ORIGINAL ARTICLE / ORIGINALBEITRAG

Chinese Wheat Hybrids 18A-1 and 18A-2 Surpass Local Check (Ghaneemat-2016) under Deficit Irrigation when Sown Early in Semiarid Climatic Conditions

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Abstract

Global food security demands the development and delivery of new technologies to increase and secure cereal production on limited arable land without increasing water use and other inputs. Climate change has induced a consistent decrease in winter rainfall, which has forced farmers to postpone wheat sowing from October to November and even December under rainfed conditions. It is therefore essential to optimize irrigation strategies to increase water use in order to develop sustainable crop production. A 2-year field experiment was carried out at the Agronomy Research Farm (ARF), University of Agriculture, Peshawar, during 2018–19 and 2019–20 in randomized complete block design with split-plot arrangement and three replications. Irrigation at different growth stages based on Zadok's growth stages, sowing dates (15 November, 30 November, and 15 December), and wheat hybrids 18A-1 and 18A-2 were used, with the local variety Ghaneemat-2016 as check. Results exhibited that sowing on 15 November increased spike length by 11.7%, spike weight by 31%, grains per spike by 17.8%, and thousand-grain weight by 23.2%. Irrigation given at four and three critical stages increased spike length by 8.4%, spike weight by 14%, grains per spike by 10.3%, and thousand-grain weight by 15.4% as compared to a single irrigation at tillering stage. Hybrid wheat 18A-2 recorded higher spike length (18%), spike weight (6.2%), grains per spike (7%), and thousand-grain weight (8.9%) as compared to hybrid wheat 18A-1. Local check variety Ghaneemat-2016 resulted in lower spike length (5%), spike weight (12%), grains per spike (5%), and thousand-grain weight (4%). It is concluded that irrigation can be restricted to three critical growth stages (tillering, booting, and flowering) to obtain higher yield from wheat hybrids. Wheat hybrids 18A-1 and 18A-2 may be sown on 15 November, when there is no or lower availability of irrigation water or rainfall, due to their potential to withstand water stress.

Keywords Deficit irrigation · Quality attributes · Yield · Sowing date · Semi arid condition

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Die chinesischen Weizenhybriden 18A-1 und 18A-2 übertreffen die lokale Kontrolle (Ghaneemat-2016) unter Defizitbewässerung, wenn sie unter semiariden Klimabedingungen früh gesät werden

Zusammenfassung

Die globale Ernährungssicherheit erfordert die Entwicklung und Bereitstellung neuer Technologien zur Steigerung und Sicherung der Getreideproduktion auf begrenzten Anbauflächen, ohne den Einsatz von Wasser und anderen Betriebsmitteln zu erhöhen. Der Klimawandel hat zu einem stetigen Rückgang der Niederschläge im Winter geführt, sodass die Landwirte gezwungen sind, die Weizenaussaat im Regenfeldbau von Oktober auf November und sogar Dezember zu verschieben. Daher ist es wichtig, die Bewässerungsstrategien zu optimieren, um die Wassernutzung zu erhöhen und eine nachhaltige Pflanzenproduktion zu entwickeln. Ein zweijähriges Feldexperiment wurde auf der Agronomy Research Farm (ARF) der University of Agriculture Peshawar in den Jahren 2018–19 und 2019–20 im komplett randomisierten Blockdesign mit 3 Wiederholungen durchgeführt. Bewässerung in verschiedenen Wachstumsstadien auf der Grundlage von Zadoks Wachstumsstadien und Aussaatterminen (15. November, 30. November und 15. Dezember) und die Weizenhybriden 18A-1 und 18A-2 wurden eingesetzt, mit der lokalen Sorte Ghaneemat-2016 als Kontrolle. Die Ergebnisse zeigten, dass die Aussaat am 15. November die Ährenlänge um 11,7 %, das Ährengewicht um 31 %, die Körner pro Ähre um 17,8 % und das Tausendkorngewicht um 23,2 % erhöhte. Die Bewässerung in 4 und 3 kritischen Stadien erhöhte die Ährenlänge um 8,4 %, das Ährengewicht um 14 %, die Körner pro Ähre um 10,3 % und das Tausendkorngewicht um 15,4 % im Vergleich zur einmaligen Bewässerung im Bestockungsstadium. Hybridweizen 18A-2 verzeichnete im Vergleich zu Hybridweizen 18A-1 eine größere Ährenlänge (um 18 %), ein höheres Ährengewicht (6,2 %), mehr Körner pro Ähre (7 %) und ein höheres Tausendkorngewicht (8,9 %). Die lokale Kontrollsorte Ghaneemat-2016 ergab niedrigere Werte bezüglich Ährenlänge (5 % weniger), Ährengewicht (12 %), Körner pro Ähre (5 %) und Tausendkorngewicht (4 %). Daraus wird geschlossen, dass die Bewässerung auf 3 kritische Wachstumsstadien (Bestockung, Austrieb und Blüte) beschränkt werden kann, um höhere Erträge bei Weizenhybriden zu erzielen. Die Weizenhybriden 18A-1 und 18A-2 können am 15. November ausgesät werden, wenn kein oder nur wenig Bewässerungswasser bzw. Niederschlag zur Verfügung steht, da sie einem Wassermangel standhalten können.

Schlüsselwörter Qualitätsmerkmale · Klimawandel · Ernteertrag · Zeitpunkt der Aussaat · Ernährungssicherheit

Wheat (*Triticum aestivum L.*) is a major cereal crop, consumed as a staple food in many parts of the world (Ali et al. 2022). It belongs to the Poaceae family and globally, after maize and rice, is the most cultivated cereal on the basis of consumption and ranked first in Pakistan (Anjum et al. 2021). The nutritional value of wheat is extremely important, and it supplies more calories, protein, dietary fiber, B-group vitamins, and minerals to the diet of the world's population than any other cereal crop (Adhikari et al. 2016). Wheat is grown on 8.797 million hectares in Pakistan, yielding 25.07 million tons, while it is grown on 0.76 million hectares in Khyber Pakhtunkhwa (KP) province, yielding 1.4 million tons. It contributes 14.4% to the value added in agriculture and 3.1% to gross domestic product (GDP). While 85% of wheat production takes place under irrigation systems (tube well, canals), 15% is produced in rainfed areas in Pakistan (Ali et al. 2022).

Many abiotic and genetic factors can be responsible for a low yield of wheat, such as temperature, light, humidity, and agronomic factors (Pandey et al. 2017). Among the agronomic factors, sowing date is one of the most important factors involved in producing high-yielding small-grain cereal crops, which affects the timing and duration of vegetative and reproductive stages. Early sowing produces higher yields than late sowing due to longer duration of grain development (Baloch et al. 2012). Too early sowing produces weak plants with poor root systems, as the temperature is above optimum which leads to irregular germination, frequent death of embryos, and decomposition of endosperm due to the activities of bacteria or fungi (Kamrozzaman et al. 2016). Delayed sowing affects germination, growth, and grain development, and produces poor tillering in early stages of the growing season due to winter injury in low temperature, thus suppressing the yield (Shah et al. 2019). In later stages of the growing season, yield reduction occurs in wheat under heat stress, which could be caused by accelerated phase development, accelerated senescence, increased respiration, reduced photosynthesis, and inhibition of starch synthesis in developing kernels (Asseng et al. 2015).

Irrigation is an important determinant of crop yield because it is associated with many factors of the plant environment which influence growth and development (Anjum et al. 2021). Pakistan is severely affected by water scarcity and is already one of the most water-stressed countries in the world. According to the International Water Manage-

ment Institute (IWMI), Pakistan will progress to outright water scarcity by 2025, due to a high level of population growth. Current limitation of water resources is threatening winter wheat productivity, and this trend is expected to increase in the future (Anjum and Arif 2021). Hence, farmers are obliged to deal with this problem by implementing sustainable agricultural water management strategies aimed at maintaining winter wheat grain yield with less water. In order to increase irrigation water productivity in arid areas, many researchers found that deficit irrigation was an effective measure (Anjum et al. 2021).

Variety selection according to agroclimatic conditions is another factor of utmost importance that plays a pivotal role in producing a high yield of any crop commodity (Singh et al. 2008). In the province of Khyber Pakhtunkhwa (KP), wheat is cultivated on more than 52% of the cropped area as barani crop (rainfed) and its average yield is very low due to unavailability of the appropriate wheat variety for the area's climate and its appropriate time of sowing subject to the onset of winter (October–December) rains (Anjum et al. 2021; Mukhtarullah and Akmal 2016). Appropriate variety selection for the rainfed/unirrigated region is a major issue in Pakistan and in KP particularly. In deficient moisture conditions, drought-tolerant or resistant varieties can survive better (Ali et al. 2022). Planting date is one of the components for identification of an appropriate wheat variety that is well suited for growth in the climate subject to its cultivation regarding the onset of winter rain and timings (Anjum and Arif 2021; Khan and Kabir 2014). The

release of new varieties is a continuous process, and different varieties perform differently under different sowing dates. Therefore, the present study was conducted to judge the performance of various wheat varieties under different sowing dates.

Therefore, keeping in view the importance of the above objectives, a study was conducted to investigate the effect of sowing date and irrigation interval on morphology, phenology, and backing quality of hybrid wheat lines.

Materials and Methods

A field experiment was carried out at the Agronomy Research Farms (ARF), University of Agriculture, Peshawar, during the rabi season 2018–19. The research was carried out in randomized complete block design (RCBD), with a split-plot arrangement and three replications. Plot size was maintained at $3\,m \times 4.2\,m$ $(12.6\,m^2)$, with a distance between the rows (R–R distance) of 30 cm, thus accommodating 14 rows. Sowing was done manually using a hand hoe at the rate of 120 kg ha^{-1}. Hybrid seeds of wheat were obtained from the Beijing Engineering Research Centre for Hybrid Wheat, China. Nitrogen, phosphorous, and potassium were applied at 120:80:60 kg ha^{-1} in split doses. A cultivator was used to plough the soil twice, followed by rotavator. Weeds were controlled using herbicide spray (atrazine) at 30 days after sowing. Figure 1 shows the average mean monthly weather data for the 2 years (2018–19 and 2019–20) at the

Fig. 1 Average mean monthly weather data for the 2 years (2018–19 and 2019–20) at the experimental location for the crop growth season (Peshawar Metrological Department)
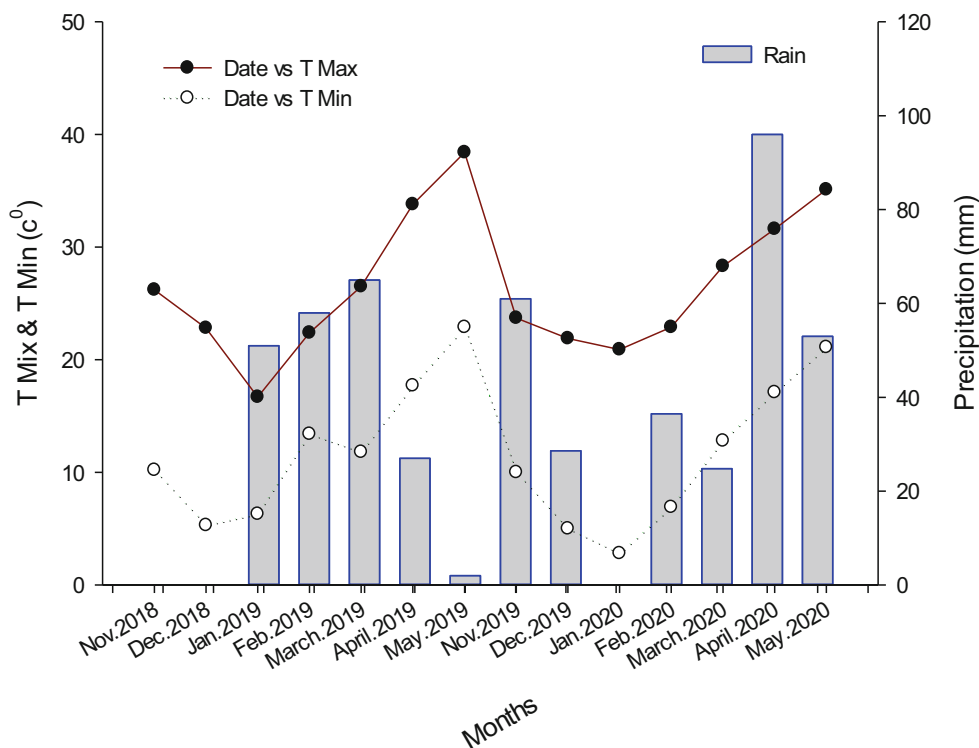
experimental location for the crop growth season (Peshawar Metrological Department).

Experimental Treatment Details

Experimental treatments consisted of different irrigation regimes, sowing intervals, and hybrid wheat lines. According to the split-plot design, irrigation and sowing intervals were allotted to the main plot factor while wheat hybrid lines were assigned to the subplot factor. Irrigation regimes consist of different levels, i.e., I1: irrigation at tillering stage (GS 20–29); I2: irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47); I3: irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69); I4: irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69) + irrigation at grain-filling stage (GS 70–89). Sowing dates consists of SD1: 15 November; SD2: 30 November; SD3: 15 December; wheat hybrids of local check (Ghaneemat-2016); H1: 18A-1; and H2: 18A-2.

Irrigation Measurement

A flume instrument was used to measure irrigation quantity in the field. It consisted of a converging upstream section, a throat (i.e., a constricted section), and a diverging downstream section. The flume was placed in the irrigation channel and leveled through the leveler. After installation of the flume in the field, the discharge was measured by allowing the stream of water to flow through the converged section of the flume with a depressed bottom.

Available Water

Available soil water (depth) is the amount of water present between field capacity and permanent wilting point and was calculated using the following formula:

$$AW = \frac{Drz\,(FC - PWP)}{100},$$

where

- AW = available water in the soil (mm)
- Drz = depth of the root zone (mm)
- FC = field capacity (%) on volume basis
- PWP = permanent wilting point (%) on volume basis

Readily Available Water

The maximum allowable depletion (MAD) of any crop is the allowable percentage of water that can be withdrawn from the soil between irrigation events without stressing the crop to the point at which significant reductions in crop yield or quality are experienced. MAD for wheat crop is about 50 to 56%. Based on this, the required water depletion was applied to the crop. Readily available water (RAW) for the crop is calculated through the product of available soil water (ASW) and MAD of that crop:

$$RAW(mm) = ASW\,(mm)\,xMAD(\%).$$

Volume

The volume of water (V) for attaining the respective MAD was applied and calculated through area (A) of the plot to the required water depth (Dw) by the formula given below:

$$V(m^3) = A(m^2)xDw(mm).$$

Discharge

Discharge, denoted by Q, was calculated by the following formula:

$$Q = V/T,$$

where

- Q = quantity of water flow in the channel (mm)
- V = volume of water flow in the channel as discharge (mm)
- T = time of water applied for a subplot

Hence, the amount of irrigation was given to the field on the basis of the above equation (Tables 1 and 2).

The physicochemical properties of the soil are shown in Table 3.

Data Recording

Days to emergence were recorded by counting the days from the date of sowing to the date when 50% emergence had occurred in each plot. Emergence data (m^{-2}) were noted by calculating the number of plants emerged in two central rows in each plot and transformed into emergence in m^{-2} via the following formula: Emergence m^{-2} = Plants counted in plots/RR Distance × Row length × Number of Rows. For recording grains spike^{-1}, ten randomly selected spikes from each plot were selected, manually threshed and grains were counted using electronic grains counting machine and then averaged. A sample of thousand grains were counted using electronic grains counting machine and separated for each plot. The grains were then weighed with the help of a sensitive electronic balance and thousand grains weight were noted. Leaf area index was calculated by multiplying the product of number of leaves and tillers m^{-2} by leaf area,

Table 1 Irrigation given to the field as per treatment required during the crop season 2018–19

I	SD	Year (2018–19)				
		Irrigation requirement (mm)	Rainfall (mm)	Irrigation applied (mm)	Rainfall after irrigation till harvest (mm)	Total water depth (mm)
I1	15 Nov	76.98	8	68.98	20	96.98
	30 Nov	76.98	58.1	18.88	10	86.98
	15 Dec	76.98	51	25.98	24	100.98
I2	15 Nov	153.96	8	145.96	20	173.96
	30 Nov	153.96	58.1	95.86	10	163.96
	15 Dec	153.96	51	102.96	24	177.96
I3	15 Nov	230.94	8	222.94	20	250.94
	30 Nov	230.94	58.1	172.84	10	240.94
	15 Dec	230.94	45	185.94	24	254.94
I4	15 Nov	307.92	8	299.92	20	327.92
	30 Nov	307.92	56.2	251.72	10	317.92
	15 Dec	307.92	45	262.92	24	331.92

I irrigation regimes, *SD* sowing dates

Table 2 Irrigation given to the field as per treatment required during the crop growing season 2019–20

Irrigation	SD	Year (2019–20)				
		Irrigation requirement (mm)	Rainfall	Irrigation applied (mm)	Rainfall after irrigation till harvest (mm)	Total water depth (mm)
I1	15 Nov	76.98	33.4	43.58	35	111.98
	30 Nov	76.98	7.6	69.38	23	99.98
	15 Dec	76.98	12.2	64.78	42	118.98
I2	15 Nov	153.96	41.2	112.76	25	178.96
	30 Nov	153.96	28.9	125.06	17	170.96
	15 Dec	153.96	51	102.96	32	185.96
I3	15 Nov	230.94	44.5	186.44	25	255.94
	30 Nov	230.94	37.8	193.14	15	245.94
	15 Dec	230.94	76	154.94	45	275.94
I4	15 Nov	307.92	33.4	274.52	20	327.92
	30 Nov	307.92	76	231.92	10	317.92
	15 Dec	307.92	99	208.92	49	356.92

I irrigation regimes, *SD* sowing dates

then divided by 10,000 according to the following formula: LAI = no. of leaves × tillers m^{-2} × LA/100 × 100. Harvest index was calculated by dividing the grain yield of wheat by biological yield and then multiplied by 100 to express as percentage. Flag leaf area was calculated by random selection of five plants, measurement of their leaf length and width through measure tap, and conversion using the following formula: leaf area × leaf width × 0.75.

Quality Traits

Grain Protein Content (%)

Grain protein content was determined by the Kjeldhal method. Flour samples were weighed about 0.2 g using a digital balance and put in the test tube. Added a 1.32 g di-gestion mixture in a digestion tube and 3 ml of concentrated sulfuric acid (H2SO4) in a test tube, the tubes were kept for assembly. The digestion mixture was prepared by taking 10 g of copper sulphate (CuSo$_4$), 100 g of potassium sulphate (K$_2$SO$_4$), and 1 g of selenium powder (Se) in a tube. In the assembly, digestion tubes were heated continuously until the solution became a light greenish color, clear, and filtered. After the greenish color had appeared, a volume of 100 ml was made in a tube and then transferred into the Kjeldahl apparatus, where 4 ml sodium hydroxide solution (NaOH) was added with a 20 ml sample taken, again heated for more distillation. The obtained distillate was collected in a conical flask containing indicator (5 ml of boric acid mix indicator) and heated until a light yellowish color appeared. After appearance of the yellowish color, distillates were treated with hydrochloric chloride (0.005 N HCl). Af-

Table 3 Two-year average soil physicochemical properties of the experimental site

Description	Value
Bulk density (g^{-1} cm^3)	1.67
Soil carbon (%)	0.82
Field capacity (%)	32
Permanent wilting point (%)	18
Sand (%)	8.67
Silt (%)	52.43
Clay (%)	41.32
Textural class	Silty clay loam
Organic matter (g kg^{-1})	0.855
Total N (%)	0.05
CaCO$_3$ (%)	14.2
PH 1:1 water	8.01
Electrical conductivity (ds m^{-1})	0.86
AB-DTPA-extractible nutrients	
P (mg kg^{-1})	3.78
K (mg kg^{-1})	104
Zn (mg kg^{-1})	0.84
Magnesium (mg kg^{-1})	2.2
Sodium	2.3

AB-DTPA ammonium bicarbonate-diethylenetriaminepentaacetic acid

ter treatment of the distillate with HCl, samples and blank readings were recorded. These values were multiplied by the correction factor (6.25) to obtain grain protein content using the following formula: grain protein content (GP) % = nitrogen (N) × 6.25.

Dry Gluten Content in Grains (%)

Dry gluten content in wheat was determined by the hand-wash method. Grains were collected from the spike, threshed, and ground. Grinding was through a partial grinding milling machine with size 1 mm/2 mm (Cyclone Mill TWISTER 220–240 V, 50/60 Hz; Retsch, Haan, Germany). After grinding, 25 g samples were collected from each experimental unit and mixed with 15 ml of distilled water to form a dough. Afterwards, the dough was allowed to stand for ½ h, after which time all the starches, carbohydrates, and other soluble matter was removed from the dough by pressing it in the water flow in a plastic cup. Then, the dough ball was placed in a flat-bottom dish and the gluten weighed as moist/wet gluten. After recording wet gluten, samples of dough were placed in an oven at 100 °C for drying to remove all moisture. When all the moisture had vanished from the dough, the dry gluten weight was estimated. Wheat gluten content (%) was determined using the following formula to express in percentage: seed gluten (%) = gluten weight (g) /sample weight (g) × 100.

Amylopectin Content (%)

Amylopectin in grains was determined by the iodine calorimetric method (Fajardo et al. 2013). Ground wheat seeds were passed through a 100 mm mesh. Afterwards, 100 g of sample was taken in triplicate in a 100 ml volumetric flask, 9 ml NaOH solution and 1 ml ethanol (95%) were added, and the contents of flasks were then boiled in a water bath for 1 h to gelatinize the starch. Once gelatinized, the samples were allowed to cool, a volume of 100 ml was established by adding 100 ml distilled water, and samples were stored at room temperature (26 °C) for 22 h. In addition, a blank sample was prepared for correction. In a flask a solution was made (1 ml glacial acetic acid and 2 ml iodine), thoroughly mixed with 5 ml sample, and pipetted into another volumetric flask. Iodine is insoluble in water; to enhance the solubility of 1 g iodine, 2 g potassium iodide was mixed in distilled water and the volume adjusted to 900 ml. Samples were thoroughly mixed by hand for 20 min until dark bluish color appeared. After calibration of the spectrophotometer at 620 nm using standards, all samples were run at 620 nm. Absorbance values were converted to amylose using the standard calibration curve for pure potato amylose.

Statistical Analysis

Using Fishers analysis of variance (ANOVA) technique, collected data were statistically analyzed and the significant mean values were separated via the least significant difference (LSD) test at 5% probability level (Steel and Torrie 1980).

Results

Days to Emergence

Data concerning days to emergence of wheat are given in Table 4. Statistical analysis of the data showed that sowing date (SD) and hybrid wheat lines (H) significantly affected the days to emergence of wheat. The SD × H interaction was found to be nonsignificant. Early sowing hastened the days to emergence, while late sowing delayed emergence. Sowing on 15 November resulted in 14 days to emergence followed by sowing on 30 November with 16 days to emergence. However, late sowing on 15 December resulted in 20 days to emergence. Hybrid wheat took comparatively fewer days to emerge compared to the local check variety. Hybrid wheat 18A-2 took 15 days to emerge followed by 18A-2 which took 17 days to emerge, while Ghaneemat-2016 took 18 days to emerge.

Table 4 Days to emergence and emergence m^2 of wheat hybrids as affected by different sowing dates

Irrigation regimes	Days to emergence			Emergence m^{-2}		
	2018–19	2019–20	Mean	2018–19	2019–20	Mean
I1	X	X	X	X	X	X
I2	X	X	X	X	X	X
I3	X	X	X	X	X	X
I4	X	X	X	X	X	X
Sowing dates						
15 Nov	13	15	14 c	139	128	133 a
30 Nov	14	19	16 b	120	108	114 b
15 Dec	19	20	20 a	75	70	72 c
Hybrids						
Ghaneemat-2016	17	19	18 a	100	93	96 c
18A-1	16	18	17 b	115	104	109 b
18A-2	14	17	15 c	119	109	114 a
LSD values (p ≤ 0.05)						
LSD$_{(0.05)}$ for irrigation	–		NS	–	–	NS
LSD$_{(0.05)}$ for sowing date		1.26		–	–	7.26
LSD$_{(0.05)}$ for hybrids	–		1.38	–	–	6.88

X shows that no irrigations were given to the crop at this stage and means in the same category having dissimilar alphabets vary significantly at 5% level of probability.
whereas: *I* irrigation, *LSD* least significant difference

Emergence (m^{-2})

Data concerning emergence (m^{-2}) of wheat are shown in Table 4. Statistical analysis of the data showed that sowing dates and hybrid wheat significantly influenced emergence (m^{-2}) of wheat. The SD × H interaction was found to be nonsignificant. Year as a source of variation was found to be significant. Early sowing resulted in higher emergence, while late sowing resulted in minimum emergence (m^{-2}). Wheat crop sown on 15 November recorded maximum emergence (133 m^{-2}) followed by 30 November (114 m^{-2}), whereas late sowing resulted in less emergence (72 m^{-2}). Wheat hybrids had higher emergence (m^{-2}) compared to the local variety. Maximum emergence (114 m^{-2}) was noted for hybrid wheat 18A-2 followed by hybrid 18A-1 with 109 seedlings m^{-2}, and the lowest emergence (96 m^{-2}) was recorded for Ghaneemat-2016.

Flag Leaf Area (cm^2)

The means table indicated that sowing date, irrigation regime, and hybrid wheat significantly affected flag leaf area of wheat crop (Table 5). All the possible interactions, i.e., I × SD, SD × H, I × H, and I × SD × H, were significant for flag leaf area of wheat crop. Year as a source of variation was found to be significant. Early sowing date produced maximum flag leaf area, while late sowing resulted in smaller flag leaf area. Sowing on 15 November produced maximum flag leaf area (50.4 cm^2) followed by 30 November (46.1 cm^2), while the lowest flag leaf area was

noted in plots sown on 15 December (42.6 cm^2). Increasing irrigation frequency in wheat crop produced maximum flag leaf area. Plots receiving four-time irrigation (at tillering, booting, flowering, and grain-filling stages) and three-time irrigation (at tillering, booting, and flowering stages) showed statistically similar results and produced higher flag leaf area, i.e., 47.8 and 47.2 cm^2, respectively. Minimum flag leaf area (44.8 cm^2) was recorded in plots irrigated once at tillering stage during the crop growing period. Hybrid wheat produced higher flag leaf area as compared to local check variety. Hybrid wheat 18A-2 produced maximum flag leaf area (49.0 cm^2) followed by 18A-1 (46.0 cm^{-2}), while Ghaneemat-2016 produced lower flag leaf area (44.2 cm^2).

Leaf Area Index

Data pertaining to the leaf area index of wheat crop are shown in Table 5. Statistical analysis of the data showed that sowing date, irrigation regime, and wheat hybrid significantly affected the leaf area index of wheat crop. All the possible interactions, i.e., I × SD, SD × H, I × H, and I × SD × H, were significant for flag leaf area of wheat crop. Year as a source of variation was found to be significant. Early sowing date produced maximum leaf area index while late sowing resulted in minimum leaf area index. Sowing on 15 November produced the maximum leaf area index (3.0) followed by 30 November (2.8), while the lowest leaf area index was noted in plots sown on 15 December (2.1). Increasing irrigation frequency produced higher leaf area index in wheat crop. Plots receiving four-time irrigation (at

Table 5 Flag leaf area (cm²), leaf area index, and spike weight (g) of wheat hybrids as affected by different sowing dates under irrigation regimes

Irrigation regimes	Flag leaf area (cm²)			Leaf area index			Spike weight (g)		
	2018–19	2019–20	Mean	2018–19	2019–20	Mean	2018–19	2019–20	Mean
I1	41.7 b	48.0c	44.8 b	2.2	2.3	2.3 c	2.3	2.6	2.4 c
I2	42.7 b	48.6c	45.7 b	2.5	2.8	2.7 b	2.4	2.8	2.6 b
I3	44.2 a	50.3 b	47.2 a	2.5	2.8	2.7 b	2.4	2.9	2.7 ab
I4	44.0 a	51.7 a	47.8 a	2.7	3	2.8 a	2.5	3	2.8 a
Sowing dates									
15 November	46.7 a	54.2 a	50.4 a	2.8	3.1	3.0 a	2.8	3	2.9 a
30 November	43.0 b	49.2 b	46.1 b	2.7	2.9	2.8 b	2.5	2.9	2.7 b
15 December	39.6c	45.5c	42.6 c	2	2.2	2.1 c	1.9	2.6	2.2 c
Hybrids									
Ghaneemat-2016	41.0c	47.4c	44.2 c	2.3	2.6	2.4 c	2.1	2.6	2.4 c
18A-1	42.6 b	49.3 b	46.0 b	2.5	2.7	2.6 b	2.5	2.9	2.7 b
18A-2	45.7 a	52.3 a	49.0 a	2.7	3	2.8 a	2.6	3	2.8 a
LSD values (p ≤ 0.05)									
LSD$_{(0.05)}$ for irrigation	1.92	1.13	1.08	0.16	0.18	0.12	0.1	0.17	0.1
LSD$_{(0.05)}$ for sowing date	1.66	0.98	0.94	0.14	0.16	0.1	0.09	0.15	0.08
LSD$_{(0.05)}$ for hybrids	1.52	1.02	0.91	0.17	0.14	0.11	0.09	0.19	0.11

I1 irrigation at tillering stage (GS 20–29), *I2* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47), *I3* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69), *I4* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69)+ irrigation at grain filling stage (GS 70–89), *LSD* least significant difference. Means in the same category having dissimilar alphabets vary significantly at 5% level of probability

tillering, booting, flowering, and grain-filling stages) produced the maximum (2.8) leaf area index followed by three-time irrigation (at tillering, booting, and flowering stages), which showed statistically similar results to irrigation given at two stages (at tillering and booting stage). The minimum leaf area index (2.3) was recorded in plots irrigated once at the tillering stage. Hybrid wheat produced higher leaf area index as compared to local check variety. Hybrid wheat 18A-2 produced the maximum leaf area index (2.8) followed by 18A-1 (2.6), while Ghaneemat-2016 produced the lowest leaf area index (2.4).

Spike Weight (g)

Perusal of the data revealed that sowing date, irrigation regime, and wheat hybrid varied significantly for spike length of wheat crop (Table 5). All the possible interactions (H × I, I × SD, H × I × SD) were found to be nonsignificant except SD × I. Year as a source of variation was also found to be significant. Early sowing produced heavier spikes, while a delay in sowing resulted in lighter spikes. Sowing on 15 November produced heavier spikes (2.9 g) followed by 30 November (2.7 g), while lighter spikes were recorded by sowing on 15 December (2.2 g). Reducing the irrigation frequency considerably decreased the spike weight. Plots irrigated four times (tillering, booting, flowering, and grain-filling stages) produced heavier spikes (2.8 g) followed by plots irrigated three times (at tillering, booting, and flowering stages) and two times (omitting irrigation at flowering

and grain-filling stages), which did not differ statistically. A lighter weight of spikes (2.4 g) was observed in plots irrigated once at the tillering stage only. Hybrid wheat produced heavier spikes as compared to local check variety. Hybrid wheat 18A-2 produced heavier spikes (2.8 g) followed by 18A-1 (2.7 g), while Ghaneemat-2016 produced lighter spikes (2.4 g).

Grains Spike⁻¹

Data relating to grains spike⁻¹ of wheat are presented in Table 6. Perusal of the data revealed that sowing date, irrigation regime, and wheat hybrid significantly influenced grains spike⁻¹. All the possible interactions were significant except I × SD × H. Early sowing resulted in a higher number of grains spike⁻¹, while a delay in sowing produced fewer grains spike⁻¹. Sowing on 15 November produced a higher number of grains spike⁻¹ (55.8) followed by 30 November (48.1), while fewer grains spike⁻¹ were obtained by sowing on 15 December (47.3). Regarding different irrigation regimes, plots irrigated four times (at tillering, booting, flowering, and grain-filling stages) produced the maximum number of grains (52.0) followed by irrigation given to wheat crop at three critical stages (at tillering, booting, and flowering stages; 51.9 grains spike⁻¹), which were statistically similar to each other, while fewer grains spike⁻¹ (47.1) were recorded in plots irrigated only once at tillering stage. Hybrid wheat produced more grains spike⁻¹ as compared to the local check variety. Hybrid wheat 18A-2

Table 6 Grains spike^{-1}, thousand-grain weight (g), and harvest index (%) of wheat hybrids as affected by different sowing dates under irrigation regimes

Irrigation regimes	Grains spike^{-1}			Thousand-grain weight (g)			Harvest index (%)		
	2018–19	2019–20	Mean	2018–19	2019–20	Mean	2018–19	2019–20	Mean
I1	43.8	50.4	47.1 c	36.7	38.7	37.7 b	33	34	33 c
I2	46.3	55	50.6 b	40.8	45.1	42.9 a	35	34	34 bc
I3	48.5	55.4	51.9 a	41.3	45.6	43.5 a	36	36	36 ab
I4	48.2	55.7	52.0 a	40.5	45.8	43.2 a	37	36	36 a
Sowing dates									
15 November	51.7	59.9	55.8 a	45.6	49.4	47.5 a	36	36	36 a
30 November	45.1	51.2	48.1 b	37.7	41.1	39.4 b	36	35	36 a
15 December	43.4	51.3	47.3 b	36.2	40.9	38.6 b	33	33	33 b
Hybrids									
Ghaneemat-2016	44.6	50.9	47.7 c	37.4	41.8	39.6 c	33	33	33 b
18A-1	45.9	54.1	50.0 b	39	43.2	41.1 b	34	34	34 b
18A-2	49.7	57.4	53.5 a	43	46.5	44.8 a	38	37	38 a
LSD values (p ≤ 0.05)									
LSD$_{(0.05)}$ for irrigation	1.65	2.04	1.27	1.67	1.89	1.22	2.3	NS	1.4
LSD$_{(0.05)}$ for sowing date	1.42	1.77	1.1	1.44	1.64	1.06	1.98	1.66	1.25
LSD$_{(0.05)}$ for hybrids	1.9	1.74	1.27	1.47	1.78	1.14	1.55	1.44	1.05

I1 irrigation at tillering stage (GS 20–29), *I2* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47), *I3* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69), *I4* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69) + irrigation at grain filling stage (GS 70–89), *LSD* least significant difference. Means in the same category having dissimilar alphabets vary significantly at 5% level of probability

produced more grains spike^{-1} (53.5) followed by hybrid 18A-2 with 50.0 grains spike^{-1}, while fewer grains spike^{-1} (47) were recorded by the local variety Ghaneemat-2016.

Thousand-Grain Weight (g)

Analysis of the data indicated significant differences among sowing dates, irrigation regimes, and wheat hybrids for thousand-grain weight of wheat (Table 6). All the possible interactions, i.e., I × SD, SD × H, and I × SD × H, were found to be significant except I × H. Early sowing resulted in heavier grain weight in comparison to delayed sowing. Sowing on 15 November resulted in heavier grain weight (47.5 g) followed by 30 November (39.4 g), while lighter grains were obtained by sowing on 15 December (38.6 g). Heavier grains were produced when the irrigation frequency was increased. Plots irrigated four times (at tillering, booting, flowering, and grain-filling stages) produced maximum thousand-grain weight (43.5 g) followed by irrigation three times (irrigation at tillering, booting, and anthesis stage) with thousand-grain weight of 43.2 g, while lighter grains (37.7 g) were recorded with a single irrigation applied at the tillering stage only. Wheat hybrid produced heavier grains as compared to local check. Hybrid wheat 18A-2 produced heavier grains (44.8 g) followed by hybrid 18A-1(41.1 g), while lighter grains (39.6 g) were obtained from the local variety Ghaneemat-2016.

Harvest Index (%)

Perusal of the data revealed that sowing date, irrigation regime, and wheat hybrid significantly influenced the harvest index of wheat crop (Table 6). All interactions were also significant for the harvest index of wheat. Years as a source of variation were found non–significant except I × H and I × SD that was found significant. Early sowing produced the maximum harvest index in comparison to delayed sowing. Sowing on 15 November produced higher harvest index (36%) followed by 30 November (36%), which were statistically similar, while the lowest harvest index was recorded by sowing on 15 December (33%). Increasing the frequency of irrigation significantly increased the harvest index of wheat crop. Plots irrigated four times (at tillering, booting, flowering, and grain-filling stages) and three times (at tillering, booting, and anthesis stages) showed similar results by producing a higher harvest index of 36%. Plots irrigated once at tillering stage produced a lower harvest index (33%). Wheat hybrid produced the maximum harvest index as compared to local check. Hybrid 18A-2 produced higher harvest index (38%) followed by Hybrid 18A-1 (34%), while local cultivar Ghaneemat-2016 produced a lower harvest index (33%).

Table 7 Dry gluten, grain protein, and amylopectin content of grains of wheat hybrids as affected by different sowing dates under irrigation regimes

Irrigation regimes	Dry gluten content (%)			Grains protein content (%)			Amylopectin content (%)		
	2018–19	2019–20	Mean	2018–19	2019–20	Mean	2018–19	2019–20	Mean
I1	10.1	9.8	10.0 b	9.5	10.5	10.0 c	78.1	78.5	78.3 a
I2	10.3	10	10.1 b	11.8	12.8	12.3 c	77.2	75	76.1 b
I3	10.9	10.8	10.8 a	12	13.2	12.6 ab	77.7	74.8	76.2 b
I4	11.2	10.9	11.0 a	12.1	13.4	12.8 a	76.7	73.9	75.3 c
Sowing dates									
15 November	11.3	11	11.2 a	10.6	11.8	11.2 c	75.5	74.7	75.1 c
30 November	10.7	10.5	10.6 b	11.5	12.6	12.0 b	76.3	75.5	75.9 b
15 December	9.8	9.5	9.7 c	12	13.1	12.5 a	80.5	76.5	78.5 a
Hybrids									
Ghaneemat-2016	10.4	10.1	10.2 b	10.8	12.1	11.4 c	78	76.3	77.2 a
18A-1	10.5	10.2	10.3 a	11	12.3	11.6 b	77.6	75.4	76.5 b
18A-2	11	10.8	10.9 a	12.3	13.1	12.7 a	76.7	75	75.8 c
LSD values (p ≤ 0.05)									
LSD$_{(0.05)}$ for irrigation	0.32	0.39	0.25	0.59	0.61	0.41	0.83	1.19	0.7
LSD$_{(0.05)}$ for sowing date	0.28	0.34	0.21	0.51	0.53	0.36	0.72	1.03	0.61
LSD$_{(0.05)}$ for hybrids	0.29	0.33	0.22	0.5	0.47	0.34	0.81	1.08	0.67

I1 irrigation at tillering stage (GS 20–29), *I2* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47), *I3* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69), *I4* irrigation at tillering stage (GS 20–29) + irrigation at booting stage (GS 41–47) + irrigation at flowering stage (GS 61–69) + irrigation at grain filling stage (GS 70–89), *LSD* least significant difference. Means in the same category having dissimilar alphabets vary significantly at 5% level of probability

Dry Gluten Content (%)

Sowing date, irrigation regime, and wheat hybrid varied significantly for the dry gluten content of wheat crop (Table 7). All the possible interactions, i.e., I × SD, I × H, and SD × H, were found to be significant for dry gluten content except I × SD × H. Year as a source of variation was also found to be significant. Early sowing significantly increased dry gluten content, while late sowing decreased the dry gluten content of wheat. Sowing on 15 November produced the maximum dry gluten content in grains (11.2%) followed by 30 November (10.6%), while the minimum dry gluten content was produced by sowing on 15 December (9.7%). Dry gluten content consistently decreased with reducing frequency of irrigation. Plots irrigated four times (tillering, booting, flowering, and grain-filling stages) and three times (tillering, booting, and flowering stages) produced higher dry gluten content in grains (11.0 and 10.8%, respectively), which was statistically similar. A lower dry gluten content in grains (10.0%) was recorded for irrigation given to wheat crop only at the tillering stage. Hybrid wheat produced maximum dry gluten content in grains as compared to the local check variety. Hybrid wheat 18A-2 produced a higher dry gluten content in grains (10.9%), followed by 18A-1 (10.3%). Ghaneemat-2016 produced the lowest dry gluten content (10.2%).

Grain Protein Content (%)

Analysis of the data revealed that sowing date, irrigation regime, and hybrid wheat were significant for grain protein content (Table 7). All the possible interactions, i.e., I × SD, I × H, SD × H, and I × SD × H, were also significant for grain protein content. Year as a source of variation was also found to be significant. Early sowing significantly decreased the protein content, while late sowing increased the grain protein content of wheat. Higher grain protein content was produced by sowing on 15 December (12.5%). However, sowing on 15 November produced the minimum protein content in grains (11.2%), followed by 30 November (12.0%). Plots irrigated four times (tillering, booting, flowering, and grain-filling stages) and three times (tillering, booting, and flowering stages) produced a higher protein content in grains (12.8 and 12.6%, respectively), which were statistically similar. A lower protein content in grains (10.0%) was recorded for irrigation given to wheat crop only at tillering stage. Hybrid wheat produced higher protein content in grains as compared to local check variety. Hybrid wheat 18A-2 produced a higher concentration of protein content in grains (12.7%) followed by 18A-1 (11.6%), while Ghaneemat-2016 produced the lowest grain protein content (11.4%).

Table 8 *F* statistics for the effects of hybrid, sowing date, and irrigation regime on growth and yield of wheat during the 2018–19 and 2019-20 growing seasons

Variables	*F*-values				
	DTE	Emergence m^{-2}	Spikelets spike^{-1}	Flag leaf area (cm^2)	Leaf area index
Year (Y)	39.52**	17.93**	596.78*	190.68***	13.72*
Reps within year	0.45756**	3.25475**	0.68**	1.55^{NS}	2.67*
Irrigation (I)	X	X	4.55*	13.18**	36.55***
Sowing date (SD)	30.17*	886.722*	277.43**	143.41***	156.81***
I× SD	X	X	1.28^{NS}	15.11**	64.88**
Y× I	X	X	0.66^{NS}	1.12^{NS}	0.51^{NS}
Y× SD	3.07^{NS}	3.51^{NS}	0.24^{NS}	1.51^{NS}	0.58^{NS}
Y× I× SD	X	X	0.58^{NS}	0.63^{NS}	1.33^{NS}
Hybrids (H)	15.48**	28.55***	258.51***	56.71*	32.91***
I× H	X	X	1.04^{NS}	5.81**	48.12***
SD× H	0.45*	0.61*	3.03**	0.74**	67.84*
I× SD× H	X	X	1.07^{NS}	25.33***	37.32**
Y× H	5.24*	3.26**	0.46^{NS}	0.03^{NS}	0.83^{NS}
Y× I× H	X	X	0.33^{NS}	0.46^{NS}	0.76^{NS}
Y× SD× H	1.83^{NS}	1.82^{NS}	0.07^{NS}	0.10^{NS}	1.53^{NS}
Y× I× SD× H	X	X	0.87^{NS}	0.53^{NS}	0.90^{NS}

DTE days to emergence, *I* irrigation regimes, *SD* sowing dates, *H* hybrids, *Y* year, *NS* nonsignificant, *I1* irrigation at tillering stage (GS 20–29), *I2* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47), *I3* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69), *I4* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69)+ irrigation at grain filling stage (GS 70–89)
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Amylopectin Content in Grains (%)

Sowing date, irrigation regime, and wheat hybrid significantly affected the amylopectin content of wheat crop (Table 7). The interactions between I× SD, I× H, and I× SD× H were found to be nonsignificant; the exception was SD× H. Early sowing produced the lowest amylopectin content, while a delay in sowing increased the amylopectin content in grains. Sowing on 15 December produced the maximum amylopectin content (78.1%) followed by 30 November (75.9%), while less amylopectin was recorded for sowing on 15 November (75.1%). Decreasing the irrigation frequency significantly increased the amylopectin in wheat crop. Irrigation given four times (irrigation at tillering, booting, flowering, and grain-filling stages) produced less amylopectin (75.3%) followed by irrigation given to wheat crop at three critical stages (irrigation at tillering, booting, and flowering; 76.2%), while a higher amylopectin content (78.3%) was recorded in plots irrigated once at tillering stage. Hybrid wheat produced lower amylopectin as compared to local check variety. Local check variety Ghaneemat-2016 produced maximum amylopectin (77.2%), while hybrid wheat 18A-2 produced minimum amylopectin (75.8%) followed by 18A-1 (76.5%).

Tables 8 and 9 show the *F* statistics for the effects of hybrid, sowing date, and irrigation regime on growth and yield of wheat during the 2018–19 and 2019–20 growing seasons.

Discussion

Emergence

Early sowing resulted in fewer days to emergence, while late sowing delayed the emergence of wheat crop. Sowing on 15 December delayed emergence by 6 days as compared to early sowing on 15 November (Anjum et al. 2021). Hybrids 18A-2 and 18A-1 had 3 and 1 day less to emergence, respectively, as compared to the local variety Ghaneemat-2016. The reason for delayed emergence may be a low temperature at the late sowing time reducing germination rate and delaying the emergence of wheat crop (Awan et al. 2017). Mumtaz et al. (2015) and Aslani and Mehrvar (2012) reported that wheat winter duration varied from 7 to 14 days by delay in sowing made from early to late in the season, which was due to decrease in the daily mean temperature. Among wheat genotypes, variation was found which could be due to their genetic potential and variable germination rates (Anjum et al. 2021; Tahir et al. 2009).

Crop sown on 15 December resulted in 16% less emergence compared to crop sown on 15 November. Wheat hybrid 18A-2 resulted in 19% higher emergence in compar-

Table 9 *F* statistics for the effects of hybrid, sowing date, and irrigation regime on growth and yield of wheat during the 2018–19 and 2019-20 growing seasons

Variables	*F*-values						
	Spike weight (g)	Grains spike^{-1}	1000-grain weight (g)	Harvest index (%)	Dry gluten content (%)	Grains protein content (%)	Amylopectin content (%)
Year (Y)	222.6***	162.3***	120.17***	4.15^{NS}	4.45^{NS}	58.94**	157.12***
Reps within year	0.71^{NS}	1.70^{NS}	0.72**	0.24^{NS}	1.79^{NS}	1.05^{NS}	0.37^{NS}
Irrigation (I)	18.37***	26.46 **	40.90**	6.24***	37.81***	80.25***	27.65**
Sowing dates (SD)	150.99***	145.99*	176.99***	12.80***	99.63***	29.57**	70.74**
I× SD	2.97***	8.99**	7.62***	3.59**	65.94***	29.55*	24.05***
Y×I	1.56^{NS}	1.03^{NS}	2.50^{NS}	0.52^{NS}	0.30^{NS}	0.26^{NS}	9.73***
Y×SD	14.49***	2.18^{NS}	0.64^{NS}	0.57^{NS}	0.24^{NS}	0.02^{NS}	19.31*
Y×I×SD	0.96^{NS}	0.54^{NS}	2.52*	1.52^{NS}	0.35^{NS}	0.10^{NS}	1.46^{NS}
Hybrids (H)	35.66***	41.58***	42.62	44.81^{NS}	21.33***	31.64***	7.81***
I×H	1.18^{NS}	2.98**	1.15^{NS}	23.15^{NS}	4.25*	7.18***	3.72***
SD×H	0.54^{NS}	4.01**	6.46***	1.71^{NS}	11.60**	2.47**	2.16***
I×SD×H	1.77^{NS}	1.77^{NS}	3.00***	9.14^{NS}	2.86*	2.40*	3.75**
Y×H	0.49^{NS}	1.18^{NS}	0.39^{NS}	0.74^{NS}	0.20^{NS}	1.77^{NS}	0.25^{NS}
Y×I×H	0.51^{NS}	0.51^{NS}	0.25^{NS}	3.19**	0.35^{NS}	0.24^{NS}	0.28^{NS}
Y×SD×H	0.35^{NS}	0.05^{NS}	0.60^{NS}	1.80*	0.29^{NS}	0.08^{NS}	0.35^{NS}
Y×I×SD×H	0.50^{NS}	1.05^{NS}	1.68^{NS}	1.96^{NS}	0.25^{NS}	0.19^{NS}	0.32^{NS}

DTE days to emergence, *I* irrigation regimes, *SD* sowing dates, *H* hybrids, *Y* year, *NS* nonsignificant, *I1* irrigation at tillering stage (GS 20–29), *I2* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47), *I3* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69), *I4* irrigation at tillering stage (GS 20–29)+ irrigation at booting stage (GS 41–47)+ irrigation at flowering stage (GS 61–69)+ irrigation at grain filling stage (GS 70–89)
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

ison to local check variety Ghaneemat-2016 (Anjum and Arif 2021). The yield of wheat crop is always determined by its crop stand, which is a function of its initial emergence (Tahir et al. 2009). Higher emergence in early-sown plots might be due to the favorable temperature required for good emergence and better crop growth and development later on (Mumtaz et al. 2015). The low emergence in late-sown plots may be due to the temperature falling below the optimum and resulting in a lower emergence count (Aslani and Mehrvar 2012). Similarly, Aslam et al. (2013) and Tahir et al. (2009) concluded that differences among genotypes in terms of emergence could be due to varying genetic potential and diversity. Awan et al. (2017) also reported that variation in emergence m^{-2} among genotypes is due to genetic makeup (genetic potential and genetic diversity).

Flag Leaf Area and Leaf Area Index

Increasing the irrigation frequency significantly increased flag leaf area and leaf area index. Irrigation given at four and three critical stages of wheat resulted in maximum flag leaf area and leaf area index of 6.4 and 26.0%, respectively, as compared to irrigation given only at the tillering stage. Late sowing resulted in the minimum flag leaf area and leaf area index. Sowing on 15 November produced 18.4% max-

imum flag leaf area and 40.8% leaf area index, followed by 30 November, while late sowing on 15 December resulted in lower flag leaf area and leaf area index (Anjum et al. 2021). Hybrid wheat, i.e., 18A-2 and 18A-1, produced higher flag leaf area (18.0%) and leaf area index (6.4%), while the minimum flag leaf area was produced by local check variety Ghaneemat-2016.

Drought stress adversely affects crop growth and development, i.e., it restricts leaf expansion, stem elongation, and internodular elongation by inhibiting cell expansion (Namich and Alia 2007). Delfine et al. (2002) reported in their study that water stress during sensitive stages of the crop causes severe water losses from tissues, which results in reduced turgor pressure in cells, thereby inhibiting division and enlargement of cells and reducing plant growth and development, i.e., leaf expansion and dry mass accumulation. Comparable outcomes were also described by Maria et al. (2008), who stated from their study that drought stress severely decreased plant growth and development (Anjum et al. 2021). The findings were also on a par with those of Mahamed et al. (2011), who described that drought stress during sensitive stages adversely affects plant physiological and yield traits, i.e., leaf area, leaf area index, biomass yield, grain yield, and harvest index. Mujtaba et al. (2007) confirmed the similar study that drought stress inhibits in-

ternodal elongation and leaf expansion, resulting in reduced ability to capture assimilates from the light due to a lower leaf area index.

Delayed sowing produced the minimum leaf area index and flag area of wheat crop. This might be due to temperature stress that adversely affected crop growth and development (Hossain et al. 2013). High temperature hastens the crop lifecycle, which results in less expansion (Bita and Gerats 2013). Parallel outcomes were also reported by Styles and Jones (2007), who acknowledged that delayed sowing considerably reduced leaf expansion and ultimately reduced the assimilates, which decreased the flag leaf area and leaf area index. Ahmad et al. (2010) and Ahuja et al. (2010) reported from their study that late sowing reduced leaf expansion and other assimilates by opting for an escape mechanism to complete the lifecycle.

Yield-Related Traits

Yield attributes of wheat, i.e., spike length, grains spike^{-1}, and thousand-grain weight, decreased with a delay in sowing date (Anjum et al. 2021; Yadav et al. 2017). Delay in sowing decreased spike length, grains spike^{-1}, and thousand-grain weight. The increase in yield attributes of wheat could be due to early, uniform, and more emergence; better crop stand; and, thus, superior crop growth with a higher amount of photosynthetic assimilates during the crop growing season (Mukherjee 2012). The other possible reason might be the optimum availability of weather conditions that hasten crop growth and development and enhance the process of photosynthesis by formation of a good canopy (Wahid and Al-Hilfy 2018). Optimum sowing time provides a favorable environment to the crop that provides adequate assimilates from the vegetative part to the reproductive part during its growing season. Reiad et al. (2007) also reported that delaying sowing from November onwards significantly reduced the yield attributes of wheat. Among yield attributes, spike length was reduced due to inadequate transfer of assimilates from the source and the reduced photosynthesis rate (Sial et al. 2005). Khan and Kabir (2014) also stated that crop sown on 25 December significantly reduced the yield attributes as compared to crop sown on 20 November. Optimum sowing time in wheat provides adequate moisture to the crop, which results in production of the maximum number of fertile tillers which contributes to a higher number of grains spike^{-1} (Wang et al. 2011). Comparable findings were shown by Xu et al. (2015). Kaur et al. (2010) indicated that late planting decreased the yield attributes of wheat, i.e., spike length, tiller m^{-2}, and thousand-grain weight. These attributes contribute to the maximum number of grains spike^{-1} in wheat (Yadav et al. 2017). Anjum and Arif (2021); Awan et al. (2017) reported the same results, namely that yield attributes of wheat decreased due

to delayed sowing. Mukhtaruallah and Akmal (2016) also stated that delayed sowing significantly reduced the yield. Alam et al. (2013) depicted the same results, showing that delaying sowing significantly reduced the number of grains spike^{-1}, spike length, and thousand-grain weight. Due to a reduction in growing-degree days and shriveling of grains during the critical stages of wheat, i.e., milking and grain-filling stages, thousand-grain weight decreased (Sikder and Paul 2010; Ram et al. 2012).

Irrigation regimes significantly influenced spike length, grains spike^{-1}, and thousand-grain weight of wheat. Irrigation applied to wheat crop at four stages produced the maximum yield attributes (Anjum et al. 2021). Irrigation given at four stages of wheat (I4) produced the maximum spike length, which might be due to the availability of adequate assimilates from the source (Pal et al. 2002). Murungu and Madanzi (2010) also reported from their findings that increasing irrigation frequency significantly enhanced the yield traits. This may be due to the proper availability of moisture during sensitive stages of the crop, which provides favorable conditions and enhances yield attributes, i.e., spike length, spike weight, and thousand-grain weight (Sarkar et al. 2010). Irrigation applied during critical stages of wheat produced heavier grain weight and the maximum number of grains spike^{-1} (Pal et al. 2002). Hussain et al. (1997) also stated that frequent irrigation significantly enhanced the yield attributes. Water stress significantly reduced yield attributes, i.e., spike length, spike weight, and 1000-grain weight (Kolawole and Samson, 2009). Similarly, Barnett et al. (2005), Clay et al. (2001), Oweis et al. (2000), and Yurtsever (1984) reported that irrigation given to wheat crop at crown root initiation + booting + grain filling stages could enhance yield productivity and produced the maximum number of grains spike^{-1} and spike length (cm), as well as heavier grain weight (g) and spike weight. Ngwako and Mashiqa (2013) reported that irrigation given to wheat at two and four stages produced the maximum grain yield and yield attributes, while water use efficiency was enhanced by irrigation given to crop during sensitive stages. Mubeen et al. (2013) also demonstrated that irrigation application to wheat at four stages (irrigation at tillering + stem elongation + booting + grain filling stage) produced a higher grain yield of wheat.

Significant differences among wheat hybrids were observed for yield attributes by Sial et al. (2005). The weight of 1000 grains decreased due to delayed sowing, while heavier grains were observed for sowing on 20 November by Sial et al. (2005) and Dhyani et al. (2013).

Harvest index is the ratio between economic and biological yield of the crop (Gholinezhad et al. 2009). Irrigation given at only one stage significantly diminished the harvest index of wheat crop, as described by Anjum et al. (2021) and Anjum and Arif (2021). Brahma et al. (2007) confirmed

the similar results that drought stress linearly decreased the crop biological and grain yield, which ultimately resulted in decreased harvest index. Chaves and Oliverira (2004) stated that drought stress during sensitive growth stages linearly reduced the harvest index of the crop. Comparable outcomes were also confirmed by Pandey et al. (2000), who reported that limited irrigation decreased the economical and biological yield of wheat crop, which resulted in a lower harvest index.

Early sowing of wheat significantly produced the maximum harvest index (Said et al. 2012). Delayed sowing resulted in lower harvest index due to accumulation of fewer assimilates during the crop lifecycle (Yasmeen et al. 2012). Due to fewer growing-degree days, plants cannot complete their lifecycle properly, due to which less biomass accumulation occurs and produces a lower harvest index (Bolaños and Edmeades 1993). Similar results were also reported by Shahzad et al. (2002), Miralles and Slafer (1995), and Fletcher et al. (2009), who stated that drought stress produced lower harvest index due to less biomass production and lower economical yield. Wajid et al. (2002) confirmed these results, and reported that harvest index was decreased by reducing irrigation frequency.

Quality Traits

Grain protein content in wheat crop is one of the most important indices for evaluating the quality of wheat (Sun et al. 2013). Among hybrid lines, 18A-2 produced higher protein than local check (Ghaneemat-2016). The increase in grain protein recorded under stress compared to optimum conditions proved that grain responded directly to high temperature and water stress by modifying the source–sink balance (Ali et al. 2022; Rharrabti et al. 2003; Motzo et al. 2007; Minocha et al. 2014). Changing the sowing time had a large effect on grain protein, which might be due to the modification of thermal conditions during grain filling and variability in rainfall (Singh et al. 2010; Souza et al. 2004). Gil et al. (2011) reported a decrease in wheat grain yield with delayed sowing but an increase in grain protein. The late-sown materials come under heat stress during flowering, resulting in reduced grain size but increased protein accumulation compared to starches and vice versa (Wardlaw and Moncur 1995; Hurkman et al. 2009; Labuschagne et al. 2009). Grain protein content showed an inverse relationship with delayed sowing (Ragaee and Abdel-Aal 2006). The results are also in conformity with Blazek and Copeland (2008), showing that the concentration of protein content increased with delayed sowing compared to early sowing. This might be due to high temperature that resulted in production of small grains but with enhanced protein content.

Among different irrigation regimes, the maximum protein content was recorded in plots irrigated four times, followed by three times. This might be due to the sufficient amount of moisture available in the soil through which the plant takes nutrients and all other assimilates easily (Suchy et al. 2003; Singh et al. 2008; McKenzie et al. 2011). Comparable outcomes were also described by Farooq et al. (2015), who showed that adequate availability of moisture in the soil root zone enhanced the translocation of all assimilates in plants and increased the quality traits, i.e., protein content. Intsar et al. (2019) reported that the concentration of protein in wheat increased due to a sufficient amount of moisture available in the soil. Similar results were also reported by Ali et al. 2022; Iqtidar et al. (2010), López-Bellido et al. (2001), Flagella et al. (2010), and Gooding and Davies (1997).

Grain amylopectin contents are branched-chain (1–4)-linked α-d-glucopyranosyl units joined through (1–6) linkages. Amylopectin is the largest biopolymer, with a molecular weight of 10–200 MDa (Massaux et al. 2008). Amylopectin is the major component of wheat grain starches and comprises 75% of the total carbohydrates. Of them, waxy starches are comprised of amylopectin only. Different starches have diverse food uses, i.e., adhesion, binding, dusting, film formation, foam strengthening, gelling, glazing, moisture retention, thickening, texturizing, and stabilizing applications (Gray and Bemiller 2003). The amylose-to-amylopectin ratio of wheat grains defines their nutritional and technological properties. Yamakawa et al. (2007) stated that grain amylopectin contents are reported to increase during the grain-filling stage of the crop, where accumulation of starches is high (Ali et al. 2022). However, amylopectin content is reported to decrease under drought and temperature stress imposition.

Conclusion and Recommendations

It is concluded that wheat hybrids produced higher grain yield at all sowing dates compared to local check, but that grain yield was reduced with a delay in sowing. This decline with a delay in sowing was not so prominent in hybrid wheat, but a delay in sowing drastically declined the grain yield of the local check variety. Quality attributes of wheat hybrids, i.e., 18A-2 and 18A-1, resulted in higher dry gluten (15.2%) in wheat grains as compared to local check Ghaneemat-2016 when sown on 15 November, while wheat hybrids sown on 15 December produced the maximum protein (12%) and amylopectin content (4.5%) in grains as compared with early sowing (15 November). Increasing irrigation frequency (irrigation at tillering, booting, and flowering stage) in wheat crop significantly increased grain protein content (27.7%) and dry gluten (11%), while reducing the irrigation frequency (irrigation only at tillering stage) resulted in higher amylopectin in grains (4%).

Based on the results, it is recommended that in case of water deficit at any growth stage of the crop, either due to non-availability of irrigation or rainfall, wheat hybrids are recommended for higher wheat yield or components by mitigating the adverse effects of water stress.

Conflict of interest M.M. Anjum, M. Arif, N. Ali, B. Khan, and G.R. Khan declare that they have no competing interests.

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