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Development of Short Duration, Tolerance to High Temperature and *Bipolaris* Leaf Blight, and Moderately Susceptible to Blast Disease of Wheat Genotype with Trials in Various Agroecological Zones in Bangladesh

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Abstract
Wheat production in Bangladesh faces to the detrimental effects of biotic and abiotic stresses that have been exacerbated by climate change. The development of short duration, high temperature and disease tolerant wheat variety is the most importance to produce higher yield combating the deleterious effects of the stresses. Some wheat lines (line was expressed by E) were evaluated at the different research stations of Bangladesh Wheat and Maize Research Institute (BWMRI) and farmers' fields in consecutively three years under irrigated timely sowing (ITS) and irrigated late sowing (ILS) conditions. The days to heading (DH), days to maturity (DM), plant height (PH), spikelet spike^{-1} (SPS), grain spike^{-1} (GPS), thousand grain weight (TGW), and grain yield were depicted comparatively higher in ITS and ILS than ITS, but the severity of *Bipolaris* leaf blight (BpLB) and blast diseases were exhibited lower in BAW 1194 (E9) line than check varieties and other lines same conditions (BAW = Bangladesh Advanced Wheat). Those phenotypic and yield contributing characters, and BpLB and blast diseases were also observed lower in ILS than other genotypes. Further, E9 exhibited the lower percentage of yield loss in the ILS compared to ITS than check and other genotypes indicated its high temperature tolerance. In addition, E9 exhibited relatively higher grain yield than other genotypes in the candidate variety demonstration and multiplication yield trials. Therefore, BAW 1194 line may be released as a short duration, tolerance to high temperature and BpLB, and moderately tolerance to blast disease wheat variety to accelerate wheat production.

Keywords: *Bipolaris* leaf blight, high temperature, grain yield, short duration, wheat.

Introduction

Wheat is currently the second staple food grain consumed by the people of Bangladesh after rice. In Bangladesh, wheat accounts for 2.9% of all cropped land, and 3.7% of all main cereal production [1]. The initiations of food habit diversification strategy, malnutrition minimization, and ensuring food security to the people, wheat flour consumed by the people as curative or preventive measure of diabetic disease, wheat demand in the country increases annually @7.11% [1]. Wheat consumption boosts @2% in 2020/21 than in 2019/20 [1]. As the Ministry of Food, wheat import as food grain reached to 7.0 ton in fiscal year of 2019/20. As the BBS, the country's population will be projected to 196.5 million and 202.2 million by the year 2030 and 2050, respectively[1]. Wheat demand was increased by 0.7 million ton between 2015 and 2020, and additional demand will be 0.5 million ton by 2030 [2].

The cropping intensity of Bangladesh in 2017 was 200% [1]. Transplanting (T) *boro* rice, maize, mustard, tobacco, potato, vegetables and other crops are cultivated hugely in Rabi season (from 16 Oct to 15 Mar) because of their higher price and convenient for cultivation and processing. After potato, tobacco, and mustard, etc. harvest, the farmers want to cultivate T. *Aus* rice or maize at the end of Rabi and entire Kharif 1 seasons, etc. which are highly profitable. Hence, the farmers find short duration crops. Several wheat varieties were released by the BWMRI, Dinajpur, Bangladesh having maturity more than 115 days [3].

The deleterious effects of biotic and abiotic stresses increase worldwide because of global warming and climate change, even in Bangladesh [4]. According to global climate models, an average periphery temperature is forecasted to increase from 1.0 to 6.0 °C at the end of twenty-first century [5]. Lobell and Burke (2008) [6] measured 3-17% yield decline along with each degree temperature rise. In fact, wheat crop has to face immense harmful effects of these stresses resulting in stunted growth and massive decline of yield [7,8].

Heat stress at anthesis period causes poor fertility of pollen grains resulting the pollination hampering. Optimum sowing time of spring wheat in Bangladesh is from 15 November to 30 November, and even upto 7 December in the northern region of the country [9]. However, almost 60% wheat is cultivated in irrigated late sowing condition after harvesting T. *Aman* rice in Bangladesh [10]. In late sowing, the yield loss of wheat was observed 16.1-23.0%, 30.3-35.5%, 31.5-49.2% seeded on 15 Dec, 30 Dec and 14 Jan, respectively [3]. Because, in late sowing, wheat crop passes its grain-filling period from 20 February to 20 March whereas high air temperature (around mean 25ºC temperature or above) exists in Bangladesh resulting in small sized- and unfilled grains, and the reduction of SMPS, SPS, GPS, TGW and yield [3, 11]. During the period, sometimes rainfall also occurs which increase a havoc of diseases [12]. In addition, high temperature and humidity, and rainfall from panicle initiation to grain filling period, wheat diseases like BpLB and blast caused severely which were proven as the major wheat disease in the country [7]. Result, wheat production declines severely because of the effects of biotic and abiotic stresses although the farmers nourish wheat crop properly [13]. Thus, the farmers face to huge financial loss. To fit wheat crop in the existing cropping pattern by competing with other crops, and reduce the severity of BpLB and blast disease caused severely by high temperature, relative humidity and rainfall in ILS, the study was commenced to develop a short duration, high temperature and diseases tolerant wheat variety to increase wheat production to meet up its deficit.

Materials and methods

Experimental locations, plant materials, experimental design and sowing dates

The experiments were carried out with several spring wheat genotypes (*Triticum aestivum* L.) in the research fields of headquarter (HQ), Dinajpur (Din) and Regional Station (RS), Jashore (Jash) in the 2014-15, and RS, Jash and RS, Joydebpur (Joy) in the 2015-16. The candidate variety demonstration (CVD) trial in the fields of HQ, Din and RS, Jash and the multi-location trials (MLTs) in the fields of different RS, BWMRI and the regions of the country [HQ, Din and farmer's field, Din; Cumilla, OFRD and farmer's field; RS, Joy and Tangail (farmer's field); RS, Jamalpur and farmer's field; RS, Jash and farmers' fields; RS, Rajshahi and farmers' fields] were also performed. The research farm of the HQ, Din; RS, Jash and RS, Joy of

BWMRI belonging to the Old Himalayan Piedmont Plain (AEZ, Agro-ecological Zone-1), the High Ganges River Floodplain (AEZ-11), and Madhupur Tract (AEZ-28), respectively [14]. The land of AEZ-1 is flood free, high land having sandy loam soil, poor in organic matter, and strongly acidic (pH: 4.5-5.5). The land of AEZ-11 is predominantly calcareous dark grey and brown floodplain soils, slightly alkaline in reaction (pH: 6.1-7.9) having low fertility. AEZ-28 having dark grey heavy clays and strongly acidic soils (pH: 4.8-5.5) which are low in organic matter content. The soils of RS, Jamalpur, and Tangail and Cumilla districts belong to the AEZ-9 and AEZ-19, respectively [14].

Plant materials and experimental design

The experiments were conducted with sixteen genotypes including two check varieties viz. BARI Gom 28 and BARI Gom 30 of spring wheat (*Triticum aestivum* L.) by following the alpha lattice design with two replications in the 2014-15 and 2015-16 seasons (Table 1). In the 2016-17 season, ten genotypes including two varieties (viz. Shatabdi and BARI Gom 26 as check) were used in the CVD trials whereas in the MLTs four genotypes including one variety (BARI Gom 26 as check) were used. The sowing times of different research stations and regions were depicted in the Table 1.

Table 1: Spring wheat genotypes were sown at the headquarter (HQ), Dinajpur (Din), regional station (RS), Jashore (Jash), RS, Joydebpur (Joy) of Bangladesh Wheat and Maize Research Institute and various regions of Bangladesh at the irrigated timely sowing (ITS) and the irrigated late sowing (ILS) conditions

Research station	HQ, Din		RS, Jash		RS, Jash		RS, Joy		HQ, Din& RS, Jash (CVD trial)		MLTs
Sowing time	2014				2015				2016		2016
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS
	23 Nov	22 Dec	20 Nov	20 Dec	20 Nov	20 Dec	19 Nov	21 Dec	22 Nov	25 Dec	Nov

CVD, Candidate Variety Demonstration; MLTs, Multi-location trails

Land preparation, fertilizing, seed sowing and crop management

The lands were tilled four times horizontally upto 12-15 cm depth along with laddering. Fertilizers were applied to soils @100-27-50-20-1-4.5 kg ha^{-1} as N-P-K-S-B-Zn which sources were Urea, Triple super phosphate, Muriate of potash, Gypsum, Boric acid, and Zinc sulphate heptahydrate, respectively. The cowdung was also applied @5000 kg ha^{-1}. All fertilizer including cowdung and two-third of Urea were applied during the final ploughing of land preparation. The unit plot size was consisted of four rows with 2.5 m length, and spacing 20 cm apart between two rows. Seeds were sowed into 1.5-3.0 cm soil depth. All experiments were performed as the manual of crop production and disease management technologies, developed by WRC-BARI (2014) [10]. Weather data recorded regularly at the meteorological stations, HQ, Din, and RS of Jash and Joy of BWMRI were presented in the Fig. S1, S2, S3, S4.

Diseased leaf area and area under disease progress curve

BpLB data was recorded thrice on double digit (00-99) [15], and started from water ripe to dough stages of Zadoks scale [16,17]. Disease data were converted to the percentage of diseased leaf area (%DLA), and then area under disease progress curve (AUDPC) was calculated according to [15].

%DLA = D1/9 × D2/9 × 100

Where, D1, 1st digit, represents relative disease height; D2, 2nd digit, indicating disease severity

$$\text{AUDPC} = \sum_{i=0}^{n} [(Yi + 1 + Yi) \times 0.5] [Ti + 1 - Ti]$$

Where, Y_i= Disease severity at the ^{i}th observation, T_i = Time (days) of the ^{i}th observation, and n = Total number of observations (at least 3 observations)

Statistical analysis

Experiments were conducted with *Alpha Latic* design with two biological replicates for data consistency. CVD and MLTs were performed as randomized complete block design with three replications. Statistical analysis was performed by MSTAT-C [18]. Treatment means were averaged with two biological replications, expressed by least significant difference (LSD) at $p \leq 0.05$ probability levels.

Results

In the 2014-15 and 2015-16 seasons, DH, DM, PH, SPMS, SPS, GPS, TGW, AUDPC and grain yield the genotypes were depicted comparatively higher in the ITS than the ILS (Table S1, Table S2). Again, DH, DM, PH, SPMS, SPS, GPS, TGW and grain yield were recorded more at the HQ, Din than at the RS, Jash in the 2014-15 except AUDPC (Table S3). In addition, the same increased trends of these parameters were observed in the 2015-16 season at the RS, Jash than the RS, Joy (Table S4).

Days to heading

DH showed a significant difference in all seasons except 2015-16 at the RS of Jash and RS, Joy (Table 2, Table 3, Table 4). Ck1 exhibited the highest DH, while the lowest one was recorded in E4 and E16 in the 2014-15 (Table 2). In the 2015-16, Ck1, E7, E11, and E12 had the highest DH, while the lowest one was recorded in E5 and E9 (Table 3). In the 2014-15, Ck1 demonstrated the highest DH at the HQ, Din and RS, Jash while the lowest DH exhibited by E9, E16 at the HQ, Din, and E4, E13, E14, E15, and E16 at the RS, Jash in ITS (Table 4). In ILS, Ck1 demonstrated the highest DH at the RS, Jash in the 2014-15 while the lowest DH exhibited by E9 and E16 at the HQ, Din (Table 4). In the 2015-16, the highest DH was displayed in Ck1 in ITS at the RS, Joy whereas the lowest one was exhibited by E9 and E10 same location (Table 4). Same season, in ILS the lowest DH was exhibited by E11 at RS, Joy, and the highest one by E13 at the RS, Jash.

Days to maturity

DM showed a significant difference in 2014-15 except 2015-16 at the RS, Jash and Joy (Table 2, Table 3, Table 4). Ck1 had the highest DM in the 2014-15 in ITS at the HQ, Din, while the lowest one by E9 in the 2014-15 (Table 2). In the 2015-16, the highest DM was recorded in E3, E6, E7 and E12, and the lowest one E9 (Table 3). Ck1 had the highest DM in the 2014-15 in ILS at the HQ, Din, while the lowest one by E13, E14 and E16 same location (Table 4). Further, in ILS, the highest DM was observed in Ck1 at the HQ, Din in the 2014-15 and the lowest one in E5 and E13 at the RS, Jash (Table 4). In the 201-165, the highest DM were demonstrated by E15 in ITS at the RS, Joy while the lowest one by E9 (Table 4). Moreover, in the ILS, the highest DM was observed in Ck1 at the RS, Jash and the lowest one in E4 at the RS, Joy (Table 4).

Table 2: Mean of physiological, yield and yield contributing characters, and disease reaction of wheat genotypes recorded in the farm of headquarter, Dinajpur and the regional station, Jashore, Bangladesh Wheat and Maize Research Institute in the of 2014-15 season

Genotypes	Days to heading(d)	Days to maturity(d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
Ck1	63	104	96	401	18.2	47.5	39.2	141	3654
Ck2	62	102	92	407	18.0	44.8	41.3	138	3693
E3	62	103	94	365	19.3	49.1	39.9	141	3631
E4	58	102	91	339	17.2	45.9	45.4	137	3623
E5	59	101	95	366	17.2	40.0	46.0	152	3654
E6	60	99	96	357	18.7	41.7	47.6	161	3408
E7	62	102	92	350	17.7	44.4	41.2	151	3401
E8	60	100	96	357	18.1	36.2	47.9	145	3418
E9	59	98	90	340	19.7	53.2	44.5	125	3853
E10	61	100	95	371	18.5	40.4	46.5	130	3497
E11	62	102	94	317	19.8	52.4	46.1	142	3452

E12	62	102	97	371	19.2	56.9	41.6	152	3412
E13	59	99	99	338	19.3	39.4	49.1	162	3151
E14	59	99	98	325	19.0	36.7	49.6	147	3490
E15	59	100	97	353	19.0	46.0	44.2	156	3348
E16	58	100	98	353	19.0	42.4	47.8	144	3445
F-test	**	**	**	**	**	**	**	**	**
CV (%)	0.78	1.05	3.27	14.9	0.92	5.67	2.88	29.8	14.6

**Significance at the 0.05 probability level, *Significance at the 0.01 probability level, NS, Non-significance at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve;Ck1, BARI Gom 28; Ck2, BARI Gom 30; E3, BAW 1135; E4, BAW 1170; E5, BAW 1211; E6, BAW 1212; E7, BAW 1215; E8, BAW 1220; E9, BAW 1194; E10, BAW 1196; E11, BAW 1202; E12, BAW 1192; E13, BAW 1193; E14; HTWYT 16; E15, HTWYT 17; E16, HTWYT 18; BAW, Bangladesh Advanced Wheat; AUDPC, Area under the disease progress curve; HTWYT, Heat tolerant wheat yield trial.

Table 3: Mean of physiological, yield and yield contributing characters, and disease reaction of wheat genotypes recorded in the field of regional station (RS), Jashore and RS, Joydebpur, Bangladesh Wheat and Maize Research Institute in the of 2015-16 season

Genotypes	Days to heading (d)	Days to maturity (d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
Ck1	61	98	88	368	17.1	42.6	30.4	190	3250
Ck2	59	97	89	377	17.9	41.7	30.3	172	3325
E3	60	99	89	345	17.7	40.1	29.7	178	3098
E4	58	98	86	331	18.2	39.3	36.9	228	3252
E5	57	97	88	352	17.3	36.9	33.7	292	3267
E6	59	99	91	348	17.6	39.2	32.5	286	3108
E7	61	99	85	346	16.9	41.5	27.8	272	3145
E8	58	98	88	324	18.2	36.5	36.0	200	3075
E9	57	96	87	349	18.6	43.9	39.6	160	3424
E10	59	98	84	362	18.2	36.5	34.2	264	3007
E11	61	98	87	326	18.4	43.2	34.4	179	3289
E12	61	99	92	366	18.3	43.7	29.0	221	3190
E13	59	97	92	333	18.1	38.8	36.8	313	3271
E14	59	97	90	331	18.3	39.4	37.6	318	3243
E15	59	98	89	345	18.5	41.5	31.3	295	3107
E16	59	97	91	341	18.4	43.2	36.0	323	3302
F-test	**	**	**	**	**	**	**	**	**
CV(%)	2.59	1.17	4.27	14.5	0.92	13.4	9.20	26.2	14.5

**Significance at the .05 probability level, *Significance at the .01 probability level, NS, Non-significance at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve;Ck1, BARI Gom 28; Ck2, BARI Gom 30; E3, BAW 1135; E4, BAW 1170; E5, BAW 1211; E6, BAW 1212; E7, BAW 1215; E8, BAW 1220; E9, BAW 1194; E10, BAW 1196; E11, BAW 1202; E12, BAW 1192; E13, BAW 1193; E14, HTWYT 16; E15, HTWYT 17; E16, HTWYT 18; BAW, Bangladesh Advanced Wheat; AUDPC, Area under the disease progress curve; HTWYT, Heat tolerant wheat yield trial.

Plant height

In the 2014-15, PH was observed statistically significance. The highest PH was exhibited by E13 followed by E16, and lowest one by E9 followed by E4 (Table 2). In the 2015-16 seasons, PH was found to be considerably different (Table 3). E12 and E13 displayed the highest PH, while E4 had the lowest followed by E9 and E11 (Table 3). In both seasons, E9 and E11 showed the second highest PH (Table 2, Table 3).

Spike m^{-2}

SPMS was discovered to be significantly different in both seasons (Table 2, Table 3). Ck2 had the greatest SPMS followed Ck1, and minimum on was showed by E11 in the 2014-15 (Table 2). In the 2015-16, the maximum numbers of SPMS was found in Ck2 whereas E11 had the lowest (Table 3).

Spikelet spike^{-1}

SPS demonstrated statistical significance in both seasons (Table 2, Table 3). E9 had the mean highest SPS in the 2014-15 season, while the lowest number of SPS were depicted by E4 and E5 (Table 2). In the 2015-16, the maximum number of SPS was exhibited by E9 whereas Ck1 had the lowest (Table 3).

Grain spike^{-1}

In both seasons GPS was observed statistically significance (Table 2, Table 3). In the 2014-15, the highest GPS was observed in E9 and lowest one by E8 (Table 2). The lowest GPS was observed in E8 and E10, while the highest one in E9 in the 2015-16 season (Table 3).

Thousand grain weight

The TGW was shown to be statistically significance in both seasons (Table 2, Table 3). The highest TGW was recorded in E14 in the 2014-15, while the lowest was recorded in Ck1 (Table 2). In the 2015-16, The maximum TGW were displayed by E9 and E14 and the lowest one by E7 (Table 3).

Table 4: Physiological and yield attributes, and disease reaction of wheat genotypes recorded in the fields of the headquarter (HQ), Dinajpur (Din) and regional station (RS), Jashore (Jash) in the 2014-15season, and RS, Jashore and RS, Joydebpur (Joy) in the 2015-16 seasons, Bangladesh Wheat and Maize Research Institute

Genotypes	Days to heading(d)								Days to maturity(d)							
	2014-15				2015-16				2014-15				2015-16			
	HQ, Din		RS, Jash		RS, Jash		RS, Joy		HQ, Din		RS, Jash		RS, Jash		RS, Joy	
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS
Ck1	64	62	64	63	63	60	65	58	112	99	108	97	107	91	111	86
Ck2	62	61	63	61	59	61	62	57	111	97	107	94	106	87	111	86
E3	63	60	62	62	61	61	63	56	112	98	108	94	109	86	111	87
E4	60	57	59	58	59	58	61	57	109	97	107	96	108	91	109	85
E5	60	59	60	59	61	58	61	56	103	95	106	93	105	89	108	86
E6	61	58	60	60	57	58	59	56	103	95	106	94	108	90	111	87
E7	64	61	62	61	62	59	61	57	106	98	107	96	107	90	111	87
E8	61	59	60	59	62	62	62	58	106	97	105	94	106	89	111	86
E9	59	57	59	58	59	57	58	56	105	98	104	94	103	90	104	86
E10	63	59	60	61	60	56	58	55	105	97	105	95	106	90	108	87
E11	62	61	63	62	60	59	60	57	106	97	108	96	108	89	110	87
E12	62	61	63	63	61	63	60	57	107	97	108	97	109	90	110	88
E13	60	57	59	59	62	65	63	57	101	96	106	93	107	88	108	86
E14	61	58	59	59	60	59	61	57	101	96	107	94	107	89	108	86
E15	62	59	59	59	61	59	60	56	102	97	107	95	108	88	110	86
E16	59	57	59	59	62	58	61	58	101	98	106	94	106	89	109	86
F-test	**				NS				**				NS			
CV (%)	1.29				2.59				1.04				1.17			

Table 4 Continued.

Genotypes	AUDPC								Grain yield (kg ha^{-1})							
	2014-15				2015-16				2014-15				2015-16			
	HQ, Din		RS, Jash		RS, Jash		RS, Joy		HQ, Din		RS, Jash		RS, Jash		RS, Joy	
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS

Ck1	153	173	65	124	128	245	128	260	4872	2662	4855	2228	4615	2115	4248	2021
Ck2	153	162	59	179	115	213	125	235	4886	2771	4860	2253	4690	2240	4255	2116
E3	158	179	65	160	107	221	145	240	4894	2813	4590	2225	4355	2000	4173	1863
E4	155	171	56	167	155	302	155	301	4700	3063	4500	2228	4670	2260	4035	2044
E5	166	173	99	170	224	366	224	354	4766	2974	4688	2188	4425	2135	4294	2215
E6	165	175	86	219	234	343	234	331	4398	2509	4533	2190	4570	2240	3795	1826
E7	181	198	78	145	191	352	191	355	4798	2694	4175	1938	4415	2115	4229	1820
E8	150	165	78	188	131	267	121	279	4778	2335	4618	1940	4440	1900	4118	1840
E9	122	153	54	131	109	210	119	210	4962	2918	4915	2615	4755	2295	4381	2265
E10	144	174	56	145	200	333	190	332	4618	2625	4768	1975	4220	1975	3956	1875
E11	167	199	56	147	162	215	120	220	4846	2717	4518	1725	4695	2025	4295	2141
E12	170	188	93	158	171	267	186	259	4454	2504	4550	2138	4540	2205	4070	1945
E13	150	178	83	235	226	409	217	398	4042	2183	4370	2009	4670	2190	4170	2055
E14	123	162	80	222	251	398	241	381	4660	2694	4535	2070	4505	2240	4171	2055
E15	159	187	68	210	214	377	221	369	4350	2465	4618	1960	4425	2150	4110	1744
E16	162	183	62	167	250	410	235	395	4514	2557	4630	2078	4690	2210	4246	2061
F-test		**				*				NS				*		
CV (%)		13.78				9.27				14.50				14.65		

**Significance the 0.05 probability level, *Significance the .01 probability level, NS, Non-significance at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve;Ck1, BARI Gom 28; Ck2, BARI Gom 30; E3, BAW 1135; E4, BAW 1170; E5, BAW 1211; E6, BAW 1212; E7, BAW 1215; E8, BAW 1220; E9, BAW 1194; E10, BAW 1196; E11, BAW 1202; E12, BAW 1192; E13, BAW 1193; E14, HTWYT 16; E15, HTWYT 17; E16, HTWYT 18; BAW, Bangladesh Advanced Wheat; AUDPC, Area under the disease progress curve; HTWYT, Heat tolerant wheat yield trial.

Responses of genotypes to diseases (BpLB and Blast of wheat)

The study portrayed mean AUDPC as statistically significance in the season of 2014-15 and 2015-16 in all stations (Table 2, Table 3, Table 4). E9 exhibited the lowest mean AUDPC in the 2014-15 (Table 2), and E16 had the highest mean AUDPC in the 2015-16 (Table 3). Additionally, in the 2014-15 at the RS, Jash E13 in ILS had the maximum AUDPC, and E9 in ITS had the lowest AUDPC same location (Table 4). In the 2015-16, E16 also showed the highest AUDPC in ILS in the RS, Jash, and the lowest one depited by E9 in ITS in the RS, Joy (Table 4). The trial conducted as the candidated variety demonstration, Ck1 and Ck2 used as check exhibited susceptibile and highly susceptibile to wheat blast disease, respectively. Oppositely, E9 demonstrated moderately susceptible to wheat blast disease (Table 6).

Table 5: Depiction of the percentage of yield loss of wheat genotype sin the irrigated late sowing (ILS) compared to irrigated timely sowing (ITS) conducted trials in the research field of headquarter (HQ), Dinajpur (Din) in the 2014-15 and 2015-16 seasons

Geno-types	Grain yield (kg ha^{-1})								Yield loss (%) in ILS compared to ITS			
	2014-15				2015-16				2014-15		2015-16	
	HQ, Din		RS, Jash		RS, Jash		RS, Joy		HQ, Din	RS, Jash	RS, Jash	RS, Joy
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS				
Ck1	4872	2662	4855	2228	4615	2115	4248	2021	45.4	54.1	54.2	52.4
Ck2	4886	3071	4860	2253	4690	2240	4255	2116	37.1	53.6	52.2	50.3
E3	4894	2913	4590	2225	4355	2000	4173	1863	40.5	51.5	54.1	55.4
E4	4700	3063	4500	2228	4670	2260	4035	2044	34.8	50.5	51.6	49.3
E5	4766	2974	4688	2188	4425	2135	4294	2215	37.6	53.3	51.8	48.4
E6	4398	2609	4633	2190	4670	2240	3795	1826	40.7	52.7	52.0	51.9
E7	4798	2994	4175	1938	4415	2115	4229	1820	37.6	53.6	52.1	57.0
E8	4878	2335	4618	1940	4440	1900	4118	1840	52.1	58.0	57.2	55.3
E9	4962	3218	4915	2615	4755	2295	4381	2265	35.1	46.8	51.7	48.3
E10	4618	2875	4768	1975	4220	1975	3956	1875	37.7	58.6	53.2	52.6

E11	4846	2717	4518	1725	4695	2025	4295	2141	43.9	61.8	56.9	50.2
E12	4454	2904	4550	2138	4540	2205	4070	1945	34.8	53.0	51.4	52.2
E13	4042	2583	4370	2009	4670	2190	4170	2055	36.1	54.0	53.1	50.7
E14	4660	2894	4535	2070	4505	2240	4171	2055	37.9	54.4	50.3	50.7
E15	4350	2765	4618	1960	4425	2150	4110	1744	36.4	57.6	51.4	57.6
E16	4514	2857	4630	2078	4690	2210	4246	2061	36.7	55.1	52.9	51.5
F-test		NS				NS			-		-	
CV (%)		14.50				14.65			-		-	

AUDPC, Area under the disease progress curve; Ck1, BARI Gom 28; Ck2, BARI Gom 30; E3, BAW 1135; E4, BAW 1170; E5, BAW 1211; E6, BAW 1212; E7, BAW 1215; E8, BAW 1220; E9, BAW 1194; E10, BAW 1196; E11, BAW 1202; E12, BAW 1192; E13, BAW 1193; E14, HTWYT 16; E15, HTWYT 17; E16, HTWYT 18; BAW, Bangladesh Advanced Wheat; HTWYT, Heat tolerant wheat yield trial; NS, Non-significance at the .05 probability level.

Table 6: Assessment of gain yield and the percentage of infection and severity of blast disease in wheat genotypes in the irrigated late sowing (ILS) compared to irrigated timely sowing (ITS) sowed in the candidate variety demonstration trial in the research station of headquarter (HQ), Dinajpur (Din) in the 2016-17 season

Genotypes	Yield (kg ha^{-1})				Wheat Blast		
	ITS		ILS		%Incidence	%Severity	Diseasse reaction
	HQ, Din	RS, Jash	HQ, Din	RS, Jash			
Ck1	4730	3130	2585	1514	10	60	S
Ck2	4140	3285	2624	1660	100	100	HS
E3	4900	3850	2346	1888	8	30	MR
E4	4505	3795	2256	1732	90	70	S
E5	4625	3945	3058	2392	12	30	MR
E6	4475	3625	2406	2155	6	25	MR
E7	4865	3330	2474	2046	7	30	MR
E8	4860	3690	2772	1914	13	30	MR
E9	4985	4215	3447	2504	17	50	MS
E10	4585	3595	2670	2326	trace	5	R
F-test	NS		NS		-		
CV (%)	0.10		0.23		-		

*Selected entries, Ck1,Shatabdi; Ck2, BARI Gom 26; E3, BAW 1254 (HTWYT17); E4, BAW 1195; E5, BAW 1203; E6, BAW 1208; E7, BAW 1222; E8, BAW 1253; E9, BAW 1194; E10, BAW 1260 (HTWYT18); CV, Co-efficient of variation; BAW, Bangladesh Advanced Wheat; HTWYT, Heat tolerant wheat yield trial; NS, Non-significance at the .05 probability level; Categories of wheat blast disease severity: Resistant (R) = 0.20-10%, Moderately resistant (MR) = 11-30%, Moderately susceptible (MS) = 31-50%, Susceptible (S) = 51-75%, Highly susceptible (HS) = 76-100%, described by Alam et al. [21].

Table 7: Depiction of grain yield of advanced lines of wheat selected from the trials conducted as the multi-location trials in the farmer's fields and research stations in the 2016-17 season in irrigated timely sowing (ITS)

Trial Site	BAW 1194 (E1)*	BAW 1203 (E3)	BAW 1254 (E8)	Prodip
Din 1 (HQ, Din)	4858	4736	4537	4637
Din 2 (Farmers' field)	4833	4659	4388	4511
Cum 1 (OFRD, Cum)	4640	4430	4300	4290
Cum 2 (Farmers' field)	4520	4300	4210	4210

RS, Joy	4280	4220	4240	4180
Tangail (Farmers' field)	4590	4160	4140	4060
Jam 1 (RS, Jam)	4330	4220	4230	4280
Jam 2 (Farmer's field)	4200	4160	4120	4080
Jash 1 (RS, Jash)	4454	4396	4268	4205
Jash 2 (Farmer's field)	4260	4220	4153	4197
Raj 1 (RS, Raj)	4756	4530	4424	4359
Raj 2 (Farmer's field)	4467	4474	4392	4203
Mean	4516	4375	4284	4268
F-test	NS	NS	NS	NS
CV (%)	0.20	0.17	0.23	0.17

*Selected entries; HQ, Headquarter; Din, Dinajpur; Cum, Cumilla; Jam, Jamalpur; Jash, Jashore; Raj, Rajshahi; BAW 1194,BAW 1203 and BAW 1260 were expressed as E9, E5 and E10 in the Table 6, respectively; CV, Coefficient of Variation; NS, Non-significance at the .05 probability level.

Grain Yield

Mean grain yield was statistically significance in the 2014-15 and 2015-16 (Table 2, Table 3). The maximum mean grain yield was shown by E9 in both seasons, while the lowest yield exhibited by E13 in the 2014-15, and E10 in the 2015-16 (Table 2, Table 3). In the 2014-15, the highest grain yield was exhibited by E9 at the HQ, Din in ITS whereas the lowest one demonstrated by E7 at the RS, Jash (Table 4). In ILS, the maximum grain yield was portrayed by E9 the HQ, Din while the lowest one demonstrated by E11 at the RS, Jash (Table 4). In the 2015-16, E9 exhibited the highest grain yield at the RS, Jash in ITS whereas the lowest one demonstrated by E10 at the RS, Joy (Table 4). In ILS, the highest yield was showed by E9 the RS, Jash while the lowest one demonstrated by E15 at the RS, Joy (Table 4). In the comparison study, the percentage of grain yield loss in the ILS compared to ITS might be influenced by different factors like temperature, relative humidity, rainfall, and sowing time, etc. (Fig. S1, S2, S3, S4, Table 1). The minimum % yield loss was demonstrated by E3 and E12 followed by E9 in the 2014-15 at the HQ, Din, and the highest one depicted in E11 at the RS, Joy (Table 5). In the 2016-17 in ITS in the CVD, E9 (treated as E9) exhibited the highest grain yield at the HQ, Din, whereas the lowest one in Ck1 at the RS, Jash in the ILS (Table 6). When the trials were conducted at the farmers' fields and research stations of BWMRI in ITS as the MLTs same season, E9 demonstrated more yield compared to other genotypes, while Prodip (BARI Gom 24) was used as check. The highest yield was recorded in E9 at the HQ, Din, and the lowest in the farmer's field of Tangail (Table 7).

Discussion

Genetic inheritance, rainfall, relative humidity, temperature, location, sowing time, biotic and abiotic stresses have significant impacts on the growth and development, DH, DM, PH, SPMS, grain formation, and other phenotypic and yield contributing character of a genotype [7,19,20,21]. The stickiness of stigma of female's flower is induced by high temperature resulting in the lower cope of pollen grains reaching to the ovary inside the flower style. Finally, fertilization becomes lower resulting in infertile grains [6]. The number of spike and spikelet of wheat were reduced when the mean seasonal temperature exceeded 25.5 °C in arid and semi-arid regions [22] while temperatures should be between 12 and 22 °C during the anthesis and grain filling of wheat. When grain filling period of wheat exposed to high temperature, grain yield was significantly reduced [12,23,24]. In Bangladesh, wheat sowed in the late December resulted almost 50% yield loss compared to optimal sowing [9,25]. In addition, for getting maximum yield of spring wheat in Bangladesh, an average temperature 10-25 °C is favorable for its growth and development throughout the growing season [3,8,9]. While wheat seeds were sown from 15 November to 30 November, DH and anthesis occur in the first and second weeks of February, respectively, and grain filling occurs from the 1st week of February to the 2nd week of March, producing the highest yield [3,19]. According to Rehman et al. (2021), [24] and Hasan and Ahmed (2005) [26] post-anthesis heat stress on wheat caused by late sowing shortens the grain-filling period and inhibits

several physiological functions, resulting in smaller grain size. Our study depicted that higher DH, DM, PH, SMPS, SPS, GPS, TGW, and grain yield were observed in ITS than ILS (Table 2, Table 3, Table 4, Table 6, Table 7). Higher temperature existed in the experimental areas in ILS than ITS from the seedling emergence to maturity (Figure 1; Fig. S1, S2, S3, S4) resulting in lessening of DH, DM, PH, SMPS, SPS, GPS, TGW and grain yield (Table 2, Table 3, Table 4, Table 6) [9,27,28,29,30]. Because of higher temperature, DH, DM, PH, SMPS, SPS, GPS, TGW, AUDPC and grain yield were higher in the 2014-15 season than in the 2015-16 season (Table 2, Table 3, Table 4, Table 6; Fig. 1; Fig. S1, Fig. S2, Fig. S3, Fig. S4). However, among the genotypes comparatively lower DH, DM and PH, but higher grain yield was depicted by E9 than other genotypes in all locations and seasons in ITS and ILS. BAW 1194 was improved crossing between BARI Gom 21 (Shatabdi) used as male and Ck1 (BARI Gom 24/Prodip) used as female, which were moderately resistant and moderately susceptible to blast, respectively (Table 8). Both varieties were BpLB and high temperature tolerance attributes, semi-dwarf (95-100 cm height), and yielded comparatively more in ILS. Further, Ck1 exhibited an early maturing attribute (having short duration) [31]. The severity of BpLB (measured as AUDPC) observed more in ILS than ITS might be because of higher temperature, rainfall and relative humidity in ILS than ITS (Table 4; Fig. 1; Fig. S1, Fig. S2, Fig. S3, Fig. S4) [7]. Furthermore, AUDPC was found less in E9 compared to other genotypes in ITS and ILS of all locations in both seasons was the evidence of E9 resistant to BpLB (Table 4). Phenotypic expression of E9 grown in the CVD in the 2016-17 was another proof of its BpLB resistance, as none eye-shaped brown spots were found in leaves at milking stage (Fig. 2).

Table 8: Pedigrees of BAW 1194 crossed in the research farm of Bangladesh Wheat and Maize Research Institute

SL. No.	Variety/Genotype	Pedigree	Released Year
01.	BAW 1194	Shatabdi/BARI Gom 24	-
02.	BARI Gom 21 (Shatabdi)	MRNG/BVC//BLO/PVN/3/PJB-81	2000
03.	BARI Gom 24 (Prodip)	G.162/BL 1316//NL297	2005

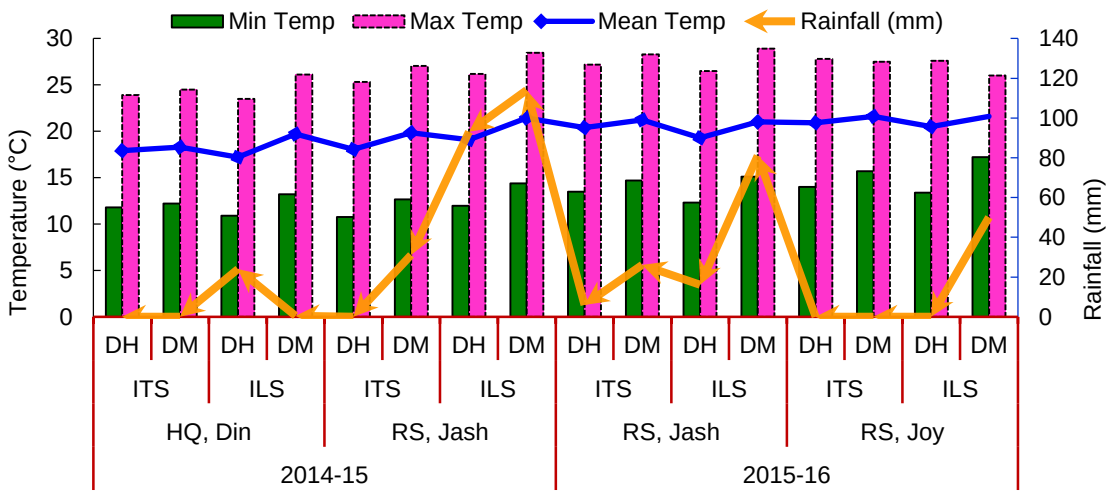

Fig. 1 Minimum (Min), maximum (Max), and mean temperature (Temp), and rainfall (mm) during days to heading (DH) and days to maturity (DM) of wheat genotypes sown in the irrigated timely sowing (ITS) and irrigated late sowing (ILS) conditions at the headquarter (HQ), Dinajpur (Din), and regional station (RS), Jashore (Jash), Bangladesh Wheat and Maize Research Institute (BWMRI) in the 2014-15 season, and the RS, Jash and RS, Joydebpur (Joy), BWMRI in the 2015-16 season.

Fig. 2: Phenotypic expression of BAW 1194 (E9). The picture was captured from the candidate variety demonstration grown at the headquarter, Bangladesh Wheat and Maize Research Institute, Dinajpur in the 2016-17 season

Wheat blast disease caused by *Magnaporthe oryzae* pathotype: *Triticum* observed in the south and south-western parts of Bangladesh in 2016 might be virulent from the flowering stage of wheat due to the rise of high air temperature and relative humidity (Islam et al. 2019). In our study, E9 exhibited moderately susceptible to wheat blast and higher yield (Table 6). BAW 1194 produced higher yield than other genotypes evidenced by MLTs (Table 7). The summary revealed that genotype BAW 1194 had short duration and higher yield, and was tolerance to high temperature, BpLB, and moderately susceptible to blast diseases.

Conclusions

E9 exhibited comparatively lower DH, DM and PH, but higher SPSM, SPS, GPS, TGW and grain yield than other genotypes except SPMS of Ck1 and Ck2. E9 demonstrated also the lowest percentage of yield loss in the ILS compared to ITS than other genotypes evidencing high temperature tolerance. Moreover, E9 exhibited tolerance to BpLB and moderately susceptible to blast disease than other genotypes. Again, the relatively higher yield was produced by E9 than other genotypes in the MLTs and CVD trials in the 2016-17. Because of having a higher grain yield, short duration habit, tolerance to high temperature and BpLB, and moderately tolerance to blast disease, BAW 1194 may be released as a variety for minimizing the detrimental effects of biotic and abiotic stresses to increase wheat production in Bangladesh.

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Conflicts of Interest

The authors have no conflicts of interest to report regarding the study.

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Table S1 Evaluation of physiological, yield and yield contributing characters of wheat genotypes sown at the research farms of headquarter, Dinajpur and regional station, Jashore, Bangladesh Wheat and Maize Research Institute in the 2014-15 season

Location	Days to heading (d)	Days to maturity (d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
HQ, Din	60	101	99	396	17.8	45.2	47.6	121	3657
RS, Jash	60	100	92	318	19.5	44.4	41.9	166	3359
F-test	NS	NS	**	**	**	NS	*	*	**
CV (%)	1.64	1.76	2.05	16.99	4.77	17.8	15.3	26.1	6.46

**Significant at the .05 probability level, *Significant at the .01 probability level; NS, Non-significant at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve

Table S2 Assessment of physiological, yield and yield contributing characters, and disease reaction of wheat genotypes sowed at the field of regional station, Jashore and regional station, Joydebpur, Bangladesh Wheat and Maize Research Institute in the 2015-16 season

Location	Days to heading(d)	Days to maturity (d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
RS, Jash	60	98	93	374	19.2	42.1	46.5	198	3343
RS, Joy	59	98	84	361	18.9	41.9	42.2	229	3076
F-test	**	**	NS	**	*	**	*	*	**
CV (%)	2.59	1.17	4.27	14.1	4.89	13.4	9.24	14.8	13.5

**Significant at the .05 probability level, *Significant at the .01 probability level, NS, Non-significant at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve

Table S3 Validation of physiological, yield and yield contributing characters, and disease reaction of wheat genotypes sowed in the irrigated timely sowing and irrigated late sowing in the field of headquarter, Dinajpur and the regional station, Jashore, Bangladesh Wheat and Maize Research Institute in the 2014-15 season

Seeding time	Days to heading (d)	Days to maturity (d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
ITS	60	106	96	366	18.4	45.4	47.7	127	4633
ILS	59	96	93	348	18.8	44.2	41.7	160	2383
F-test	*	**	**	NS	NS	NS	*	*	**
CV (%)	1.64	1.76	2.05	16.9	4.77	17.8	15.3	26.0	6.46

**Significant at the .05 probability level, *Significant at the .01 probability level, NS, Non-significant at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve

Table S4 Evaluation of physiological, yield and yield contributing characters, and disease reaction of wheat genotypes sowed in the irrigated timely sowing and irrigated late sowing in the field of regional station, Jashore, and the regional station, Joydebpur, Bangladesh Wheat and Maize Research Institute in the 2015-16 season

Seeding time	Days to heading (d)	Days to maturity (d)	Plant height (cm)	Spike m^{-2}	Spikelet $spike^{-1}$	Grain $Spike^{-1}$	TGW (g)	AUDPC	Yield (kg ha^{-1})
ITS	60	108	89	371	18.5	43.5	44.3	160	4351
ILS	58	88	88	352	18.6	37.2	42.1	217	2068
F-test	*	**	**	NS	*	*	*	**	*
CV (%)	2.59	1.17	4.27	17.17	4.63	13.42	9.24	13.58	14.50

**Significant at the .05 probability level, *Significant at the .01 probability level, NS, Non-significant at the .05 probability level; CV, Co-efficient of Variation; TGW, Thousand grain weight; AUDPC, Area under Disease Progress Curve

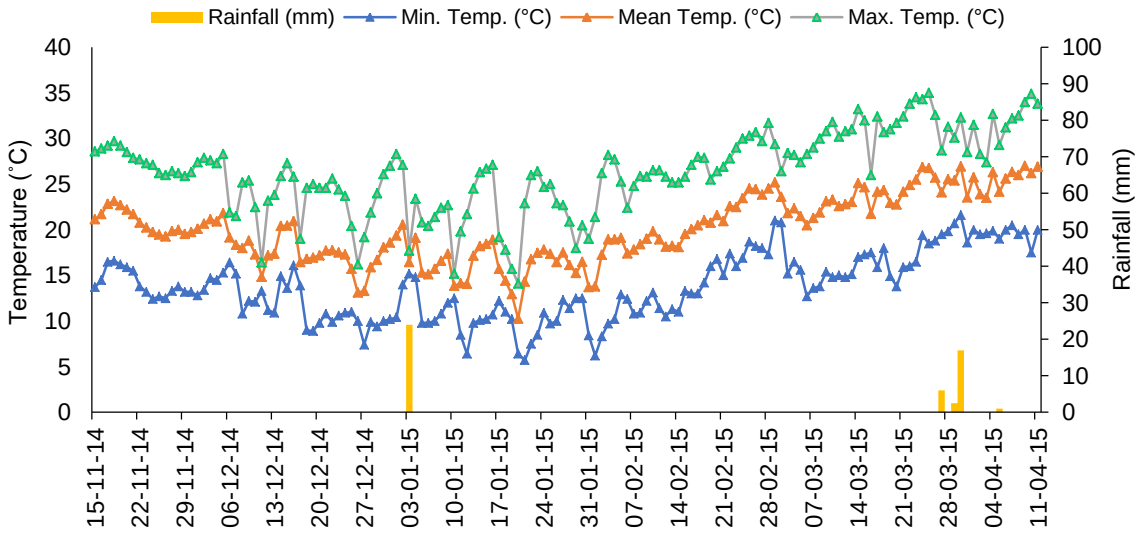

Fig S1 Meteorological information (Min, Max and Mean temperature, and rainfall) at the headquarter, Dinajpur, Bangladesh Wheat and Maize Research Institute, Bangladesh in the 2014-2015 wheat growing season

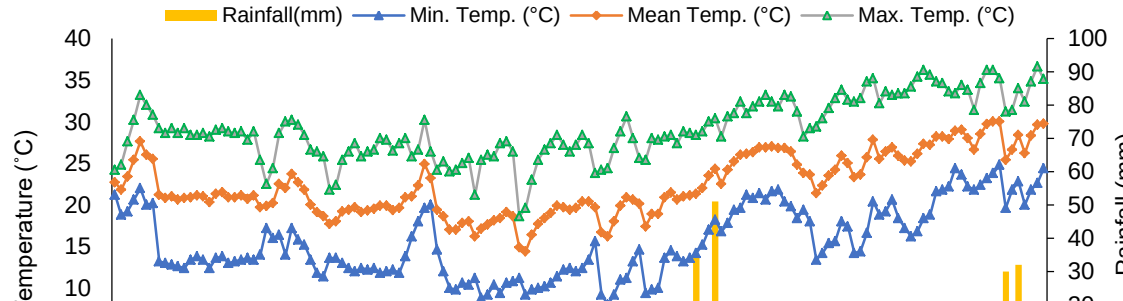

Fig S2 Meteorological information (Min, Max and Mean temperature, and rainfall) at the regional station, Jashore, Bangladesh Wheat and Maize Research Institute in the 2014-2015 season

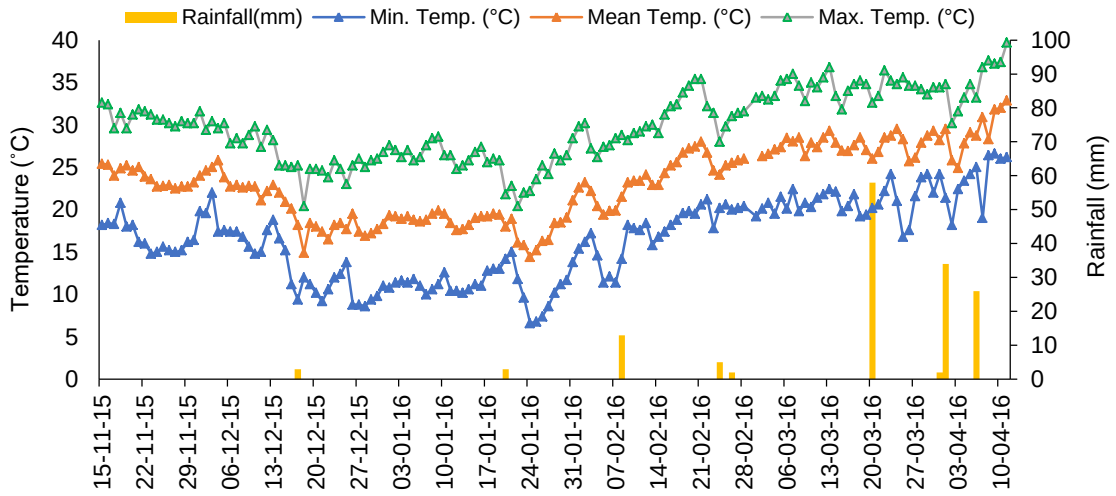

Fig. S3 Meteorological information (Min, Max and Mean temperature, and rainfall) at the regional station, Jashore, Bangladesh Wheat and Maize Research Institute in the 2015-16 season

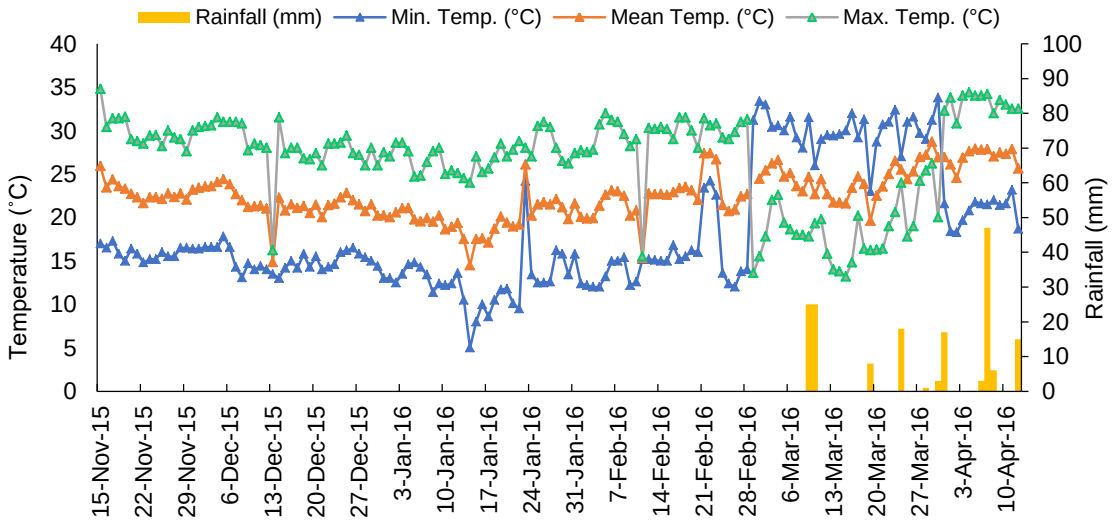

Fig. S4 Meteorological information (Min, Max and Mean temperature, and rainfall) at the regional station, Joydebpur, Bangladesh Wheat and Maize Research Institute in the 2015-16 season