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EVALUATION OF WHEAT GENOTYPES FOR HEAT STRESS AND DISEASE RESISTANCE IN MULTIPLE ENVIRONMENTS OF BANGLADESH

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Abstract

Twenty-seven advanced lines including three exiting varieties (BARI Gom 21, BARI Gom 32 and BARI Gom 33) were evaluated in alpha lattice design with two replications at Bangladesh Wheat and Maize Research Institute, Dinajpur and regional stations at Joydebpur, Jashore and Rajshahi under irrigated timely sown (ITS) and irrigated late sawn (ILS) conditions. The objective of the study was to find out the heat-tolerant wheat lines for future breeding programme to develop heat-tolerant wheat varieties. The genotypes were evaluated for phenological variation such as heading and maturity, yield and yield components, disease reaction, sterility, visual grain quality, etc. The results showed that the highest grain yield (5951 kg ha^{-1}) was recorded with genotype BAW 1415 at Dinajpur under ITS condition and the lowest grain yield (1923 kg ha^{-1}) was observed in BAW 1416 at Rajshahi under ILS condition. Considering the overall performances, genotypes BAW 1402, BAW 1403, BAW 1406, BAW 1407, BAW 1408, BAW 1411, BAW 1422 and BAW 1425 performed better. Considering disease infestation, genotypes BAW 1374, BAW 1393, BAW 1394, BAW 1397, BAW 1399 and BAW 1401 showed a good level of resistance to both leaf rust (LR) and wheat blast (WB). These genotypes could be selected for future breeding programmes to develop heat-tolerant and diseases resistance varieties.

Keywords: Blast, BpLB, Grain yield, Leaf rust, Wheat lines

Introduction

Wheat contributes 20% of the calories and 20% of the protein for daily human consumption (Shiferaw *et al.*, 2013). Among the world's three most important staple food crops, wheat is grown on more than 215 million hectares (ha) worldwide, producing over 735 million tons (t) of grain (Crespo-Herrera *et al*., 2021). Continual heat stress (mean daily temperature of over 17.5^{0}C in the coolest month of the season) affects

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approximately 7 million ha of wheat in developing countries, while terminal heat stress affects 40% of temperate environments, covering 36 million ha (Reynolds *et al.*, 2010). Heat is a non-uniform phenomenon that has a negative impact on plant growth, morphology, physiology, and yield, depending on crop developmental stage, time, and stress severity (Ahmed and Prasad, 2011). Crops at various stages of development require varying temperatures for optimal growth. Under heat stress, plants have limited nutrient uptake capacity and photosynthetic efficiency. Additionally, this stress can shorten the growth period for several developmental phases at the tillering, booting, heading, anthesis, and grain filling stages as well as the size of the organs such as, leaf, tiller, and spikes (Hossain *et al.*, 2013). Plant sensitivity to high temperatures leads to a disrupted metabolic process and lower plant biomass accumulation (Hasanuzzaman *et al.*, 2013).

According to Slafer and Satorre (1999), wheat is extremely susceptible to high temperatures, and trends in rising growing season temperatures have already been noted for the major wheat-producing regions (Gaffen and Ross, 1998; Alexander *et al.*, 2006; Hennessy *et al.*, 2008). Heat stress affects wheat to varying degrees at different phenological stages, but heat stress is more pronounced during the reproductive phase than during the vegetative phase due to the direct effect on grain number and dry weight (Wollenweber *et al.*, 2013).

The optimum time for wheat cultivation in Bangladesh is November. However, due to the late harvesting of the previous crop i.e. Aman rice (monsoon rice), farmers frequently sow the seeds late, even at the end of December. As a result, during the reproductive phase of growth, the wheat plant experiences much higher temperatures than is optimal. High temperatures, during the terminal growth stage, reduce growth, development and finally causes reduce grain yield. However, under high-temperature conditions, there may be varietal differences in growth and yield performance. The purpose of this experiment was to identify heat tolerant wheat genotypes under late sown condition for future wheat breeding programme.

Materials and Methods

Location of the experiment

The experiment was carried out during November to March 2020-21 in four regional stations e,g., Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur (25.380 N, 88. 410 E, Elevation 39 M) in AEZ-1(Old Himalayan Piedmont Plain); the Regional Station of BWMRI, Joydebpur (*23.989014 N, 90.418167 E, Elevation 11.54*) in AEZ–28 (Modhupur Tract); the Regional Station of BWMRI, Khaertala-Jessore (23.170664 N *89.212418*, E; *15 m*) in AEZ–11(High Ganges River Floodplain) and the Regional Station of BWMRI, Shampur, Rajshahi (*24.3635886* N, *88.6241351*, Elevation 18 M) in AEZ-11 (High Ganges River Flood plain soil).

Treatments, design and experimental procedures

Twenty-seven promising wheat genotypes including three existing popular wheat varieties namely ‘BARI Gom 21’, ‘BARI Gom 32’ and ‘BARI Gom 33’ were evaluated in this study to identify heat-tolerant genotypes for growing in Bangladesh conditions (Table 1). The experiment was laid out in an alpha lattice design with two replications.

The genotypes were evaluated under irrigated timely sown (ITS) and late sown (ILS) conditions in all locations. In the ITS, all genotypes were sown in lines by hand on November 21-28, whereas in ILS (late sown heat stress) condition, all the genotypes were sown on December 20-25 (Table 2). The seeding rate was 120 kg ha^{-1} for each genotype. Before sowing, seeds of all varieties were treated with a popular fungicide, Provax-200 WP (marketed by Hossain Enterprise Bangladesh Ltd., in association with Chemtura Corp., USA), which contains Carboxin (17.5%) and Thiram (17.5%). For controlling soil-borne insects, Furadan 5G (containing carbofuran, marketed by FMC International S.A. Bangladesh Ltd.) was broadcasted at 15 kg ha^{-1}. Seeds were sown continuously in 5 m long 6 rows plot with a row spacing of 20 cm.

Table 1. Pedigree and selection history of wheat genotypes

Entry	Cross/pedigree
BAW 936	BARI Gom 21 (Shatabdi)
BAW 1202	BARI Gom 32
BAW 1260	BARI Gom 33
BAW-1402	KANCHAN/BAW 1135 BD13DI4S-099DI--050DI-050DI-030DI-4DI
BAW-1403	SHATABDI/BAW 1135 BD13DI13S-099DI-050DI-050DI-030DI-1DI
BAW-1404	BIJOY/BAW 968/SHATABDI BD13DI16S-099DI-050DI-050DI-030DI-19DI
BAW-1405	RODIP/BAW 824 BD13DI22S-099DI-050DI-050DI-030DI-5DI
BAW-1406	BARI Gom 25/CNDO/R143//ENTE/MEXI75/3/AE.SQ/4/2*OCI/5. BD13DI34S-099DI-050DI-050DI-030DI-1DI
BAW-1407	BARI Gom 25/CNDO/R143//ENTE/MEXI75/3/AE.SQ/4/2*OCI/5. BD13DI34S-099DI-050DI-050DI-030DI-9DI
BAW-1408	HUW234+LR34/PRINIA//KRONSTAD F2004/ SWARNA//BARI Gom 26 BD13DI160T-099DI--050DI-050DI-030DI-11DI
BAW-1409	F1 (CB 7 (Prodip) X CB 42 (BAW 1130 (GOURAB/PAVON 76) Ï CB-90 (BAW1051 (KLAT/SOREN//PSN/3/BOW//4 /VEE #5.10/5 /CNO67 /MFD//MON/3/SERI/6/NL297 NC2142 7B-020B-025B-3B-0B)
BAW-1410	BORL14//BECARD/QUAIU #1 CMSS12Y00070S-099Y-099M-099NJ-099NJ-21Y-0WGY
BAW-1411	MACE/5/TILILA/JUCHI/4/SERI.1B//KAUZ/HEVO/3/AMAD/6/KACHU/BECARD//WBLL1*2/BRAMBLING CMSS13Y01525T-099TOPM-099Y-099M-0SY-11M-0WGY
BAW-1412	KACHU//KIRITATI/2*TRCH/3/KFA/2*KACHU CMSS13B00118S-099M-0SY-1M-0WGY

Table 1. Contd.

Entry	Cross/pedigree
BAW-1413	WBLL1*2/BRAMBLING*2//BAVIS/3/KACHU #1/KIRITATI//KACHU CMSS13B00377S-099M-0SY-26M-0WGY
BAW-1414	BORL14//BECARD/QUAIU #1 CMSS12Y00070S-099Y-099M-099NJ-099NJ-14Y-0WGY
BAW-1415	SUP152/AKURI//SUP152/3/MUCUY CMSS12Y00300S-099Y-099M-099NJ-099NJ-50Y-0WGY
BAW-1416	MUTUS*2/JUCHI//COPIO CMSS12Y00303S-099Y-099M-099NJ-099NJ-10Y-0WGY
BAW-1417	SUP152/KENYA SUNBIRD//KFA/2*KACHU CMSS13B00156S-099M-0SY-19M-0WGY
BAW-1418	WBLL1*2/BRAMBLING*2//BAVIS/3/KACHU #1/KIRITATI//KACHU CMSS13B00377S-099M-0SY-26M-0WGY
BAW-1419	SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-19Y-020Y-0B
BAW-1420	BARI GOM-28 / BAW-1051 BD13JA1951S-099JA-50JA-50JA-30JA-06JA
BAW-1421	PRODIP / KINGBIRD #1 BD13JA1972S-099JA-50JA-50JA-30JA-010JA
BAW-1422	Y 3338
BAW-1423	BAW1170/SOURAV BD15JO1800S
BAW-1424	-
BAW-1425	-

Table 2. Sowing dates of wheat genotypes at different locations

Location	Sowing dates	
	Irrigated timely sown (ITS)	Irrigated late sown (ILS)
Dinajpur	21 November 2020	24 December 2020
Joydebpur	28 November 2020	24 December 2020
Jashore	21 November 2020	25 December 2020
Rajshahi	26 November 2020	20 December 2020

Intercultural operations

BWMRI recommended fertilizers such as N, P, K, S and B, respectively were applied at 100, 27, 40, 20, and 1 kg ha^{-1}. During final land preparation, two-thirds of N and the full amount of the other fertilizers were applied as basal. The remaining 1/3 N fertilizer was applied immediately after the first irrigation (16-18 days after sowing, DAS); while second, third and fourth irrigations were applied at 50, 75 and 85 DAS. Mulching was done at 25 DAS and hand weeding at 45 DAS. Phenological data like days to heading and maturity were recorded during the crop growth stage. The crop was harvested at full maturity on 10 April 2021. Grain yield (GY) and yield contributing characters were measured from the middle 4 rows (4 m area) among 6 rows. The harvested samples from each plot were bundled separately, tagged and manually threshed on a threshing floor after drying the bundles thoroughly in bright sunshine. GY and 1000-grain weight (TGW) were measured at 12% moisture in grain (Hellevang, 1995).

Inoculation procedures

At Dinajpur, a mixture of susceptible varieties such as Sonalika, Kanchan, Morocco, Ciano 79 etc was planted around the experimental plots spreader rows. The susceptible mixture acts as a substrate for multiplication and the spread of BpLB and rust inoculum. At the booting stage of the crop in Dinajpur, the spreader rows were inoculated with an aqueous suspension of uredospores of *Puccinina triticina* for disease development of leaf rust. The highly blast susceptible variety 'BARI Gom 26' was sown around the experimental field at Jashore for development of wheat blast diseases. Starting three weeks after sowing and continuing until the primary infection was observed, the spreader rows at Jashore were inoculated with *Magnaporthe oryzae* pathotype Triticum (MoT) spores (20000 spores per mL) for blast symptom development. The inoculum of MoT was multiplied at the plant pathology laboratory of Regional Station, BWMRI, Jashore.

% Diseased Leaf Area (DLA) = $D_1/9 \text{ X } D_2/9 \text{ X } 100$

where, D_1 = First digit, representing relative disease height; D_2 = Second digit, indicating disease severity on the foliage

$$\text{AUDPC} = \sum_{i=1}^{n} [(Y_{i+1} + Y_i) \text{ x } 0.5] [T_{i+1} - T_i]$$

where, Y_i = Disease severity at the ith observation, T_i = Time (days) of the ith observation and n = Total number of observations (at least 3 observations).

Assessment of Wheat Blast

Wheat blast severity was recorded as per the following equation:

% Disease severity= (%spike incidence/100) x (%diseased area on spike/100)*100

Statistical analysis

Statistical analysis was conducted by the CropStat 7.2 programme with an F-test at 1% and 5% levels.

Results and Discussion

Days to heading

As the young spike expands within the leaf sheaths, it can eventually be felt and seen as a sheath swelling or boot after the flag leaf stage (Acevedo *el at.*, 2002). The length of time required for heading is entirely determined by growth conditions as well as the genetic makeup of specific genotypes (BARI, 2016, Hossain *et al*., 2012; Hossain *et al*., 2013). Days to heading of various genotypes varied significantly depending on genotype, location, and sowing time (Table 3, 4, 5, 6a). All the genotypes headed earlier than check variety Shatabdi except BAW 1410, BAW 1412, BAW 1413, BAW 1414, BAW 1417, BAW 1418 and BAW 1424. All genotypes took a long time to reach heading and maturity in optimum sowing conditions in the case of favorable environmental conditions in Dinajpur, Rajshahi, Jashore, and Joydebpur. All genotypes, however, showed faster heading and maturity at late sowing conditions than at optimum sowing conditions (Table 3). This finding was similar to that of Hossain *et al.*, (2018), who discovered that in some spring wheat genotypes, days to heading were faster in late sowing conditions than in timely sowing conditions. Several studies have confirmed this result (Fischer 1985; Yang *et al.*, 2002; Nahar *et al.*, 2010; Hakim *et al.*, 2012), where they discovered that crops mature significantly more quickly in high temperatures than in normal temperatures. However, genotypes influence the variation of phenological stages (Wahid *et al.*, 2007). Phenological stage is the biological life cycles of wheat such as germination/emergence, tillering, stem elongation, boot, heading/flowering, and grain-fill/ripening etc.

Table 3. Effects of seeding times on yield and other characters of wheat genotypes, 2020-21

Seeding time	Heading (days)	Maturity (days)	Plant height (cm)	Grains spike^{-1}	TGW (g)	Yield (kg ha^{-1})
ITS	65	108	96	52	45	4200
ILS	63	94	92	49	36	3209
CV (%)	1.9	1.2	2.6	9.4	6.8	12.3
LSD (0.05)	1	1	1	1	1	86
F-test	**	**	**	**	**	**

Table 4. Effects of locations on yield and other characters of genotypes

Location	Heading (days)	Maturity (days)	Plant height (cm)	Grains spike^{-1}	TGW (g)	Grain Yield (kg ha^{-1})
Dinajpur	64.2	104.6	98.7	49	44.1	4068
Joydebpur	63.6	98.3	85.8	52.7	36.3	3741
Jashore	64	98.8	96.2	52.4	40.3	3796
Rajshahi	64.2	100.7	94	49.2	40.3	3212
CV (%)	1.9	1.2	2.6	9.4	6.8	12.3
LSD (0.05)	0.3	0.3	0.6	1.3	0.7	122
F-test	**	**	**	**	**	**

Table 5. Performances of genotypes on the yield and other characters of wheat genotypes (Mean results)

Genotype	Heading (days)	Maturity (days)	Plant height (cm)	Grains spike^{-1}	TGW (g)*	Grain Yield (kg ha^{-1})
BARI Gom 21	69	104	100	51	41	3514
BARI Gom 32	58	96	86	45	45	3840
BARI Gom 33	61	100	100	54	44	3723
BAW 1402	57	98	97	50	42	4461
BAW 1403	58	98	89	49	41	4307
BAW 1404	61	99	90	46	38	3442
BAW 1405	58	97	89	50	39	3331
BAW 1406	59	98	91	47	43	3848
BAW 1407	59	98	89	50	42	3833
BAW 1408	63	100	96	54	42	3782
BAW 1409	63	100	94	52	42	3825
BAW 1410	70	103	91	52	40	3835
BAW 1411	66	101	98	53	37	3698
BAW 1412	69	102	90	51	38	3590
BAW 1413	71	103	94	52	36	3455
BAW 1414	70	104	91	52	39	3830
BAW 1415	66	101	97	53	37	3672
BAW 1416	66	102	97	52	37	3031
BAW 1417	71	103	97	55	35	3403
BAW 1418	70	102	88	52	36	3470
BAW 1419	66	101	96	51	34	3343
BAW 1420	61	100	96	42	47	3540
BAW 1421	65	100	97	47	43	3601
BAW 1422	58	99	89	63	40	3998
BAW 1423	62	101	96	44	50	3980
BAW 1424	71	103	99	59	37	3608
BAW 1425	61	101	93	45	41	4056
CV (%)	1.9	1.2	2.6	9.4	6.8	12.3
LSD (0.05)	1	1	2	3	2	317
F-test	**	**	**	**	**	**

*TGW: Thousand Grain Weight

Days to maturity

Days to maturity of wheat, like days to heading, were significantly influenced by sowing times, locations, and genotypes (Tables 3, 4, 5 and 6a). Late sown wheat genotypes completed their life cycle earlier than timely sown wheat genotypes in all four locations, whereas all genotypes took a long time to complete their life cycle under the weather conditions of Dinajpur, followed by Rajshahi, Jashore, and Joydebpur, due to environmental factors, particularly temperature. Among the genotypes, BAW 1402, BAW 1403, BAW 1404, BAW 1405, BAW 1406, BAW 1407 and BAW 1422 took a short time for maturity than the check BARI Gom 21 and BARI Gom 33 might be due to the different genetic makeup. This finding was consistent with the findings of Hossain *et al.*, (2018), who discovered that late-sown wheat completed its life cycle faster than timely-sown wheat. Several studies have found that environmental factors, particularly temperature, influence the days to maturity of wheat genotypes (Spink *et al.,* 1993; Araus *et al.,* 2007 Shahzad *et al.,* 2007).

Plant height (cm)

Plant height is one of the most important parameters of yield contributing characters. In all locations, the highest plant height was in ITS condition (Tables 3 and 6b). In the current study, the favorable environment for plant height was Dinajpur compared to other locations in both ITS and ILS conditions (Table 6b). Considering the genotypes, the lowest plant height was recorded in genotypes BARI Gom 32 and BAW 1418 (Table 5). Plant height data revealed that both sowing dates and varieties had a significant impact on plant height. Anwar *et al.,* (2015) confirmed our findings, observing that plant height was significantly higher under optimal sown conditions.

Grains per spike

The genotypes' performance for trait grains per spike at various sowing times and locations was presented in Tables 3, 4, 5 and 6b. The reproductive stage of wheat is the most temperature sensitive (Hossain *et al*., 2018). In high-temperature stress (above 30 °C) at the flowering stage, nearly all field crops reducing grain set ultimately decreased the grain number per spike due to lower fertilization caused by pollen sterility and/or ovule abortion (Yang *et al.,* 2002; Prasad *et al.,* 2008). In the current study, the highest grain spike was recorded in the ITS condition (Table 3), owing to favorable weather conditions, which ultimately helps to increase grain set. In terms of environmental conditions, Joydebpur's environment was superior to other locations for setting grains per spike (Table 4). BAW1422 and BAW1424 produced more grains per spike than the other genotypes tested in this study. The genotypic difference could be due to genetic variation as well as climatic and edaphic factors as determined by field conditions.

Thousand-grain weight (g)

Heat stress reduces TGW under late sown conditions due to a decrease in individual grain weight, whereas optimum sowing increases TGW (Rahman *et al*., 2018). The highest TGW is obtained as a result of the maximum individual grain weight, which may be due to favorable environmental conditions (Rahman *et al*., 2018). In this study, wheat sown in ITS condition produced the highest TGW, while wheat sown in ILS condition produced the lowest TGW (Tables 3 and 6c). Considering locations, the wheat genotypes produced the highest TGW in Dinapur than other locations (Table 4). The highest TGW was found in BAW 1423 (50 g) followed by BAW 1420 (47g) and BARI Gom 32 (45g) (Table 5). In terms of location, Dinajpur had the highest TGW due to favorable weather conditions during the wheat growth stage (Table 6c).

Table 6a. Interaction effects of location, sowing date and genotype on heading and maturity of wheat genotypes

Genotype	Heading (days)								Maturity (days)							
	Dinajpur		Joydebpur		Jashore		Rajshahi		Dinajpur		Joydebpur		Jashore		Rajshahi	
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS
BARI Gom 21	75	68	70	66	70	66	75	67	119	101	106	97	110	93	112	99
BARI Gom 32	56	59	58	62	55	60	56	58	108	92	101	94	100	88	100	90
BARI Gom 33	62	62	63	61	61	62	62	61	113	97	103	93	103	91	105	95
BAW 1402	55	57	57	62	56	59	56	58	111	95	102	91	103	89	106	94
BAW 1403	58	59	57	62	57	59	58	59	110	93	103	92	104	87	106	94
BAW 1404	61	61	60	62	60	61	61	62	109	96	104	92	104	90	106	96
BAW 1405	55	58	60	61	58	59	56	58	107	93	103	90	101	88	105	89
BAW 1406	59	58	59	61	58	58	59	58	109	94	103	92	101	89	105	92
BAW 1407	57	58	59	62	60	60	60	59	111	93	103	90	103	89	105	92
BAW 1408	64	64	64	64	64	62	62	62	111	96	106	92	105	91	106	94
BAW 1409	65	63	63	64	64	62	65	62	114	97	103	93	107	91	106	95
BAW 1410	76	67	71	67	76	65	75	65	115	100	106	93	113	93	112	96
BAW 1411	69	63	66	62	70	62	72	62	114	97	104	94	109	91	108	94
BAW 1412	73	67	69	67	75	67	73	66	114	99	105	94	110	94	109	96
BAW 1413	77	68	70	68	78	67	77	67	116	100	105	94	113	93	111	96
BAW 1414	73	66	71	67	76	66	77	66	118	100	106	95	113	94	112	96
BAW 1415	69	65	67	64	70	63	72	63	116	96	102	93	108	93	109	95
BAW 1416	68	64	64	65	71	63	72	62	113	99	105	94	108	93	109	94
BAW 1417	77	68	70	67	78	66	77	67	118	98	105	94	112	94	112	97
BAW 1418	77	67	70	64	76	66	75	66	118	99	105	95	105	93	111	95
BAW 1419	72	63	65	63	69	63	72	63	114	94	103	94	107	90	109	95
BAW 1420	62	57	64	63	63	61	63	61	116	93	104	94	105	90	105	94
BAW 1421	71	63	64	65	68	63	65	60	114	95	105	93	108	93	105	93
BAW 1422	57	59	57	64	57	60	57	58	112	95	102	93	105	90	103	93
BAW 1423	63	63	58	61	61	60	70	61	114	93	103	94	104	102	109	93
BAW 1424	80	68	72	67	77	66	72	67	118	99	105	93	111	93	110	96
BAW 1425	59	64	60	62	61	60	61	60	114	99	104	94	108	90	106	96
CV (%)				1.9									1.2			
LSD (0.05)				2									2			
F-test				**									**			

Table 6b. Interaction effects of location, sowing date and genotype on plant height and grains spike^{-1} of wheat genotypes

Genotype	Plant height (cm)								Grains spike^{-1}							
	Dinajpur		Joydebpur		Jashore		Rajshahi		Dinajpur		Joydebpur		Jashore		Rajshahi	
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS
BARI Gom 21	108	102	98	86	106	98	101	99	51	43	63	47	61	48	49	49
BARI Gom 32	93	85	81	80	84	90	89	84	44	44	46	44	43	44	44	50
BARI Gom 33	109	105	97	92	100	102	98	100	56	46	61	61	60	52	54	47
BAW 1402	98	99	95	84	99	105	97	100	49	43	54	49	52	54	47	52
BAW 1403	88	91	85	84	91	96	89	90	47	48	52	52	50	50	45	47
BAW 1404	88	91	84	86	95	98	93	89	48	41	52	44	42	45	40	55
BAW 1405	89	88	82	86	93	97	88	90	47	46	56	54	52	47	50	52
BAW 1406	99	86	86	84	90	95	96	91	41	45	55	54	42	45	44	55
BAW 1407	95	85	87	85	90	94	90	89	46	48	55	49	45	51	55	49
BAW 1408	111	96	93	84	96	98	97	95	56	48	59	53	62	58	42	52
BAW 1409	109	94	89	81	96	98	96	94	59	51	58	41	56	56	46	53
BAW 1410	98	95	83	80	98	87	94	92	54	49	59	45	55	47	57	51
BAW 1411	111	99	90	87	106	100	100	95	50	44	65	52	48	58	53	58
BAW 1412	102	90	85	83	92	88	95	91	53	48	61	46	52	56	54	42
BAW 1413	107	91	87	82	102	92	99	92	48	50	71	44	59	56	45	47
BAW 1414	101	95	83	82	101	85	91	90	53	50	55	44	57	48	54	57
BAW 1415	113	100	88	83	104	99	99	96	54	52	60	52	53	60	50	48
BAW 1416	110	102	90	86	103	96	98	94	58	46	59	49	55	48	56	47
BAW 1417	113	98	91	89	102	90	101	95	57	46	62	46	61	56	55	56
BAW 1418	103	89	82	76	91	88	90	89	58	54	60	54	58	51	34	52
BAW 1419	104	99	91	85	100	98	97	97	56	38	60	49	60	53	47	47
BAW 1420	111	92	90	81	97	103	104	93	47	37	47	38	44	44	40	40
BAW 1421	111	98	94	88	99	99	97	91	47	44	50	44	53	48	45	47
BAW 1422	95	93	80	83	90	93	88	89	61	66	71	60	76	64	47	64
BAW 1423	107	100	89	87	98	103	99	91	49	39	47	44	46	41	40	46
BAW 1424	110	106	90	91	107	96	103	93	67	55	62	54	63	57	60	58
BAW 1425	101	97	90	81	95	97	97	92	40	37	49	46	47	49	44	51
CV (%)	2.6								9.4							
LSD (0.05)	5								9							
F-test	**								*							

Table 6c. Interaction effects of location, sowing date and genotypes on TGW and grain yield of wheat genotypes, 2020-21

Genotype	TGW								Grain yield (kg ha^{-1})							
	Dinajpur		Joydebpur		Jashore		Rajshahi		Dinajpur		Joydebpur		Jashore		Rajshahi	
	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS	ITS	ILS
BARI Gom 21	46	41	42	34	45	35	44	41	4447	3244	4137	3469	4001	2721	3528	2564
BARI Gom 32	57	45	47	35	49	34	52	39	5466	3445	4268	3766	4034	3531	3345	2868
BARI Gom 33	46	44	47	38	51	41	48	37	4995	3436	4260	3838	3579	3236	3708	2735
BAW 1402	51	39	42	31	49	40	48	38	5288	3512	4842	4220	5782	4085	4254	3709
BAW 1403	50	42	42	29	47	37	46	37	4789	4162	4833	4342	4532	3605	4328	3868
BAW 1404	28	38	42	33	47	35	47	34	3823	2900	3414	3491	4275	2740	4092	2800
BAW 1405	49	34	44	26	48	39	50	26	3955	2586	3429	3399	4299	3454	3414	2110
BAW 1406	56	39	42	35	49	40	50	30	5068	3354	3916	4252	3929	3418	3520	3330
BAW 1407	56	40	45	29	50	33	49	37	4877	3253	4782	3897	3963	3293	3735	2868
BAW 1408	52	41	43	32	46	39	46	35	4584	2676	4053	4010	4399	3733	3577	3223
BAW 1409	53	42	45	32	49	37	46	38	4970	3751	4117	3573	5104	2909	3499	2679
BAW 1410	45	38	40	32	43	37	43	38	5278	3719	3553	3815	4237	3510	3767	2798
BAW 1411	45	36	38	32	38	35	40	36	4698	2721	4012	3769	4658	3441	3105	3180
BAW 1412	46	40	39	31	41	39	39	32	5219	3195	3701	3207	4058	3080	3138	3120
BAW 1413	48	38	41	26	36	28	39	32	5286	3360	3617	2730	4855	2560	3156	2078
BAW 1414	42	38	39	31	42	40	43	40	5688	3532	3346	3186	4845	2936	3802	3310
BAW 1415	47	35	38	25	42	34	42	36	5951	3438	3492	3225	4033	3082	3435	2719
BAW 1416	49	37	40	23	39	33	41	36	4798	2301	3032	2746	3899	2545	3005	1923
BAW 1417	41	32	36	26	39	35	37	36	4644	1946	4279	3344	4148	2876	3324	2667
BAW 1418	42	40	40	30	39	34	35	32	5660	2797	3932	3238	3133	3164	3204	2633
BAW 1419	40	33	40	21	36	34	35	32	4410	2108	3810	2907	4019	3202	3242	3049
BAW 1420	61	50	46	33	50	41	53	40	5107	2196	3604	3132	4009	3304	4014	2951
BAW 1421	55	44	46	30	47	37	48	39	4811	3679	4128	3337	3728	3060	3659	2407
BAW 1422	52	40	41	28	44	31	44	39	4555	4035	3887	3522	4947	4158	4051	2833
BAW 1423	59	49	51	39	55	48	52	47	5452	3346	4792	4082	4810	3339	3292	2726
BAW 1424	47	40	33	31	38	36	39	37	4264	3705	3534	3219	4201	3788	3289	2863
BAW 1425	44	44	46	35	44	36	43	36	5463	3721	3927	3636	5158	3599	4218	2727
CV (%)	6.8								12.3							
LSD (0.05)	5								896							
F-test	**								NS							

genotypes, BAW 1423 had the highest TGW, followed by check BARI Gom 32, and BAW 1419 had the lowest TGW. All genotypes achieved the highest TGW under ITS conditions, regardless of location. Due to early heading and maturity, high temperatures (soil, air) and a lack of soil moisture (drought) in late sowing reduced individual grain weight (Hossain *et al.,* 2018).

Grain yield

Grain yield was significantly influenced by sowing time, environmental locations and genotypes (Table 3, 4, 5 and 6c). In all locations, the highest yield was obtained in the ITS condition rather than the ILS condition. Wheat that was planted late faced high-temperature stress in the field, followed by drought, which significantly reduced yield. Several reports revealed comparable outcomes (Hossain *et al.,* 2012; Hossain *et al.,* 2013; Hossain *et al.,* 2018). The poor GY of wheat sown in December may be assigned to a decrease in the number of productive tillers/spikes and grains per spike. Considering both seeding time and all the locations, the highest yield was found in genotype BAW 1402 (4461 kg ha^{-1}) followed by BAW 1403 (4307 kg ha^{-1}) and BAW 1425(4056 kg ha^{-1}) and the lowest yield was found in BAW 1416 (3031 kg ha^{-1}). At Dinajpur, the highest grain yield was obtained in BAW 1415 (5951 kg ha^{-1}) in ITS and BAW 1403 (4162 kg ha^{-1}) in ILS condition. The lowest grain yield (1923 kg ha^{-}1) was obtained in BAW 1416 at Rajshahi under ILS conditions. The highest yield loss (37%) due to late seeding was recorded in BAW 1413 while the lowest yield loss (11%) was recorded in BAW 1424 (Table 7).

BpLB, leaf rust and wheat blast

Out of 27 genotypes tested, three genotypes (BAW 1403, BAW 1409 and BAW 1423) were low infection based on area under the disease progress curve (AUDPC) under ITS condition. Singh *et al.,* 2014 also stated that the some inbred recombinant lines of wheat were tolerant to spot blotch in three hotspot regions in India under natural conditions. Under field conditions, one genotype (BAW 1408) was immune to wheat blast, 16 genotypes including three checks were resistant (0.2-10 percent disease index), 4 genotypes were moderately resistant (11-30 percent disease index), 3 genotypes were moderately susceptible (31-50 percent disease index), and 3 genotypes were highly susceptible (76-100 percent disease index). Wheat blast disease was only found in tropical South American regions (Kohli *et al.,* 2011). Wheat blast disease has recently become a major disease in Asia (Islam *et al.,* 2016; Malaker *et al.,* 2016). Among all genotypes, 12 genotypes showed a positive 2NS segment (Alam *et al., 2021*). Under field conditions, the severity of leaf rust varied among advanced genotypes and varieties (Table 7). Varieties/advanced lines demonstrated 0 to 50% severity with various types of disease response, whereas spreader lines demonstrated 80% severity with susceptible reaction. Out of 27 genotypes, 22 genotypes, including three checks, were completely free of leaf rust infection, 3 genotypes displayed moderate resistance (rust severity 11-30%), and 2 genotypes displayed moderate susceptibility (31-50 percent severity). Muhammad *et al.,* (2015) also screened 325 wheat genotypes based on the leaf rust severity scale and discovered that 225 wheat genotypes showed no reaction to leaf rust, 12 genotypes showed a resistant response, 20 moderately resistant, 40 moderately susceptible, 15 moderately resistant to moderately susceptible, and 13 genotypes showed susceptible response.

Table 7. Mean yield, percent yield loss due to late sowing and disease reaction of wheat genotypes

Genotype	ITS	ILS	% Yield loss due to late Seeding	BpLB in Dinajpur (AUDPC)		Wheat Blast index (%) (ILS) at Jashore	2NS	Leaf Rust
				ITS	ILS			
BARI Gom 21	4028	2999	26	47	183	6.65	-	0
BARI Gom 32	4278	3402	20	105	258	5.09	-	0
BARI Gom 33	4135	3311	20	132	217	0.15	2NS	0
BAW 1402	5041	3882	23	121	307	7.45	-	0
BAW 1403	4620	3994	14	91	253	2.13	-	0
BAW 1404	3901	2983	24	200	257	3.87	-	0
BAW 1405	3774	2887	23	224	272	11.62	-	20MSS
BAW 1406	4108	3588	13	177	290	34.25	-	0
BAW 1407	4339	3328	23	229	285	24.18	-	0
BAW 1408	4153	3410	18	103	134	0	-	20MSS
BAW 1409	4422	3228	27	91	157	32.87	-	60s
BAW 1410	4209	3460	18	132	121	0.19	2NS	0
BAW 1411	4118	3278	20	278	210	11.98	2NS	0
BAW 1412	4029	3151	22	372	168	3.54	2NS	0
BAW 1413	4228	2682	37	126	251	3.82	2NS	0
BAW 1414	4420	3241	27	108	168	2.98	2NS	0
BAW 1415	4228	3116	26	200	295	9.51	2NS	0
BAW 1416	3683	2379	35	313	232	25.73	2NS	0
BAW 1417	4099	2708	34	244	226	0.16	2NS	0
BAW 1418	3982	2958	26	198	215	7.44	2NS	0
BAW 1419	3870	2816	27	438	361	32.55	-	0
BAW 1420	4184	2896	31	144	269	100	-	50MSS
BAW 1421	4081	3121	24	264	168	100	-	30MSS
BAW 1422	4360	3637	17	113	173	1.06	-	0
BAW 1423	4586	3373	26	84	182	4.07	-	0
BAW 1424	3822	3394	11	147	301	0.01	2NS	0
BAW 1425	4691	3421	27	102	246	92.3	2NS	0

Conclusion

Based on the overall performance of the experimental results, it can be concluded that irrigated timely sown is better than irrigated late sown conditions for wheat production in Bangladesh. Late planting causes a significant yield loss in every year. Wheat is often late because of delayed harvesting of T. Aman rice, longer time for land preparation, unavailability of labourers, late monsoon and some cases of excess moisture in the soil. As a result, when screening wheat genotypes, late sown conditions are given more weight than optimum sown conditions.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this manuscript.

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