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Estimation of Variability, Heritability and Genetic Advance for Phenological, Physiological and Yield Contributing Attributes in Wheat Genotypes under Heat Stress Condition

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Abstract

The investigation was carried out in focusing the genetic variability for different traits of wheat influenced by heat tolerance mechanism to find out relationships among phenological, physiological and yield contributing traits. Spring wheat cultivar of 25 genotypes were selected and cultivated under late sowing condition at the Regional Wheat Research Institute, Shympur, Rajshahi, Bangladesh from December, 2016 to April, 2017. Significant variability among the genotypes exposed for different traits related to heat tolerance. Results showed that the genotypes G24, G10, G01, G13, G16, G25 and G14 ranked as better category considering maximum number of traits in mean performance indicating their tolerance to heat stress under late sowing condition. Phenotypic variances (σ_p^2) of all traits were greater than those of genotypic variances (σ_g^2). The same trends were also found in their co-efficient of variances. The phenotypic co-efficient of variances (PCV) of all traits were greater compare to those of genotypic co-efficient of variances (GCV) and their values were closer to each other. The heading days (HD), canopy temperature at vegetative stage (CT_{vg}), canopy temperature at grain filling stage (CT_{gf}), biomass, plant height (PH), spike/m² (SPM), spikelet/spike (SPS), grain/spike (GPS), thousand grain weight (TGW) and yield exhibited higher heritability (h_b^2) estimated under irrigated late sowing (ILS) condition. Under the same ILS condition SPAD, SPM, SPS, GPS, TGW and yield showed moderate to high genetic advance (GA) obtained through computing their mean percentage (%) and the rest traits HD, maturity days (MD), CT_{vg}, CT_{gf}, biomass, PH and harvest index (HI) exposed smaller genetic advance (% mean). The

co-efficient of variation (CV%) of all attributes in all genotypes were significantly lower (1.36 - 6.96). Both heritability and genetic advance were found lower for MD, SPAD and HI indicated their non additive genetic effects for which these traits might not be recommended for selection. However, spike/m^2, spikelet/spike, grain/spike, thousand grain weight and yield belonged to higher heritability and high to moderate genetic advance in mean percentage (%) along with wide genetic variation and lower environmental influence in heat stress situation indicated the most likely heritability due to the effects of additive genes that might be suggested as effective process of selection for these traits in heat stress condition.

Keywords

Wheat Genotype, Variability, Heritability, Genetic Advance, PCV (Phenotypic Co-Efficient of Variation), GCV (Genotypic Co-Efficient of Variation), Heat Tolerance

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely grown cereal crop that plays an important role in world food security. It occupies the second position among the cereals next to rice and it ensures a vital role in the food security of teeming hungry millions of people of Bangladesh. The average wheat yield of the world will have to increase during the coming 25 years from 2.6 to 3.5 tones ha^{-1} [1]. This is very much essential to maintain global food security that requires a continuing supply of improved germplasm with regard to climate change bringing global warming. The effect of climate change on wheat production is inconclusive and model dependent [2]. The wheat production in the subcontinent is often carried out lately subjecting it to hotter growing seasons [3]. Under the changing climatic conditions, heat stress is one of the major challenges for wheat production.

Bangladesh is a sub-tropical country and here about 80% of the total wheat is grown after rice under short and dry winter season from November to March. Researchers showed that the main constraint related to low yield in wheat production in Bangladesh is late sowing. For each day delay sowing after optimum time (30th November) wheat yield reduces @ 1.3% per day [4]. It happens as the grain filling stage of wheat is forced into very high temperature of late March to mid-April reducing the duration of grain filling [5]. Thus heat stress is a major obstacle limiting wheat yield in Bangladesh. Wheat is a cool season crop but it can be grown in different agro-climatic zones. The optimum growing temperature is about 25°C, with minimum and optimum temperature of 3°C - 4°C and 30°C - 32°C respectively [6]. It is subjected to heat stress when the mean daily temperature in the coolest month of the winter season is over 17.5°C [7].

The optimum temperature from anthesis to maturity is around 25°C or lower

[8]. Maximum leaf photosynthesis was recorded at 22°C [9]. Genotypes varied for both grain filling rate and duration but increasing temperatures during grain filling tends to stop grain growth prematurely and to hasten physiological maturity [10]. Due to overall shortening of the reproductive stage, the opportunity for the fixation of photosynthate and its translocation to developing grain is also short causing significant reduction of grain yield and size [11]. Fischer and Maurer [12] demonstrated a 4% reduction in grain yield for every unit increase in temperature between tillering and grain filling stage. Hence, increased heat tolerance in late planted wheat having greater stability in growth and yield attributes would certainly be of great importance to stabilize and increase the productivity of wheat in Bangladesh. The analysis of physiological determinants of yield response to heat will pick out some information to identify the traits as screening tool and thus might be helpful in designing future breeding program related to heat tolerance. The objectives of this study were to examine the performance of wheat genotypes in late sowing condition, estimate the variability, heritability, genetic advance, identify heat tolerant genotypes for hybridization program expecting to provide superior segregates.

2. Materials and Methods

2.1. Information about the Experimental Site and Temperature

The present study was conducted at the experimental field of the Regional Wheat Research Centre (RWRC), Shyampur, Rajshahi under Bangladesh Agricultural Research Institute (BARI) from December 31, 2016 to April 10, 2017 in late sowing condition. The experimental site is situated between 24°22' North latitude and 88°39' East longitude with elevation of about 14 m above the sea level. It is located about 6.5 Km East from Rajshahi city. The site belongs to the Agro Ecological Zone of High Ganges River Floodplain (AEZ-11). The soil of the field is silty clay or Gangetic alluvial type having slightly alkaline with a pH value of 7.1 to 8.5, low in organic matter and fertility level, deficient in boron but high in iron content.

Optimum time for sowing of wheat in Bangladesh is between mid-November and first week of December. In extremely late sowing (December 31) condition, during germination, minimum temperature was very low ≤12°C and at vegetative stage temperature was maximum ≥25°C and minimum ≤11°C, but at grain filling stage maximum was ≥35°C and minimum was ≤19°C to 22°C (Mach-April), which was also not suitable for proper growth and good yield. Moderately high temperatures (25°C - 32°C) and short periods of very high temperatures (33°C - 40°C and above) during grain formation severely affect the yield, yield components of wheat due to heat stress. Early sowing always produces higher yield than late sowing. Each day delay in sowing from 20th November decreases grain yield @ 39 kg/ha per day [13]. The adverse effect of temperature could be minimized by adjusting sowing time to an optimum date and to find out heat tolerant genotypes, which are suitable for late and very early sown conditions to

ensure high grain yield. In late planting the wheat variety should be short duration that may escape from high temperature at the grain filling stage.

2.2. Base Materials and Their Sources

For conducting the experiment, the base materials were collected from the on-going breeding program of Regional Wheat Research Center (RWRC), Shyampur, Rajshahi. Twenty five wheat genotypes (varieties/line) were used in this study, and these were G01 (BARI Gham 21) check, G02 (BARI Gham 21) check from BARI and the rest G03, G04, G 05, G06, G07, G08, G09, G10, G11, G12, G13, G14, G15, G16, G17, G18, G19, G20, G21, G22, G23, G24 and G25 were collected from CIMMYT (International Maize and Wheat Improvement Center).

2.3. Experimental Design and Seed Sowing

The experiment was laid out in Alpha Lattice Design with two replications. The experimental plot was initially divided into two super blocks; the blocks were subdivided into 5 sub-blocks and finally each sub-block was further divided into 5 plots where genotypes were assigned randomly. Seeds of each genotype were sown in unit plot size of 4 m long with 5 rows. Plot to plot distance was 40 cm and sub-block to sub-block distances was 60 cm. A spacing of 1.5 m was maintained between the two blocks. The seeds were sown by hands continuously in lines 20 cm apart within the rows on the 22nd December, 2016 under Irrigated Late Sowing (ILS) condition. Each plot was seeded at the seed rate of 120 kg/ha to establish a uniform plant population of about $200/m^2$.

2.4. Wheat Cultivation and Fertility Management

The experimental field was prepared thoroughly by ploughing with tractor followed by harrowing and laddering to bring good tilth. All the stubbles and uprooted weeds were removed from the experimental plot and the plot was leveled properly. RWRC recommended doses of fertilizers and manures were applied to the field. The field was fertilized with N, P, K, S and B @100, 28, 40, 20 and 2.5 kg/ha respectively to ensure proper growth and development. The elements N, P, K, S and B were applied in the form of urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and boric acid respectively. Two-third of urea and the entire quantity of other fertilizers were applied at final land preparation along with Furadon 30 @ 8 kg/ha. The rest one-third urea was top-dressed at crown root initiation stage (17 - 21 days after sowing) following the first irrigation.

2.5. Intercultural Operations and Harvesting

Intercultural operations were performed from time to time during the wheat crop growth. Weeding was done once at tillering stage *i.e.* 28 - 30 days after sowing and mulching was done twice *i.e.* the first one was after germination (13 - 15

DAS) and the another was after the 1st irrigation. The 1st, 2nd and 3rd irrigations were provided at 20 (Crown root initiation stage), 55 (Booting stage) and 75 (Grain filling stage) days after sowing (DAS). Wheat plants were harvested when all the crop plants turned brown and matured properly. Different genotypes matured at different times and the harvesting for the collection of yield data was completed by April 06, 2017.

2.6. Data Collection (Phenological and Physiological Parameters and Yield)

Data on different phenological, physiological and yield contributing characters were collected. Ten matured plants were randomly selected from each plot for collecting post-harvest data. Mean of the ten plants for each characters were used for statistical analysis.

Heading days (HD) was determined by counting the days from seeding to a stage at which 50% of the spikes came out fully from the leaf sheath. Maturity days (MD) were recorded by computing days from the date of seeding to the date when 50% peduncle of 50% plants of each plot became yellow. Plant height (PH) of the crop measured by meter scale from bottom to the top of the spike at physiological maturity stage and expressed as cm. The number of spikes in $1m^2$ (SPM) area were counted and expressed as spikes/m^2. Total number of spikelet was quantified from ten randomly selected spikes of each unit plot and mean of ten spikes was used as number of spikelets/spike (SPS). After threshing of crop plants total number of grain was calculated from ten randomly selected spikes of each unit plot and mean of ten spikes was used as number of grains/spike (GPS). The canopy temperature (°C) for individual genotype was measured 2 times at 5 day interval by a hand held infrared thermometer at vegetative and grain filling stage at noon under bright sunlight with less wind flow. The chlorophyll content of flag leaf at grain filling stage (SPAD) was determined by a Minolta SPAD meter from 5 flag leaves with fully expanded sunlit during anthesis and 21 day after anthesis period.

The harvested crop including all spikes, leaves and stems was sun dried for a couple of days, then weighted in kilogram (kg) and expressed as biomass in kg/ha. After harvest two hundred sun dried clean grains were randomly counted from each plot and weighed in a digital balance in gram (g) and this was converted into 1000-grain weight. After complete maturity the weight of dried clean seeds was recorded from the harvested area as per unit plot and then converted the yield into kg/ha. The harvest index (HI) was calculated by using the following formula-

$$HI = \frac{\text{Grain yield kg} \cdot \text{ha}^{-1}}{\text{Biomass kg} \cdot \text{ha}^{-1}}$$

2.7. Data Analysis by Univariate Statistics (Variability Statistics)

The data collected on different yield contributing, phonological and physiological traits were subjected to analysis following Univariate statistics. For univariate

analysis, analysis of variance (ANOVA) was done individually by F-test, mean of all genotypes over replications were computed and mean values were separated by STAR program.

2.7.1. Estimation of Genotypic and Phenotypic Variances

The genotypic and phenotypic variances were estimated according to the formula suggested by Johnson *et al.* [14]. The error MS was considered as environmental variances (σ_e^2). Genotypic variances (σ_g^2) and phenotypic variances (σ_p^2) were calculated using the following formula-

$$\sigma_g^2 = \frac{\text{GMS} - \text{EMS}}{r} \quad \text{with } (n-1) \text{ df}$$

$$\sigma_p^2 = \sigma_g^2 + \sigma_e^2$$

where, GMS and EMS are the genotypic mean squares and error mean squares respectively and r is the number of replications.

2.7.2. Estimation of Genotypic and Phenotypic Coefficient of Variation

The genotypic and phenotypic coefficients of variations were estimated according to the formula suggested by Burton (1952) [15].

$$\text{Genotypic coefficient of variation, } \text{GCV}(\%) = \frac{\sigma_g \times 100}{\bar{x}}$$

where, σ_g = Genotypic standard deviation

$\bar{x}$ = Population mean

Similarly, the phenotypic coefficient of variation was calculated from the following formula-

$$\text{Phenotypic coefficient of variation, } \text{PCV}(\%) = \frac{\sigma_g \times 100}{\bar{x}}$$

where, σ_p = Phenotypic standard deviation

$\bar{x}$ = Population mean.

2.7.3. Estimation of Heritability

Heritability in broad sense (h_b^2) was estimated for different traits by the formula suggested by Johnson *et al.* [14]. Heritability estimates from single environment was completed using the following formula-

$$\text{Heritability in broad sense, } h_b^2 = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

where, σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance.

2.7.4. Estimation of Genetic Advance (GA)

The expected genetic advance (GA) for different traits under selection was estimated using the formula suggested by Johnson *et al.* [14].

$$\text{Genetic advance } (\text{GA}) = h_b^2 \cdot i \cdot \sigma_p$$

where, h_b^2 = Heritability in broad sense (decimal)

i = Selection differential, the value of which is 1.76 at 10% level of selection intensity.

σ_p = Phenotypic standard deviation.

2.7.5. Estimation of Genetic Advance in Percent of Mean

The genetic advance in percent of mean was calculated by using formula Johnson *et al.*, given by Comstock and Robinson [16].

Where,

$$\text{GA \% mean} = \frac{\text{GA}}{\overline{x}} \times 100$$

GA = Genetic advance

$\overline{x}$ = Population mean.

3. Results

3.1. Performance of the Genotypes in Late Sowing Condition

3.1.1. Phenological and Physiological Parameters

Table 1 showed different phenological and physiological characters of 25 wheat genotypes cultivated under irrigated late sowing (ILS) conditions.

Table 1. Performances of 25 wheat genotypes on phenological and physiological characters under irrigated late sowing (ILS)/heat stress conditions.

Genotypes	HD	MD	CT_{vg}	CT_{gf}	SPAD	Biomass
G 01(ck)	62.50abc	102.0a	20.60a-g	27.25c-g	39.10abc	12460.00ab
G 02(ck)	68.00de	99.50a-e	20.30d-g	27.35c-g	39.10abc	9457.50d
G 03	66.00b-e	100.0a-d	21.85ab	27.35c-g	28.75c	10395.0a-d
G 04	67.00a-d	100.0a-d	21.40a-e	28.60a-e	44.50a	9757.50cd
G 05	67.00a-d	100.5abc	21.95a	30.10a	28.75c	10,722.50a-d
G 06	67.00a-d	102.0a	20.75a-g	28.70a-d	38.05abc	11400.0a-d
G 07	68.00ab	99.00b-f	21.80abc	29.85a	32.40bc	11792.50a-d
G 08	67.50abc	101.0ab	21.40a-e	29.00abc	39.25abc	11612.50a-d
G 09	68.00ab	100.00b-f	21.85ab	29.65ab	37.43abc	12722.50a
G 10	64.50abc	97.00ab	20.85a-f	29.65ab	39.05abc	10595.0a-d
G 11	68.50a	101.0ab	21.70a-d	28.90a-d	37.03abc	11198.12a-d
G 12	66.50a-e	100.0a-d	20.30d-g	26.90d-g	32.55bc	10232.50bcd
G 13	65.50c-e	100.0a-d	20.65a-g	27.65b-f	37.80bc	11925.0abc
G 14	65.00ab	98.00a-e	19.65efg	25.90fg	32.75bc	10627.50a-d
G 15	67.50ef	100.50def	19.35g	25.95fg	37.43abc	11425.0a-d
G 16	65.50de	98.50a-d	19.80fg	25.55g	40.25ab	11077.50a-d
G 17	68.00ab	99.00b-f	20.20efg	26.60efg	35.50abc	11198.12a-d
G 18	67.50fg	101.00ef	20.55a-g	28.40a-e	37.70abc	12102.50abc

Continued

G 19	68.00ab	100.5abc	20.35c-g	28.16ab	39.85ab	11198.12a-d
G 20	67.50abc	100.0a-d	20.45b-g	28.90a-d	38.10abc	11295.0a-d
G 21	68.00de	100.0a-d	20.20fg	28.16ab	36.55abc	11198.12a-d
G 22	68.00ab	99.00b-f	20.79abc	29.40ab	37.85abc	11422.50a-d
G 23	68.00ab	99.50c-f	20.41ab	28.00abc	38.05abc	11198.12a-d
G 24	62.00g	96.50f	19.35g	28.32a-e	39.10abc	11507.50a-d
G 25	65.00ab	99.50abc	19.85efg	28.18ab	39.25abc	11432.50a-d
Mean	66.620	99.680	20.80	28.16	37.43	11198.12
CV (%)	1.62	1.36	1.67	1.76	6.96	5.25
LSD	2.232	2.792	2.1912	2.0152	10.5874	2389.9961

ILS = Irrigated late sowing, HD = Heading days, MD = Maturity days, CT_{vg} = Canopy temperature at vegetative stage, CT_{gf} = Canopy temperature at grain filling stage, SPAD = Chlorophyll content at flag leaf at grain filling stage, CV = Coefficient of Variation and LSD = Least significance difference.

The mean value for heading time (HD) of all genotypes was 66.62 days where the shortest was observed in G 24 (62.00 days). The genotypes G24, G01, G10, G25, G14, G13, and G16 took significantly shorter time for heading under heat stress condition. The average time of maturity (MD) of all genotypes was 99.68 days, the shortest was in G25 (95.50 days). The genotypes G25, G24, G10, G14 and G16 took minimum time for their maturity. The mean canopy temperature at vegetative stage (CT_{vg}) of all genotypes was 20.80˚C, the maximum in G05 (21.95˚C) and the minimum was showed in both G15 and G24 (19.35˚C). The genotypes G14, G16, G21 and G25 had cool canopy temperature at vegetative stage. The average canopy temperature at grain filling stage (CT_{gf}) of all genotypes was 28.16˚C, while the maximum and minimum were showed in G05 (30.10˚C) and G16 (25.55˚C) respectively. It was also observed that the genotypes G12, G14, G15, G01, G02 and G03 belonged to cool canopy temperature at grain filling stage (Table 1).

The average chlorophyll content of flag leaf at grain filling stage (SPAD) of all genotypes was 37.43 SPAD unit, where as the highest was in G04 (44.50 SPAD unit) and the lowest was found in both G03 and G05 (28.75 SPAD unit). The genotypes G01, G02, G08, G10, G16, G19, G24 and G25 had maximum chlorophyll content under heat stress condition. The average biomass was 11,198.12 kg/ha produced in all genotypes, and the highest and lowest were obtained from the genotypes G09 (12,722.50 kg/ha) and G02 (9457.50 kg/ha) respectively. The higher biomass was produced from genotypes G01, G07, G13 and G18 (Table 1).

3.1.2. Yield and Yield Contributing Parameters
Table 2 indicated performances of yield and different yield contributing parameters of 25 wheat genotypes under ILS conditions. The average plant height of all genotypes was 85.50 cm and the tallest and the shortest height were observed

Table 2. Performances of 25 wheat genotypes on plant height, yield and yield contributing characters under ILS/heat stress conditions.

Genotypes	PH	SPM	SPS	GPS	TGW	Yield	HI
G 01 (ck)	87.50a-d	346.5b-g	18.50a-d	38.25k	36.10bcd	2545bc	0.3800
G 02 (ck)	85.15d-i	356.0b-g	16.80d-h	46.60def	30.00fg	2285d-h	0.3824
G 03	83.00f-j	342.0b-h	18.45a-d	50.60bc	29.05fgh	1923k	0.3745
G 04	83.50e-j	321.0ghi	15.80gh	37.65cde	37.65bc	2228f-i	0.3445
G 05	86.15c-g	322.5f-i	15.80gh	33.80f-i	33.95de	2278d-h	0.3812
G 06	83.50e-j	333.0c-i	15.30h	35.20jk	36.15bcd	2320c-g	0.3925
G 07	81.65ij	322.0d-i	15.00h	40.55ijk	30.00fg	2150f-k	0.3825
G 08	86.50b-f	360.5b-e	18.50a-d	37.30c-f	31.40ef	1998ijk	0.3645
G 09	82.50hij	356.5b-g	17.40c-g	41.50h-j	34.70cd	2170f-j	0.3830
G 10	89.15abc	407.5a	19.10abc	40.40ijk	34.70cd	2740ab	0.3745
G 11	81.50j	332.5d-i	16.20fgh	40.30ijk	37.50bc	2193e-j	0.3735
G 12	89.00abc	345.0b-g	17.40c-g	45.00e-h	29.42fgh	2188e-j	0.3785
G 13	90.35a	408.0a	16.20f-h	37.25c-f	39.15ab	2540bc	0.3845
G 14	86.35a	366.5bcd	17.90c-f	48.80bcd	26.40h	2003i-k	0.4130
G 15	87.35a-d	346.5b-g	16.20fgh	35.25efg	27.75gh	1985jk	0.4035
G 16	88.35a-d	354.5b-g	20.00a	55.10a	34.90cd	2273d-h	0.4180
G 17	85.15d-i	300.0i	16.80e-h	34.30e-h	29.00fgh	2100g-k	0.3915
G 18	81.00j	325.5e-i	19.90ab	34.40e-h	29.25fgh	2025i-k	0.3780
G 19	82.85g-j	304.0i	17.50c-g	32.50g-j	34.30de	2503cd	0.3750
G 20	81.30j	307.5hi	16.30e-h	32.10g-j	35.40cd	2353c-f	0.3805
G 21	85.35d-h	357.0b-f	19.90ab	34.80e-h	30.70fg	2420c-e	0.3712
G 22	85.35d-h	332.5d-i	16.70d-h	51.60ab	28.00gh	2073h-k	0.3520
G 23	88.50a-d	359.5b-e	18.10b-e	51.25b	29.70fg	1990jk	0.3610
G 24	89.80ab	370.0b	16.50e-h	35.25efg	38.97fgh	2858a	0.3912
G 25	86.30b-g	368.5bc	17.50c-g	35.60d-g	41.47a	2035i-k	0.3990
Mean	85.496	345.200	17.214	40.214	32.625	2146.800	0.3812
CV (%)	1.99	5.00	5.28	3.77	4.57	5.04	5.23
LSD	3.50	35.75	1.477	3.517	3.080	233.9	-

ILS = Irrigated late sowing, PH = Plant height, SPM = Spike per meter square, SPS = spikelet per spike, GPS = Grains per spike, TGW = 1000 grain weight, HI = Harvest index, CV = Coefficient of Variation and LSD = Least significance difference.

in G13 (90.35 cm) and G18 (81.00 cm) respectively. The genotypes G07, G11, G20 and G18 produced lower plant height. The mean number of spike per 1m² (spike/m²) area of all genotypes was 345.20, the maximum and minimum were found in G13 (408.0) and G17 (300.0). The genotypes G13, G10, G24, G25 and G14 produced higher number of spikes within this area. The average number of spikelet/spike (SPS) of all genotypes was 17.21. The highest number of spikelet

was observed in G16 (20.00) and the lowest was in G07 (15.00). The higher number of spikelet/spike was found in genotypes G16, G21, G10, G08 and G01 (Table 2).

The mean number of grains/spike of all genotypes was 40.21. The greater number of grains was produced in G16 (55.10) and the lower was in G01 (38.25). The genotypes G16, G22, G23, G03 and G14 were found as higher producer of number of grains/spike. The highest weight of 1000-grain (TGW) was obtained in G25 (41.47 g) and the lowest was in G14 (26.40 g), while the average 1000-grain weight of all genotypes was 32.63g. Results also showed that the higher weight of 1000-grain was produced in genotypes G25, G13, G04, G11, G06, G01 and G20 (Table 2).

The average grain yield of all genotypes was 2246.80 kg/ha, while the highest and the lowest yield were observed in G24 (2858 kg/ha) and G03 (1923 kg/ha) respectively. The higher grain yield was obtained in the genotypes G24, G10, G01, G13, G19 and G21. The largest harvest index (HI) was exposed in G15 (0.4180), the lowest in G04 (0.3445) and the average harvest index of all genotypes was 0.3812. It (HI) was observed higher in genotypes G06, G14, G15, G16, G17, G24 and G25 (Table 2).

3.2. Variability, Heritability and Genetic Advance

3.2.1. Phenological and Physiological Parameters

Mean squares along with other determinants of heading days, maturity days, canopy temperature at vegetative stage, canopy temperature at grain filling stage, SPAD, biomass were significantly different among different genotypes (Table 3). Phenotypic variances (σ_p^2) of all phenological and physiological parameters

Table 3. Genotypic and phenotypic variation, heritability and genetic advance for different phenological and physiological parameters of wheat in ILS/heat stress conditions.

Components	HD	MD	CT_{vg}	CT_{gf}	SPAD	Biomass
Ranges	62.00 - 68.50	96.00 - 102.00	19.35 - 21.95	25.55 - 30.10	28.75 - 44.50	9457.50 - 12,722.50
σ_g^2	2.53	1.02	0.60	1.89	8.56	548,533.95
σ_p^2	3.70	2.86	0.72	2.11	14.43	893,848.78
GCV (%)	2.39	1.01	3.74	4.89	7.82	6.61
PCV (%)	2.89	1.69	4.08	5.15	10.15	8.44
h_b^2 (%)	68.34	35.72	83.92	90.06	59.32	61.37
GA % ($i = 10\%$)	2.31	1.06	1.25	2.30	3.96	1021.14
GA % of mean	3.47	1.06	6.02	8.17	10.59	9.12
CV (%)	1.36	1.36	1.67	1.76	6.96	5.25
MS	6.22***	3.87***	1.33***	4.00***	23.00***	1,442,382***

ILS = Irrigated late sowing condition, HD = Heading days, MD = Maturity days, h_b^2 = Broad sense heritability, CV = Coefficient of variation, GCV = Genotypic co-efficient of variation, CT_{vg} = Canopy temperature at vegetative stage, PCV = Phenotypic co-efficient of variation, CT_{gf} = Canopy temperature at grain filling stage, SPAD = Chlorophyll content of flag leaf at grain filling stage, σ_g^2 = Genotypic variance, σ_p^2 = Phenotypic variance, GA = Genetic advance and MS = Mean Square.

were greater than those of genotypic variances (σ_g^2). The same trends were also found in their values of co-efficient of variations. For all the traits the values of phenotypic co-efficient of variation (PCV) were higher than those of the genotypic co-efficient of variation (GCV) and these values were lower and showed closer to each other values for heading days (PCV 2.89% and GCV 2.39%), maturity days (1.69% and 1.01%), canopy temperature at vegetative stage (4.08% and 3.74%), canopy temperature at grain filling stage (5.15% and 4.89%), chlorophyll content of flag leaf at grain filling stage (SPAD10.15% and 7.82%) and biomass (8.44% and 6.61%).

Broad sense heritability estimated higher for HD (68.34%), CT_{vg}, (83.92) and CT_{gf} (90.06) and biomass (61.37), moderate for MD (35.72) and SPAD (59.32). The mean percentage of genetic advance was low for HD (3.47), MD (1.06), CT_{vg}, (6.02), CT_{gf} (8.17) and biomass (9.12), moderate for SPAD (10.59). The co-efficient of variation (CV%) of heading days (HD1.36%), maturity days (MD1.36%), canopy temperature at vegetative stage (CT_{vg}, 1.67%), canopy temperature at grain filling stage (CT_{gf} 1.76%), chlorophyll content of flag leaf at grain filling stage (SPAD 6.96%) and biomass (5.25%) were low (<10%).

3.2.2. Yield and Yield Contributing Parameters

Mean squares of plant height, spike per meter square, spikelets per spike, number of grains per spike, thousand grains weight and yield were significantly different among genotypes and the harvest index was non-significant (Table 4). Phenotypic variances (σ_p^2) of yield and yield contributing parameters were greater than those of genotypic variances (σ_g^2). The values of PCV of all traits were greater compare to those of GCV and these values were closer to each other

Table 4. Genotypic and phenotypic variation, heritability and genetic advance for yield and yield contributing characters of wheat in ILS/ heat stress conditions.

Components	PH	SPM	SPS	GPS	TGW	Yield	HI
Ranges	43.50 - 90.35	300 - 408	15.00 - 20.00	38.25 - 55.10	26.40 - 39.15	1923 - 2858	0.3520 - 0.4180
σ_g^2	6.67	584.59	1.38	22.66	20.25	108,399.5	0.0001
σ_p^2	9.56	884.62	2.20	24.56	22.48	111,237.5	0.0004
GCV (%)	3.02	7.00	6.82	11.87	13.78	15.33	2.93
PCV (%)	3.62	8.62	8.62	12.32	14.53	15.53	5.41
h_b^2 (%)	69.77	66.08	62.48	92.26	90.08	97.44	29.41
GA% ($i = 10\%$)	3.79	34.59	1.63	8.04	7.52	571.97	0.0107
GA % of mean	4.44	10.02	9.98	20.01	23.04	26.64	2.79
CV (%)	1.99	5.00	5.28	3.77	4.57	5.04	5.23
MS	16.23***	1469.21***	3.58***	47.22***	42.73***	219,637***	0.0008[NS]

ILS = Irrigated late sowing condition, HD = Heading days, MD = Maturity days, h_b^2 = Broad sense heritability, CV = Coefficient of variation, GCV = Genotypic co-efficient of variation, CT_{vg} = Canopy temperature at vegetative stage, PCV = Phenotypic co-efficient of variation, CT_{gf} = Canopy temperature at grain filling stage, SPAD = Chlorophyll content of flag leaf at grain filling stage, σ_g^2 = Genotypic variance, σ_p^2 = Phenotypic variance, GA = Genetic advance and MS = Mean Square.

(PH 3.62% > 3.02%, SPM 8.62% > 7.00%, SPS 8.62% > 6.82%, GPS 12.32% > 11.87%, TGW 14.53% > 13.78%, yield 15.53% > 15.33% and HI 5.41% > 2.93%).

The broad sense heritability was lower in traits HI (29.41%), and higher in PH (69.77%), SPM (66.08%), SPS (62.48%), GPS (92.26%), TGW (90.08) and yield (97.44). The genetic advance in percentage of mean was low for PH (4.44), and HI (2.79%), moderate in SPM (10.02%), SPS (9.98%) and higher in GPS (20.01%), TGW (23.04%) and yield (26.64%). The co-efficient of variation (CV%) was lowest (1.99) for plant height (PH) and it was low for the other traits viz. spike/m² (SPM 5.00), spkelets/spike (SPS 5.28), grains/spike (GPS 3.77), 1000-grain weight (TGW 4.57), grain yield (5.04) and harvest index (HI 5.23).

4. Discussion

4.1. Performance of the Wheat Genotypes in Late Sowing Environments

Analyzing the performance of twenty-five wheat genotypes it was observed that there might be some genotypes which were adapted to ILS condition and had the ability to perform better even under heat stress condition. Table 1 and Table 2 showed significant differences among 25 wheat genotypes upon different traits viz. heading days (HD), maturity days (MD), canopy temperature at vegetative stage (CT_{vg}), canopy temperature at grain filling stage (CT_{gf}), SPAD, biomass, plant height (PH), spike/m² (SPM), spikelet/spike (SPS), grains/spike (GPS), thousand grain weight (TGW), yield and harvest index (HI) in the late sowing environment.

The genotypes G24, G01, G10, G25, G14, G13 and G16 showed lower heading days (Table 1) indicated that these genotypes matured faster [17]. Shorter maturity days were required for genotypes G24, G25, G10, G14 and G16 (Table 1) which denoted shortening of maturity time meaning early maturing cultivars were preferable to escape heat stress and lodging resistance. Menshawy [18] obtained similar results of early maturing of wheat cultivars those were preferable from escaping heat stress injury.

The genotypes G14, G15, G16, G24 and G25 were found as traits having cooler canopy temperature at vegetative stage and completed their vegetative stage without any difficulty (Table 1). In grain filling stage the genotypes G14, G15, G16 and G17 remained cool under heat stress at grain filling period and grain filling was completed without so much desiccation of pollen grain. Cooler canopy temperature (CT), which appears to have some common genetic basis under both heat and drought stress [19].

For the trait SPAD the genotypes G04, G16, G19, G08, G25, G24, G01 and G02 accumulated maximum chlorophyll content which exposed that these genotypes had completed photosynthetic activities without any difficulties (Table 1). Jiang, Y. and Huang B. [20] reported that the leaves rapidly turned yellow with a gradual decrease in the chlorophyll content at high temperature, suggesting a drastic reduction in photosynthetic activity. The genotypes G09, G01, G18

and G13 had produced higher amount of biomass.

It was observed that the genotypes G07, G11, G20 and G18 produced shortest plant height which indicated that these genotypes were resistant to lodging which would require reduced photosynthesis (Table 2). Lower plant height had resistant capacity against heat stress. Sing *et al.* [21] observed that heat stress had negative impact on plant height of wheat as reported in the present study. Tadesse *et al.* [22] emphasized that attention needs to be given in improving lodging resistance otherwise selection for taller plants will result in lodging and increasing disease development. Plant height in wheat is a complex character and is the end product of several genetically controlled factors [23].

However, results from the Table 1 and Table 2 expressed the genotype G01 as belonged to high SPAD, biomass, SPS, TGW and yield along with low HD, CT_{gf} indicated that this genotype performed better under heat stress. Similarly, G10 showed a high value of SPAD, SPM, SPS and yield with low HD, MD which was adapted to ILS condition, G25 also exposed high SPAD, SPM, TGW and HI along with low HD, MD, CT_{vg} suggested to resist heat stress. Under the same environmental condition, the genotype G13 synthesized high SPAD, biomass, produced largest length of plant height with maximum SPM in high TGW and yield, G14 found as a producer of high SPM, GPS and HI along with low HD, MD, CT_{vg} and CT_{gf} which indicated that these genotypes resist heat stress. In the genotype G24 estimated high SPAD, SPM, yield and HI along with low HD, MD demonstrated better performance under heat stress. The highest value of SPAD, SPS, GPS and HI along with low MD, CT_{vg} and CT_{gf} were found in G16 suggested that this genotype had the ability to resist heat stress under ILS condition (Table 1 and Table 2).

4.2. Variability, Heritability and Genetic Advance

Mean squares for phenological and physiological traits such as HD, MD, CT_{vg}, CT_{gf}, SPAD and biomass showed significant differences among all wheat genotypes (Table 3). Significant differences also observed among these genotypes on different yield and yield contributing attributes like PH, SPM, SPS, TGW and yield except in harvest index which showed non-significant variation (Table 4). The co-efficient of variation (CV%) was very low for all traits indicated the difference of each individual to another was minimum which expressed the higher acceptability level of results for these traits. Decreasing CV (%) values with increasing plant population was observed in wheat [24]. Lukina *et al.* [25] also showed similar findings with minimum value of CV.

The values of PCV and GCV were low and close to each other for all the traits indicated narrow range of genetic variability along with less influence of environmental factors. The estimated GCV values were high for yield per plant (15.33), thousand grain weight (13.78), number of grains per spike (11.87). The remaining traits recorded moderate to low GCV. The lowest difference (0.20%) was also found in between PCV and GCV for yield among all the parameters

which was identically optimistic.

Phenotypic variances (σ_p^2) and genotypic variances (σ_g^2) in a crop population are important for successful plant breeding. Broad-sense heritability (h_b^2) is expressed as the percentage of the ratio between the genotypic variance and phenotypic variance. According to Johnson *et al.* [16] heritability is classified as low (below 30%), medium (30% - 60%) and high (above 60%); and genetic advance (as percentage of mean) is classified as low (<10%), moderate (10% - 20%) and high (>20%).

The estimated heritability for different phenological, physiological and yield contributing trait ranged between 29.41% and 97.44%. High heritability indicated that the selection for these characters would be effective, being less influenced by environmental effects [26]. Heritability, a measure of the phenotypic variance attributable to genetic causes, has predictive function in breeding crops [27].

The heading days, canopy temperature at vegetative stage, canopy temperature at grain filling stage, plant height, SPS, GPS and TGW exhibited high heritability (>60%) with low genetic advance (<10%) expressed as non additive gene action for which these traits would not be suggested for selection. Barma *et al.* [28] reported a narrow range of genotypes for these traits.

Broad-sense heritability was medium (30% - 60%) and genetic advance (in percentage of mean) was low (<10%) for maturity days denoted as the pre-dominance of non-additive gene action indicated for not considered as an effective trait. In chlorophyll content of flag leaf stage the broad sense heritability was medium (30% - 60%) and genetic advance was moderate (10% - 20%) expressed the presence of both additive and non-additive gene effect of the trait. Sufian [5] reported similar findings of medium broad sense heritability with moderate genetic advance (percentage of mean).

Heritability in conjunction with genetic advance would give a more reliable selection value [16]. High heritability accompanied with high to moderate genetic advance in the case of SPM, GPS, TGW and yield per plant denoted that the most likely heritability was due to additive gene actions and selection might be effective for these traits in heat stress condition (Table 4). Sachan & Singh [29] reported high heritability estimated for grain yield, number of seeds per spike, 1000-seed weight which supported the present findings. Similar findings have also been reported by Sharma & Garg and Dwivedi *et al.* [30]. The higher the heritability estimates, the simpler are the selection procedures [31]. The traits maturity days, SPAD, harvest index exhibited low heritability with low genetic advance which indicated that the characters highly influenced by environment and selection might not be effective (Table 3 & Table 4). Kahrizi *et al.* [32] observed low heritability and low genetic advance of harvest index in durum wheat as reported in the present study. In general, it is considered that if a character is governed by non-additive gene action, it may give high heritability but low genetic advance, whereas if the character is governed by additive gene action, both

heritability and genetic advance would be high [33].

5. Conclusion

The genotypes G01, G10, G13, G14, G16, G24 and G25 categorized as better following the maximum number of traits indicating their high tolerance to heat stress. Summarizing the discussion of phenological, physiological results with yield and yield contributing attributes the potentiality of experimental wheat genotypes could be ranking as G24 > G10 > G01 > G13 > G16 > G25 > G14 considering better performance of maximum number of traits under heat stress condition. The traits spike per meter square, number of grains per spike, thousand grain weight and yield had high heritability (h_b^2) along with high to moderate genetic advance (GA % of mean) together with wide genetic variation and lower environmental influence under the same heat stress condition indicated additive genetic effects which might be effective for the selection of traits.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ortiz, R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, D., Dixon, J.M., Monasterio, J.I.O. and Reynolds, M. (2008) Climate Change: Can Wheat Beat the Heat? *Agricultural Ecology and Environment*, **126**, 46-58. https://doi.org/10.1016/j.agee.2008.01.019

[2] Tubiello, F.N., Rosenzweig, C.R., Goldberg, A., Jagtap, S. and Jones, J.W. (2008) U.S. National Assessment Technical Report: Effect of Climate Change on U.S. Crop Production Part I: Wheat, Potato, Corn and Citrus.

[3] Chandna, P., Hodson, D.P., Singh, U.P., Gosain, A.K., Sahoo, R.N. and Gupta, R.K. (2004) Increasing the Productivity of Underutilized Land by Targeting Resource Conserving Technologies—A GIS/Remote Sensing Approach in a Case Study of Ballila District, Uttar Pradesh in the Eastern Gangetic Plains. CIMMYT, Mexico.

[4] Saadalla, M.M., Quick, J.S. and Shanaham, J.P. (1990) Heat Tolerance in Winter Wheat. II. Membrane Thermostability and Field Performance. *Crop Science*, **30**, 1248-1251. https://doi.org/10.2135/cropsci1990.0011183X003000060018x

[5] Sufian, M.A. (2005) Sustainable Wheat Production in Bangladesh: Adoption of New Alternative Technologies in Relation to Climate Changes. *The Workshop on Sustainable Wheat Production*, Dhaka, 4 October 2005.

[6] Briggle, U.A., Oad, F.C. and Agha, S.K. (1980) A Heat Shock Stress and Cell Oxidation. *Proceedings of the National Academy of Sciences of the United States of America*, **80**, 7496-7500. https://doi.org/10.1073/pnas.80.24.7496

[7] Fischer, R.A. and Byerlee, D. (1991) Trends of Wheat Production in the Warmer Areas: Major Issues and Economic Considerations. *Wheat for the Non-Traditional Warm Areas*, *Proceedings of Conference*, Iguazu, 29 July-3 August 1990, 3-27.

[8] Sofield, I., Evan, L.T., Cook, M.G. and Wardlaw, I.F. (1977) Factors Influencing the Rate and Duration of Grain Filling in Wheat. *Australian Journal of Plant Physiology*, **4**, 785-797. https://doi.org/10.1071/PP9770785

[9]   Al-Khatib, K. and Paulsen, G.M. (1999) High Temperature Effect on Photosynthetic Processes in Temperate and Tropical Cereals. *Crop Science*, **39**, 119-125. https://doi.org/10.2135/cropsci1999.0011183X003900010019x

[10]   Bruckner, P.L. and Frohberg, R.C. (1987) Rate and Duration of Grain Fill in Spring Wheat. *Crop Science*, **27**, 451-455. https://doi.org/10.2135/cropsci1987.0011183X002700030005x

[11]   Wardlaw, I.F. and Moncur, L. (1995) The Response of Wheat to High Temperature Following Anthesis: The Rate and Duration of Grain Filling. *Australian Journal of Plant Physiology*, **22**, 391-397. https://doi.org/10.1071/PP9950391

[12]   Fischer, R.A. and Maurer, O. (1978) Crop Temperature Modification and Yield Potential in a Dwarfing Spring Wheat. *Crop Science*, **16**, 855-859. https://doi.org/10.2135/cropsci1976.0011183X001600060031x

[13]   Singh, V.P.N. and Uttam, S.K. (1999) Influence of Sowing Dates on Yield of Wheat Cultivars under Saline Sodic Conditions in Central Utter Pradesh. *Indian Journal of Agriculture*, **38**, 64-68.

[14]   Johnson, P.A., Richards, R.A. and Turner, N.C. (1983) Yield, Water Relations, Gas Exchange and Surface Reflectance of Near-Isogenic Lines Differing in Glaucousnes. *Crop Science*, **23**, 318-325. https://doi.org/10.2135/cropsci1983.0011183X002300020033x

[15]   Burton, G.W. (1952) Quantitative Inheritance in Grasses. Proc. 6th Intercropping. Grassland Cong. 1: Chowdhury, N.H. 1991. Studies on Quality of Rice in Bangladesh. In: *Proceeding of the Workshop on Chemical Aspects of Rice Grain Quality*, IRRI, Philippines, 23-127.

[16]   Johnson, H.W., Robinson, H.F. and Comstock, R.E. (1955) Estimates of Genetic and Environmental Variability in Soybean. *Agronomy Journal*, **47**, 314-318. https://doi.org/10.2134/agronj1955.00021962004700070009x

[17]   Tewolde, H., Fernandez, C.J. and Erickson, C.A. (2006) Wheat Cultivars Adapted to Post-Heading High Temperature Stress. *Journal of Agronomy and Crop Science*, **192**, 111-120. https://doi.org/10.1111/j.1439-037X.2006.00189.x

[18]   Menshawy, A.M.M. (2007) Evaluation of Some Early Bread Wheat Genotypes under Different Sowing Dates. 1. Earliness Characters. *Egyptian Journal of Plant Breeding*, **11**, 25-40.

[19]   Pinto, R.S., Reynolds, M.P., Mathews, K.L., McIntyre, C,L., Olivares-Villegas, J.J. and Chapman, S.C. (2010) Heat and Drought Adaptive QTL in Wheat Population Designed to Minimize Confounding Agronomic Effects. *Theoretical and Applied Genetics*, **121**, 1001-1021. https://doi.org/10.1007/s00122-010-1351-4

[20]   Jiang, Y. and Huang, B. (2001) Drought and Heat Stress Injury to Two Cool-Season Turfgrasses in Relation to Antioxidant Metabolism and Lipid Peroxidation. *Crop Science*, **41**, 436-442. https://doi.org/10.2135/cropsci2001.412436x

[21]   Singh, J.P., Shambhoo, P., Singh, K.N. and Randhir, S. (2007) Screening of Heat Tolerant Wheat Varieties by Membrane Thermostability Index in Relation to Yield and Yield Attributing Traits. *International Journal of Plant Science*, **2**, 159-165.

[22]   Tadesse, W., Manes, Y., Singh, R.P., Payne, T. and Braun, H.J. (2010) Adaptation and Performance of CIMMYT Spring Wheat Genotypes Targeted to High Rainfall Areas of the World. *Crop Science*, **50**, 240-248. https://doi.org/10.2135/cropsci2010.02.0102

[23]   Chemma, G.I., Bell, J.M., Gruver, C. and Berry, J.A. (1991) Physiological and Environmental Regulation of Stomatal Conductance, Photosynthesis and Transpiration: A Model That Include a Laminar Boundary Layer. *Agricultural and Forest Meteor-*

ology, **54**, 107-136. https://doi.org/10.1016/0168-1923(91)90002-8

[24] Arnall, B., Raun, W.R., Solie, J.B., Stone, M.L., Johnson, G.V., Girma, K., Freeman, K.W., Teal, R.K. and Martin, K.L. (2006) Relationship between Coefficient of Variation Measured by Spectral Reflectance and Plant Density at Early Growth Stages in Winter Wheat. *Journal of Plant Nutrition*, **29**, 1983-1997. https://doi.org/10.1080/01904160600927997

[25] Lukina, E.V., Freeman, K.W., Wynn, K.J., Thomason, W.E., Mullen, R.W., Stone, M.L., Solie, J.B., Klatt, A.R., Johnson, G.V., Elliot, R.L. and Raun, W.E. (2001) Nitrogen Fertilizer Optimization Algorithm Based on in Season Estimates of Yield and Plant Nitrogen Uptake. *Journal of Plant Nutrition*, **24**, 885-898. https://doi.org/10.1081/PLN-100103780

[26] Maniee, M., Kahrizi, D. and Mohammadi, R. (2009) Genetic Variability of Some Morpho-Physiological Traits in Durum Wheat (*Triticum durum* Desf.). *Journal of Applied Sciences*, **9**, 1383-1387. https://doi.org/10.3923/jas.2009.1383.1387

[27] Songsri, P., Joglloy, S., Kesmala, T., Vorasoot, N., Akkasaeng, C.P.A. and Holbrook, C. (2008) Heritability of Drought Resistance Traits and Correlation of Drought Resistance and Agronomic Traits in Peanut. *Crop Science*, **48**, 2245-2253. https://doi.org/10.2135/cropsci2008.04.0228

[28] Barma, N.C.D. (2005) Genetic Study of Morpho-Physiological Traits Related to Heat Tolerance in Spring Wheat. Ph.D. Thesis, Dept. of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh.

[29] Sachan, M.S. and Singh, S.P. (2003) Genetics of Yield and Its Components in Durum Wheat (*Triticum durum* Desf.). *Journal of International Academicia*, **7**, 140-143.

[30] Sharma, A.K. and Grag, D.K. (2002) Genetic Variability in Wheat (*Triticum aestivum* L.) Crosses under Different Normal and Saline Environments. *Annals of Agricultural Research*, **23**, 497-499.

[31] Khan, N. and Naqvi, F.N. (2011) Heritability of Morphological Traits in Bread Wheat Advanced Lines under Irrigated and Non-Irrigated Conditions. *Asian Journal of Agricultural Sciences*, **3**, 215-222.

[32] Kahrizi, D., Cheghamirza, K., Kakaei, M., Mohammadi, R. and Ebadi, A. (2010) Heritability and Genetic Gain of Some Morphophysiological Variables of Durum Wheat (*Triticum turgidum var. durum*). *African Journal of Biotechnology*, **9**, 4687-4691.

[33] Eid, M.H. (2009) Estimation of Heritability and Genetic Advance of Yield Traits in Wheat (*Triticum aestivum* L.) under Drought Condition. *International Journal of Genetics and Molecular Biology*, **1**, 115-120.