and harvest index.

The collecteddata were subjected to analysis of variance (ANOVA) using statistical program SAS 9.1 and the means were compared by Duncan's multiple-range test ($P \leq 0.01$).

3. Results and Discussion

3.1 Grain yield and its components

Based on the results of analysis of variance, different cultivars produced significantly different grain yields (P ≤0.01%). Sirvan and Baharan cultivars had greater grain yield (4577.3 and 4288.3 kg ha^{-1}, respectively) and their difference with Chamran and Falat cultivars was not significant. Navid, Shiraz and Bayat cultivars had lowest grain yield (2397.3, 2360 and 2199 kg ha^{-1}) (Table 2).The majority of previous studies worldwide, showed that sincethe ability of the canopy to provide assimilates to fill the grains is not limitedas such, it appears that, the potential grain yield is more limited by sink size (grain number) andthe mean grain weight does not contribute mainly in the yield differences i.e. it is almost constant (Gonzalez-Navarro *et al.*, 2016; Pedro *et al.*, 2011; Dastfal *et al.*,2011 ;Waddington *et al.*, 1986). In this study, Sirvan and Baharan cultivars, with more grains per spike (47.66 and 45 grains, respectively), had higher average grain yield. In contrast,Navid and Bayat which had the lowest grain yield, produced 31.66 and 34.66 grains per spike, respectively (Table 2).It is also interesting that Lopes et al. (2012), has reported that in Mexico, grain yield progress of CIMMYT advanced lines from 1977 to 2008 had been associated with increased 1000-grain weight.

It the present study it was also found that the 1000-grain weight among cultivars did not change drastically (Table 2).This indicated that the number of grains was more important in yield formation than the mean grain weight. Indeed, the superior cultivars in terms of grain yield (Sirvan, Baharan and Chamran) were those that produced more grains per square meter(5215, 4692.7 and 4422.7 grains/m^2,respectively) (Table 2).Therefore, it appeared thatfurther attempt for better understanding of the factors that play a role in determining the number of grains is of prime importance for yield improvement in bread wheat (Borrás *et al.*, 2004; Slafer *et al.*, 2014;PirastehAnosheh *et al.*, 2016).

In this study, Sirvan and Baharan cultivars with 119.66 and 101.66 spikes/m^2 produced more spikes/m^2compared to other cultivars. This feature of Sirvan cultivar has also been noticed by other researchers in the same area (Sedaghat & Emam, 2017). Bayat cultivar with 68.33 spikes/m^2 had the lowest mean, and this cultivar could not achieve a high grain yield (Table 2). Shearman *et al.* (2005) by comparing wheat varieties grown in the UK between 1972 and 1995, found that increases in the grains/m^2 were primarily due to increases in spikes/m^2 with little variation in grains/spike, while in warmer regions such as Argentina, significant variation in grains/spike among genotypes has been reported (Abbate *et al.*, 1998). Furthermore, Slafer *et al.* (2014) analysing a large dataset, indicated that variations in grains/m^2 due to environmental conditions were primarily attributed to changes in spike/m^2 which depended upon many developmental factors, such as plant establishment, tillering dynamics and shoot survival up to anthesis. While, comparing bread wheats in the Mediterranean area of Spain, it has been demonstrated that the increase in number of grains, which has been lineally and positively correlated to the grain yield, depended on the grains/spike rather than differences in spike/m^2(Acreche *et al.*, 2008).

Table 2: Mean comparison of grain yield, 1000 grain weight, grain number per spike, grain number per square meter, spike number per square meter, biological yield and harvest index of ten wheat cultivars. Ranking of cultivars in this table is based on grain yield.

Ranking	Cultivars	grain yield (kg.ha^{-1})	1000-grain weight (g)	grains/ spike	grains/m^2	spikes/ m^2	biological yield (kg.ha^{-1})	harvest index (%)
1	Sirvan	4577.3a	43.1a	45ab	5384.7a	119.66a	10498.3a	43.38a
2	Baharan	4288.3a	40.93ab	47.66a	4845.11ab	101.66b	10330ab	41.77a
3	Chamran	3972.3ab	39.43ab	41.33abcd	4050.34ab	98bc	10130.7ab	39.25ab
4	Falat	3667.3ab	35.86bc	39.66bcd	3622.14bc	91.33bcde	9704.7ab	37.80ab

5	Pishtaz	3486.7abc	41.76a	38.33cde	3692.32bc	96.33bcd	9830.7ab	35.30bc
6	Marvdasht	3066.7bcd	35.56bc	44abc	3417.04cde	77.66def	9243.7abc	33.17bcd
7	Azadi	3045.3bcd	33.43c	43abc	3196.19cde	74.33ef	8765.3abc	34.93bc
8	Shiraz	2360cd	40.13ab	38cde	3014.54de	79.33cdef	6876c	34.27bc
9	Navid	2397.3cd	38.93abc	31.66e	2321.62e	73.33ef	7641bc	31.35cd
10	Bayat	2199d	39.23ab	34.66de	2368.31e	68.33f	7521bc	29.23d

Means followed by the same letter in each column are not significantly different, Duncan's test ($P \leq 0.01$).

3.2 Biological yield and harvest index

In this study, different cultivars produced significantly different biological yield (Table 2). Cultivars which had higher grain yield, also had higher biological yield, for example, Sirvan, Baharan and Chamran cultivars which had ranks 1, 2 and 3 in terms of grain yield, had an average biological yield of 10498.3, 10330 and 10130.7 kg ha^{-1}, respectively. Inversely, Shiraz, Navid and Bayat cultivars with the lower grain yield also had the lower biological yield (6876, 7641 and 7521 kg ha^{-1}, respectively) (Table 2). It seems that to produce higher grain yield, better dry matter production during pre-anthesis period is necessary (Emam et al., 2007; Dastfal et al., 2011;Pirasteh Anosheh et al., 2016). Furthermore, comparison of wheat cultivars introduced by CIMMYT from 1966 to 2009 showed that the annual increase in wheat grain yield was 30 kg ha^{-1} yr^{-1} (0.59% yr^{-1}). In that study, grain yield showed a positive and significant correlation with shoot dry matter at harvest time (Aisawi *et al.*, 2015). Undoubtedly, in the future, the goal of many wheat breeding programs would be to increase the relationship between potential yield capacity and harvest index and biomass production (Aisawi *et al.*, 2015; Fischer, 2007; Pedro *et al.*, 2012) . In other words, the major part of increasing the potential production capacity of different wheat cultivars will depend on increasing biomass production, and this must be accompanied by a higher harvest index (Emam & Seghatoleslami, 2005; Dastfal *et al.*, 2011; Pirasteh Anosheh *et al.*, 2016).The cultivars tested in this study were significantly different in terms of harvest index ($p \leq 0.01$). Sirvan and Baharan cultivars had higher harvest indices (43.38% and 41.77% respectively, Table 2). In previous studies, the effect of harvest index on grain yield has been frequently mentioned(Austin *et al.*, 1980; PirastehAnosheh *et al.*, 2016; Royo *et al.*, 2007; Slafer *et al.*, 2014).In summary, it appears that the plant has the ability to produce the assimilate needed to produce yield potential (except for the period of fast growing stage of the spike),so what matters is the partitioning of carbon to the economic organs as the main determinant of yield potential.This indicates that in a plant with a high harvest index, more assimilates are allocated to economic organs and as a result, grain yield would be improved. In the present study, Sirvan, Baharan, Chamran and Falat cultivars were good examples of this trend (Table 2). It seems that the allocation of dry matter to the reproductive structure of the plant is very crucial. Therefore, the high value of both (grain yield and harvest index) are agronomically and physiologically valuable.(Acreche *et al.*, 2008). The highest harvest index in this study was 43% (Sirvan cultivar), which was similar to studies comparing Australian (Perry & d'Antuono, 1989; Siddique *et al.*, 1989) and Spanish (Acreche *et al.*, 2008) wheat cultivars. The harvest indices for the cultivars in the present study was far below what has been suggested by Austin *et al.* (1980) i.e. 62.5% under non-stressed conditions. Thus, it seems thatsuch theoretical limitsintroduced for the harvest index could not be achieved under Mediterranean conditions.

3.3 Correlation analysis

Pearson correlation of traits has been shown in Table 3. Correlation analysis showed a significant relationship between the measured traits. In present study grain yield significantly correlated with spike number per square meter, grain number per spike, grain number per square meter, biological yield and harvest index). It has been previously reported thatincreasing the grain number per spikelet, increases the grain yield(Mohamed & Marshall, 1979). The highest correlation observed between grain yield and number of grains per square meter ($r=0.96$). Grain yield significantly correlated with biological yield ($r=0.93$) (Table 3). Pre-anthesis stem dry mass accumulation plays an important role in floral development (Bidinger *et al.*, 1977). Therefore, floret primordia may benefit from an increase in different structural parts of the main shoot (more biological yield),so, final grain number and consequently grain yield could increase (Curtis *et al.*, 2002). Indeed, in this experiment, a significant and positive correlation was observed between harvest index and grain yield (r=0.94). Thus, the cultivars with the highest values of grain yield had the highest harvest indices (Table 3). So far, several studies have reported a positive correlation between harvest index and grain yield (Austin *et al.*, 1980; Royo *et al.*, 2007; Slafer *et al.*, 2014). In fact, in a plant with a high harvest index, more dry matter is allocated to the plant's economic organs and as a result, grain yield increases (Emam & Seghatoleslami, 2005). Also, a positive and significant relationship was observed between harvest index and number of grains per square meter (r=0.94) (Table 3). Therfore, the increase in potential grain yield has come essentially from an increase in harvest index and particularly from an increase in grain number rather than an increase in grain weight. Becuse the relationship between grain yield and harvest index with 1000-grain weight was not significant.

Table 3: Pearson correlation of spike number per square meter, grain number per spike, grain number per square meter, 1000 grain weight (TGW), grain yield, biological yield and harvest index of wheat cultivars

	spikes/m²	**grains/spike**	**grains/m²**	**TGW**	**grain yield**	**biological yield**	**harvest index**
spikes/m²	1						
grains/spike	0.59ns	1					
grains/m²	0.97**	0.69*	1				
TGW	0.61*	- 0.003ns	0.53ns	1			
grain yield	0.92**	0.76**	0.96**	0.34ns	1		
biological yield	0.79**	0.69*	0.84**	0.22ns	0.93**	1	
harvest index	0.91**	0.75*	0.94**	0.35ns	0.94**	0.75*	1

*,** and ns: Significant at the 5%, 1% probability levels and non-significant, respectively.

3.4 Wheat cultivars phenology

The length of different developmental stagesdiffered among cultivars (Fig. 1). Late flowering cultivars had lower grain yield. Shiraz, Bayat and Navid cultivars with low grain yield (rank 8 to 10) (Table 2), were late flowering and required 1438, 1463 and 1515 TT respectively, from sowing to anthesis(Fig. 1). In contrast, Sirvan, Baharan, Chamran and Falat which were superior cultivars in terms of grain yield (rank1 to 4) (Table 2), entered AN earlier than other cultivars (Fig. 1).

It could be argued that the higher respiration rate due to high air temperature in late flowering cultivars, can reduce the grain yield (Fisher, 2011). Adaptation of crop to environmental conditions, can coincide the transition from vegetative to reproductive phase with favorable conditions. In temperate regions with long growing seasons, late flowering cultivars might be of interest, because they can store more assimilates during the vegetative phase, which can be used later in the season (Cockram *et al.*, 2007; Pirasteh Anosheh *et al.*, 2016) However, in the Mediterranean region, with short growing seasons, which drought and high temperature stresses at post flowering stages (as shown in table 1) limit yield formation, early flowering could ensure a better pollination (Motzo & Giunta, 2007). In this study it was found that Sirvan, Baharan with 1992.5 and 1993 TT from sowing to PM (Fig. 1), were superior cultivars in term of grain yield (rank 1 and 2 in Table 2). While late cultivars such as Shiraz and Navid with 2314.9 and 2346.7 TT, respectively from sowing to PM (Fig. 1) had rank 8 and 9 in grain yield (Table 2).

Since the potential number of grains in wheat is determined during spike growth phase, which is coincided with the SEP, it appeared that earlier start of stem elongation in some studied cultivars (Sirvan, Baharan, Chamran and Falatwith 845.9, 848.5, 884.2 and 864.7 TT, respectively from sowing to onset of stem elongation (Fig. 1) was associated with higher grain yield in these cultivars (Table 2). In contrast, Navid and Bayat cultivars which needed 1022.4 and 1002.7 TT, respectively from sowing to onset of stem elongation (Fig. 1) finally produced lower grain yields (Table 2).It could be concluded that when the reproductive phase is longer, this can contribute to higher assimilate acquisition by the spikes, and higher proportion of floret primordia which are competent at anthesis (Dastfal *et al.*,2011). In general grain number may be increased by: (i) reducing the size of competing organs, such as the peduncle and number of sterile tillers during spike growth; (ii) increasing the number of spikelets per spike; (iii) extending the duration of the interval between floral initiation and terminal spikelet by extending the duration of spike growth; (iv) or increasing floret survival by avoiding carbon, water and nutrient limitations (Curtis *et al.*, 2002).Floret abortion starts in the boot stage and finishes at anthesis. Floret death occurs when the stem and peduncle are at maximum growth rate. Floret death is probably, at least partially, due to competition for carbohydrates at this stage, is the major cause of potential grain number loss(Fischer, 2007; Kirby & Appleyard, 1987). In the present study Navid, Bayat and Shiraz cultivars whit 363.4, 339.5 and 298.7 TT from booting to AN, had longer floret abortion period than others (Fig. 1).This longer period resulted to lower final grain number in these cultivars (Table 2). While, booting to AN period was very short in Falat, Chamran, Sirvan and Baharan cultivars (with 235.8, 222, 208.5 and 204.2 TT, respectively) (Fig. 1)and this led to more grain number as well as grain yield(Table 2). Other worker also had focused on the important role of floret abortion periodin determining the number of grains (Kirby, 1974; González *et al.*,2011). Recently Gou and Schnurbusch (2015) also demonstrated thatshorter floret abortion period (booting to AN) in wheat has been associated with increased final grain number.

Based on an evolutionary mechanism the spike first initiate a large number of number of floret primordia, which their production is low cost for the plant. Then a large number of floret primordia aborted, so only a relatively small fraction of those can reach the stage of fertile floret at AN. Therefore, the survival of the florets is much more vital than the floret initiation (Fischer, 2007; Kirby & Appleyard, 1987). Ferrante *et al.*, (2013) concluded that, with this method, the crop would accommodate environmental variation by production of low cost primordia. Probably the determining factor here, is the demand for assimilates, because this amount during the first stage (initiation of florets) is much less than the next stages (survival of florets).

Fig 1 Duration of periods from sowing to onset of stem elongation (SE), booting (B), anthesis (AN) and physiological maturity (PM) in wheat cultivars in thermal time units.

Conclusion

Based on the results of this study, cultivars with higher grain yields had also greater grains/m^2, biological yield as well as harvest indices. It was also showed that grain yield was more related to the grain number rather than mean grain weight. Booting to anthesis (floret abortion) period in exemplified cultivars was longer in cultivars with lower grain number per spike as well as grain yield. It was also showed that grain number was higher when duration of the SEP was lengthened. Since in the Mediterraneanregion, with short growing seasons, drought and high temperature stresses at post flowering stages limit yield formation, late flowering cultivars in this study had lower grain yield. This evidence supports the idea that cultivars with earlier stem elongation could produce greater grain yield.

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Compliance with ethical standards

NA

Conflict of interest

No

Author contributions

MJD and YE: Conceptualization, Data curation, MJD and YE: Writing & updating the manuscript for publication, MJD and YE: Supervision, and Validation. All the listed authors read and approved the manuscript.

Declaration

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