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Differential Response of Some Bread Wheat (*Triticum aestivum* L.) Genotypes for Yield and Vegetative Traits under Optimum and Late Sowing Dates

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Abstract: This research aimed at studying the effect of late sowing on the vegetative growth and yield of twelve genotypes of bread wheat (*Triticum aestivum* L.). An experiment was carried out in 2012/2013 using two sowing dates: 28th of November (reference) and 27th of December (late) at two locations (Shambat Demonstration Farm, Faculty of Agriculture University of Khartoum and Hudeiba Research Station). The experimental design was a split-plot with three replications. The results showed that late sowing significantly affected most of the vegetative characters. The results showed significant differences ($p \leq 0.05$) among genotypes for vegetative growth and yield at both locations. The interaction of sowing date and wheat genotypes was significant ($p \leq 0.05$) for 50% booting, 50% anthesis, 95% maturity, leaf area index and grain yield. Under reference sowing date total yield was 2.21 tons/ha and under late sowing it was 1.43 tons/ha with a reduction of about 35%. The genotypes exhibited large variation in their response to heat stress imposed at late sowing indicating the possibility of improving this trait genetically. Genotype 56 was the earliest in maturity at both locations; therefore, it can be tested for cultivation south of Khartoum.

Key words: Heat stress, wheat, sowing date, Sudan, yield.

1. Introduction

Wheat is a widely adapted crop grown in a wide range of environments from temperate irrigated to dry and high-rainfall areas and from warm humid to dry cold ones. Wheat contributes about 30% of the world's total grain production [1]. Wheat provides more calories and protein than any other cereal crop.

Wheat is very sensitive to high temperatures especially heat stress encountered during the reproductive stage. Heat stress during the reproductive stage adversely influences grain yields by affecting photosynthesis, anthesis, pollen formation and viability and grain filling [2, 3]. The global surface temperature is increasing continuously and a global warming of 1.5% or even more is expected to be reached in the coming 20 years. As a result, more frequent and long lasting high temperatures are expected to occur over large parts of the world [4]. This increase in global temperature will have a serious impact on global food security as a consequence of adverse effects of heat stress on growth and yields of cereal crops (e.g. wheat, barley and maize) [5].

In Sudan, wheat is the second most important cereal crop. Before 1960, Sudan grew wheat only in the northern section of the Nile valley, where there are relatively cooler and longer winters and even there only on a limited scale. Because of increasing demand for bread wheat in Sudan, local land shortage and the large cost of irrigation water in the north, non-traditional areas, south of Khartoum, are targeted for expansion in wheat cultivation, however, they are characterized by high temperature and relatively shorter winter. To fill up the gap of food security, horizontal expansion in

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these areas and development of locally-adapted heat tolerant varieties become necessary. Several studies in Sudan have shown that wheat yields are very sensitive to planting dates, irrespective of the varieties used. The largest yields are obtained from sowings from mid-October to mid-November, but sowing wheat after 20th November significantly decreases yield. In the long term, yield increases will largely depend on the evolution of high-yielding, heat-tolerant and short-duration wheat varieties.

This study aimed to determine the genotypic variability and differential response of twelve bread wheat (*Triticum aestivum* L.) genotypes to terminal heat stress across different locations of Sudan.

2. Materials and Methods

2.1 Experimental Sites

Two field experiments were conducted during winter 2012/2013 to study the effect of late sowing on growth and yield of wheat.

The treatments consisted of two sites: Faculty of Agriculture Demonstration farm in Shambat, located at 15°4′ North, latitude and 32°32′ East longitude, with soil that consists of Nile alluvium and sandy clay soil and Hudeiba Research Station located at 17°34′ North, latitude and 33°56′ East longitude, with soil that consists of 51% clay, 1% silt and 48% sand. Two sowing dates: 20th of November 2012 (reference sowing date) and 27th of December (late sowing), exposure to terminal heat stress. Twelve selected wheat genotypes (11 advanced breeding lines and a check variety, Imam) were used (Table 1).

2.2 Meteorological Data

Average monthly temperature and relative humidity were recorded at Shambat and Hudeiba Metrological stations during the growing season.

2.3 Experimental Design

The experiments were laid out in the field in split-plot design with three replications. Sowing dates were randomly assigned as main plots and genotypes were randomized as sub-plots within the main plots. Genotypes were distributed in a zigzag way, starting from left to right throughout all replications. Seed rate used was 119 kg/ha and both experiments were given eleven irrigations with an interval of 7-10 days between irrigations. Fertilizer application IN (92 kg urea/ha) was applied before the fourth irrigation. Weeding was done manually every three weeks using hand hoe.

2.4 Data Collection

During the growing season, observations were taken on five randomly selected plants, tagged in each subplot. Data were recorded on vegetative parameters and yield as follows.

2.5 Vegetative Characters

There are emergence (%), plant height (cm), number of leaves, leaf area/plant, leaf area index (calculated as

$$\frac{Area\ of\ individual\ leaf\ \times average\ number\ of\ leaves\ \times number\ of\ plants/area}{Ground\ area}$$

leaf waxiness, days to 50% booting, days to 50% anthesis, days to 95% maturity, number of productive tillers/plant, plant biomass (g) and harvest index (calculated as the percentage of grains weight divided by biological weight (including grains weight)).

2.6 Yield

The five labeled plants for each subplot were pulled after full maturity to determine kernels yield in tons/ha.

Table 1 Code numbers of 12 genotypes of wheat (*Triticum aestivum* L.) evaluated for terminal heat stress at Shambat and Hudeiba in 2012/2013.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Genotype Code number	1	14	16	33	41	53	56	63	67	83	86	95

Table 2 Means of temperature (°C) and relative humidity (%) at the two locations (Shambat and Hudeiba) during the season 2012/2013.

Month	Mean temperature (°C)		Mean relative humidity (%)	
	Shambat	Hudeiba	Shambat	Hudeiba
November	24.0	23.5	27.8	36.9
December	23.9	23.2	25.2	47.0
January	24.1	23.5	29.8	50.7
February	26.3	25.8	31.0	40.4
March	28.5	28.1	18.0	32.7
April	29.2	28.9	18.0	22.5

2.7 Statistical Analysis

Data of each parameter were collected and subjected to different statistical analyses as follows.

2.7.1 Analysis of Variance

The analysis of variance was carried out according to the procedure described by K. A. Gomez and A. A. Gomez [6] for split-plot design (Table 2) for each location separately, and it had been run for all studied traits.

2.7.2 Combined Analysis of Variance

This was done for the traits in which the mean squares of errors were homogenous. It was computed based on the description of K. A. Gomez and A. A. Gomez [6] for split plot design. The data were analyzed using the computer program Statistical Analysis System (SAS) (1997) version 9.0. [7].

3. Results

3.1 Climatic Conditions

Data were collected from meteorological observatory stations on environmental conditions. It exhibited some variations in degrees of temperature and relative humidity in Shambat and Hudeiba during the growing season 2012/2013 and between months within the same season at the two locations (Table 2). The highest temperature in Shambat (29.2 °C) was in April and the lowest (23.9 °C) was in December. In Hudeiba the highest temperature (28.9 °C) was in April and the lowest (23.2 °C) was in December. The relative humidity was higher in Hudeiba than in Shambat. The highest mean relative humidity (31%) was in Shambat during February and in Hudeiba the highest (50.7%) was during January.

3.2 Effect of Location, Sowing Date, Genotype and Interaction between Sowing Date and Genotype (S × G) on Studied Traits

Analysis of variance showed that the effect of location was highly significant for all of the studied traits, except number of productive tillers/plant (Table 3). Likewise, the effect of sowing date was highly significant for all traits except leaf waxiness, number of productive tillers/plant and harvest index (Table 3). As well the effect of genotype was highly significant for 50% booting, 50% anthesis, 95% maturity, leaf waxiness, plant height, number of leaves, leaf area index at 30 and 60 days and yield in tons/ha. While it showed no significant differences for emergence (%), leaf area index at 45 and 75 days, number of productive tillers plant^{-1}, plant biomass (g) and harvest index (Table 3).

The effect of interaction of (S × G) was highly significant for 50% booting, 50% anthesis, leaf area 45, 60, 75 days and leaf area index 60 and 75 days and was significant on 95% maturity and yield in tons/ha. There were no significant differences of (S × G) on emergence, leaf waxiness, plant height, number of leaves, number of productive tillers plant^{-1}, plant biomass and harvest index (Table 3).

3.3 Performance of Genotypes over Locations and over Sowing Dates

Mean values for some investigated vegetative characters and yield exhibited variations between the two locations (Shambat and Hudeiba) during season 2012/2013.

Table 3 Mean squares (MS) of different traits for Location (L), sowing date (S), Genotype (G) and interaction (S × G).

		MS			
No.	Character	Location (L)	Sowing date (S)	Genotype (G)	SxG
		df = (1)	df = (1)	df = (11)	df = (11)
1	Emergence (%)	729*	1,144.7**	36.2^{ns}	59.3^{ns}
4	50% booting	1,050.8**	41.2**	89.3**	13.9**
5	50% anthesis	36*	1,586.7**	24.6**	9.0**
6	95% maturity	17.4**	1,547**	131.4**	16.3*
7	Leaf waxiness	70.8**	0.1^{ns}	3.4**	0.1^{ns}
8.	Plant height 30 days	33.0^{ns}	497.3^{ns}	30.7^{ns}	22.9^{ns}
9	Plant height 45 days	95.0*	4,855.8**	81.3**	27.4^{ns}
10	Plant height 60 days	597.6**	262.8*	102.4**	14.9^{ns}
11	Plant height 75 days	478.4**	1,113.6**	111.8**	18.4^{ns}
12	Number of leaves 30 days	3.2**	3.30**	0.23*	0.17^{ns}
13	Number of leaves 45 days	24.6**	19.6**	0.34*	0.07^{ns}
14	Number of leaves 60 days	99.5**	23.1**	0.59**	0.27^{ns}
15	Number of leaves 75 days	400**	94.1**	0.45**	0.16^{ns}
16	Leaf area 30 days	487.2**	22.2^{ns}	18.4**	7.1^{ns}
17	Leaf area 45 days	794.2**	141.9**	43.5**	16.5*
18	Leaf area 60 days	1,249.8**	442.7**	60.6**	27.5*
19	Leaf area 75 days	4,699.8**	2,701.8**	45.1**	44.6**
20	Leaf area index 30 days	5.1**	0.83^{ns}	0.17*	0.13^{ns}
21	Leaf area index 45 days	4.1**	17.9**	0.25^{ns}	0.18^{ns}
22	Leaf area index 60 days	35.2**	5.2**	0.20*	0.27**
23	Leaf area index 75 days	52.7**	14.5**	0.16^{ns}	0.28**
24	Number of tillers/plant	4.2^{ns}	0.2^{ns}	0.74^{ns}	0.34^{ns}
25	Plant biomass (g)	34.0**	26.10**	0.97^{ns}	1.1^{ns}
26	Yield tons/ha	544,152*	21,790,224**	59,363.1**	499,562*
27	Harvest index (%)	0.46**	0.004^{ns}	0.01^{ns}	0.01^{ns}

** Significant at probability $p \leq 0.01$; * Significant at probability $p \leq 0.05$; ns: not significant.

The mean values for almost all characters were higher at Hudeiba than Shambat, for example grand mean yield for genotypes at Hudeiba was 1.88 tons/ha while it was 1.79 tons/ha at Shambat (Table 4). On the other hand, mean values of genotypes for vegetative characters and yield exhibited large variations between the two sowing dates (S1 and S2). The mean values for almost all characters were higher in the first sowing date than in the second one. For example, mean grain yield for genotypes in the first sowing date was 2.21 tons/ha, while it was 1.43 tons/ha in the second sowing date. Traits such as 95% maturity and leaf area index gave higher values in the first sowing date than in the second one (Table 4).

3.4 Effect of Sowing Date on Vegetative Traits

3.4.1 Emergence (%)

The mean values of emergence at both locations were higher in the first sowing date than in the second one; the mean values in Hudeiba were higher than in Shambat and the results also showed that the grand means range was 89% to 93.5% (Table 5).

3.4.2 Days to 50% Booting

Table 5 shows that all genotypes reached 50% booting earlier in Shambat than in Hudeiba. The earliest was genotype 56; which reached 50% booting in 48.5 days at Shambat and 55.5 days at Hudeiba. Meanwhile, the latest genotype was 83 that reached 50% booting in

Table 4 Means of 12 genotypes for some vegetative traits, yield and harvest index at two sowing dates (S1, S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Trait	S1	S2	Mean	LSD	Shambat	Hudeiba	Mean	LSD
Emergence %	94.10	88.40	91.30	2.90	89.00	93.50	91.30	2.91
50% booting	56.10	55.10	55.60	0.60	52.90	58.30	55.60	0.60
50% anthesis	68.90	62.30	65.60	0.80	65.10	66.10	65.60	0.80
95% maturity	97.40	90.90	94.10	0.20	93.80	94.50	94.10	0.20
Leaf waxiness	2.10	2.10	2.10	0.20	2.80	1.40	2.10	0.20
P. ht. 30 days	63.00	57.40	61.20	1.80	30.80	29.80	30.30	4.30
P. ht. 45 days	44.30	42.50	43.40	1.50	44.30	42.50	43.40	1.50
P. ht. 60 days	57.90	53.80	55.90	1.70	57.90	53.80	55.90	1.70
P. ht. 75 days	62.02	58.40	60.20	1.80	62.02	58.40	60.20	1.80
No. L P^{-1} 30 days	4.60	4.90	4.80	0.10	4.60	4.90	4.80	0.10
No. L P^{-1} 45 days	5.30	4.50	4.90	0.20	4.50	5.30	4.90	0.20
No. L P^{-1} 60 days	4.50	3.70	4.10	0.20	3.30	5.00	4.10	0.20
No. L P^{-1} 75 days	4.00	2.40	3.20	0.20	1.60	4.90	3.20	0.20
LA 30 days	11.30	10.60	11.00	1.10	9.10	12.80	11.00	1.10
LA 45 days	15.50	13.50	14.50	0.40	12.20	16.90	14.50	0.40
LA 60 days	17.90	14.30	16.10	0.30	13.20	19.10	16.10	0.30
LA 75 days	18.70	10.10	14.40	1.40	8.70	20.10	14.40	1.40
LAI 30 days	0.96	0.81	0.88	0.20	0.70	1.10	0.90	0.20
LAI 45 days	1.50	0.80	1.25	0.20	0.97	1.31	1.14	0.20
LAI 60 days	1.30	0.80	1.10	0.04	0.63	1.60	1.12	0.04
LAI 75 days	1.40	1.80	1.10	0.10	0.50	1.70	1.10	0.10
NT P^{-1}	1.20	1.20	1.20	0.50	1.02	1.40	1.21	0.50
Pt. biomass (g)	4.50	3.70	4.10	0.40	3.60	4.60	4.10	0.40
Yield in tons/ha	2.21	1.43	1.82	2.21	1.76	1.88	1.82	0.38
Harvest index	40	40	40	0.03	50	30	40	0.03

P. ht. = plant height, No. L P^{-1} = number of leaves plant^{-1}, LA = leaf area, LAI = leaf area index, NT P^{-1} = number of tillers plant^{-1}, Pt. biomass = plant biomass.

Table 5 Emergence % and days to 50% booting of 12 genotypes of wheat, at two different sowing dates (Sl and S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Genotype	Emergence (%)						Days to 50% booting					
	Shambat			Hudeiba			Shambat			Hudeiba		
	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean
1	92.7^{a}	84.7^{a}	88.7^{A}	98.0^{a}	89.0^{a}	93.5^{A}	62.0^{a}	53.0^{fgh}	57.5^{AB}	58.7^{bc}	60.0^{b}	59.3^{BC}
14	96.7^{a}	86.0^{a}	91.3^{A}	97.0^{a}	93.3^{a}	95.2^{A}	58.0^{bc}	49.0^{km}	53.5^{D}	60.3^{b}	59.3^{b}	59.8^{B}
16	93.7^{a}	90.3^{a}	92.0^{A}	95.7^{a}	91.7^{a}	93.7^{A}	54.3^{ef}	49.7^{jkl}	52.0^{E}	56.3^{cdef}	58.7^{bc}	57.5^{CD}
33	82.3^{a}	91.3^{a}	86.8^{A}	96.0^{a}	92.3^{a}	94.2^{A}	51.3^{h-j}	47.3^{mn}	49.3^{GH}	55.3^{efg}	58.0^{bcde}	56.7^{DE}
41	85.3^{a}	85.7^{a}	85.5^{A}	97.0^{a}	89.3^{a}	93.2^{A}	50.3^{j-k}	48.0^{l-n}	49.2^{GH}	53.3^{g}	59.7^{b}	56.5^{DE}
53	93.7^{a}	81.0^{a}	87.3^{A}	97.3^{a}	82.7^{a}	90.0^{A}	56.7^{cd}	50.3^{i-k}	53.5^{D}	60.0^{b}	58.0^{bcd}	59.7^{BC}
56	95.7^{a}	89.3^{a}	92.5^{A}	95.3^{a}	90.7^{a}	93.0^{A}	53.0^{f-h}	47.0^{n}	48.5^{H}	53.3^{efg}	57.7^{c}	55.5^{E}
63	86.0^{a}	88.7^{a}	87.3^{A}	97.0^{a}	95.0^{a}	96.0^{A}	49.7^{j-i}	48.7^{k-n}	50.0^{FG}	54.7^{fg}	58.0^{be}	56.3^{DE}
67	93.3^{a}	81.0^{a}	87.2^{A}	94.7^{a}	85.0^{a}	89.8^{A}	47.3^{mn}	51.7^{g-i}	55.2^{C}	55.3^{efg}	60.0^{b}	57.7^{CD}
83	96.7^{a}	86.0^{a}	91.3^{A}	94.3^{a}	91.7^{a}	93.0^{A}	48.0^{l-n}	55.0^{de}	58.2^{A}	59.7^{b}	66.3^{a}	63.0^{A}
86	94.7^{a}	86.7^{a}	90.7^{A}	97.7^{a}	94.7^{a}	96.2^{A}	50.3^{ijk}	49.0^{k-m}	51.2^{EF}	55.7^{d-g}	58.0^{b-d}	57.0^{DE}
95	92.7^{a}	82.0^{a}	87.3^{A}	94.3^{a}	94.3^{a}	94.3^{A}	59.0^{b}	54.0^{ef}	56.7^{E}	57.7^{b-e}	64.3^{a}	61.0^{B}
Mean	91.9^{a}	86.1^{b}	89.0^{A}	96.2^{a}	90.8^{b}	93.5^{A}	62.0^{a}	50.2^{b}	52.9^{B}	56.7^{b}	59.9^{a}	58.3^{A}
C.V.	11.8			4.1			2.1			2.5		

Means within column or row followed by the same letter(s) are not significantly different at ≤ 0.05 probability level according to Duncan's Multiple Range test.

Table 6 Days to 50% anthesis and days to 95% maturity of 12 genotypes of wheat, at two different sowing dates (S1 and S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Genotype	Days to 50% anthesis						Days to 95% maturity					
	Shambat			Hudeiba			Shambat			Hudeiba		
	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean
1	74.0^{a}	58.3^{f}	66.2^{AB}	67.0^{cd}	65.7^{ce}	66.3^{BD}	100.7^{b}	89.7^{de}	95.2^{bc}	96.3^{cg}	88.7^{l}	92.5^{DE}
14	71.7^{bc}	58.0^{fg}	64.8^{BE}	68.3^{bc}	66.0^{cd}	67.2^{BC}	99.3^{b}	86.0^{e}	92.7^{c}	100.0^{abc}	92.3^{gl}	96.2^{BC}
16	73.7^{ab}	57.3^{fg}	65.5^{BC}	64.3^{de}	66.0^{cd}	65.2^{CDE}	97.0^{bc}	86.3^{e}	91.7^{c}	94.7^{dh}	90.0^{il}	92.3^{DE}
33	72.3^{abc}	54.7^{h}	63.5^{EF}	65.0^{ce}	66.7^{cd}	65.8^{CDE}	99.0^{b}	85.7^{e}	92.3^{c}	93.0^{fj}	92.0^{hl}	92.5^{DE}
41	71.7^{bc}	56.0^{gh}	63.8^{DEF}	64.7^{de}	67.0^{cd}	65.8^{CDE}	98.0^{bc}	92.3^{d}	95.2^{bc}	94.3^{eh}	93.7^{fi}	94.0^{CD}
53	71.3^{c}	57.3^{fg}	64.3^{CF}	67.7^{de}	64.3^{de}	66.0^{CDE}	97.7^{bc}	89.3^{de}	93.5^{bc}	98.3^{be}	89.0^{hk}	93.7^{E}
56	71.7^{bc}	55.0^{h}	63.3^{F}	62.3^{e}	65.3^{cde}	63.8^{E}	91.3^{de}	84.7^{e}	88.0^{d}	92.7^{fk}	88.3^{l}	90.5^{E}
63	72.7^{abc}	57.3^{fg}	65.0^{BCD}	62.3^{e}	67.0^{cd}	64.7^{DE}	96.3^{bc}	88.0^{de}	92.2^{c}	91.3^{hl}	91.0^{hl}	91.7^{DE}
67	72.0^{abc}	59.0^{ef}	65.5^{BC}	62.3^{e}	66.3^{cd}	65.5^{CE}	97.3^{bc}	86.7^{de}	92.0^{c}	95.0^{dh}	89.7^{il}	92.3^{DE}
83	73.3^{abc}	61.3^{d}	67.3^{A}	67.3^{cd}	72.7^{a}	70.0^{A}	107.0^{a}	95.7^{bc}	101.3^{a}	102^{ab}	103.3^{a}	102.6^{A}
86	72.0^{abc}	57.0^{fg}	64.5^{CDEF}	64.3^{e}	64.7^{de}	64.5^{DE}	98.3^{bc}	90.7^{de}	94.5^{bc}	98.3^{be}	96.7^{cf}	97.5^{B}
95	74.0^{a}	60.7^{de}	67.3^{A}	5.7^{ce}	71.0^{ab}	68.3^{AB}	101.7^{b}	92.3^{d}	97.0^{b}	98.3^{be}	98.7^{bd}	98.5^{B}
Mean	72.5^{a}	57.7^{b}	65.1^{B}	65.3^{b}	66.9^{a}	66.1^{A}	98.7^{a}	88.9^{b}	93.8^{B}	96.2a	92.8^{b}	94.5^{A}
CV (%)	1.7			2.8			3.0			2.3		

Means within column or row followed by the same letter(s) are not significantly different at ≤ 0.05 probability level according to Duncan's Multiple Range test.

58.2 days at Shambat and 63 days at Hudeiba. Range of grand means of locations was 52.9-58.3 days.

3.4.3 Days to 50% Anthesis

Table 6 shows that all genotypes reached 50% anthesis earlier in the second sowing date at Shambat. Results showed that the grand mean at Shambat was 65.1 days, while it was 66.1 days at Hudeiba. The earliest genotype was 56, which reached 50% anthesis in 63.3 days at Shambat and 63.8 days at Hudeiba. Latest genotype was 83 that reached 50% anthesis in 67.3 days sharing the latest level of anthesis with cultivar Imam (95) at Shambat, and 70 days at Hudeiba. Grand means for this trait range was 65.1-66.1 days for the two locations.

3.4.4 Days to 95% Maturity

All genotypes at both locations reached their 95% maturity earlier in the second sowing date than in the first one except genotype 83. Results showed that the earliest genotype was 56, which reached 95% maturity in 88 days at Shambat and 90.5 days at Hudeiba. The latest genotype was 83 that reached 95% maturity in 101.3 days at Shambat and 102.6 days at Hudeiba. Grand mean for this trait at Shambat was 93.8 days and 94.5 days at Hudeiba (Table 6).

3.4.5 Leaf Waxiness (%)

Generally, the mean values of leaf waxiness in Shambat were higher than in Hudeiba. The results showed that the means for sowing dates ranged between 2.5-3.0 at Shambat and 0.2-2.8 at Hudeiba. Grand mean for this trait was 2.8 at Shambat and 1.4 at Hudeiba (Table 7).

3.4.6 Plant Height

Fig. 1a illustrates the mean values for plant height (cm) for the two sowing dates (S1 and S2) at two locations Shambat and Hudeiba taken in trend over time 30-75 days after sowing with an interval of 15 days. The results showed that plant height increased with increasing time till prematurity; and that the mean values of plant height were higher in the first sowing date than in the second one at both locations (Fig. 1a).

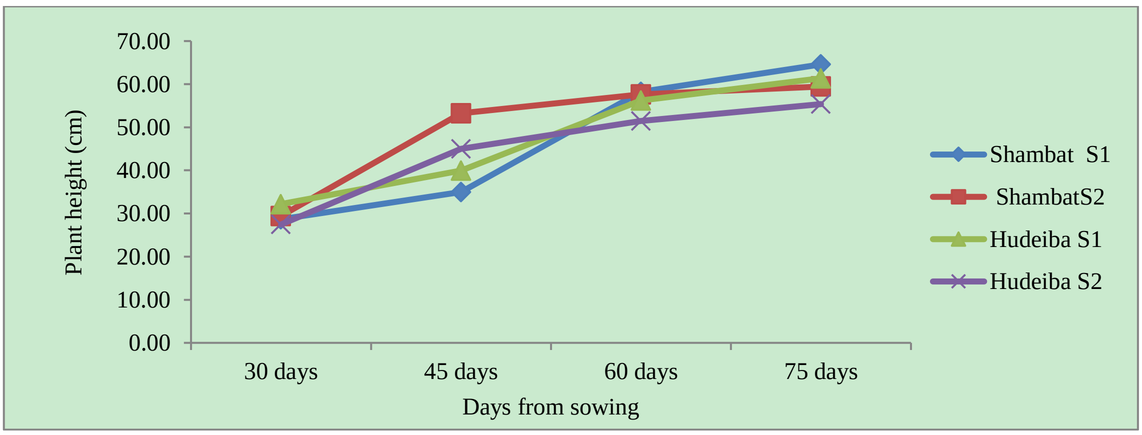
3.4.7 Number of Leaves Plant^{-1}

Fig. 1b illustrates the mean values for number of leaves plant^{-1} for the two sowing dates (S1 and S2) at two locations Shambat and Hudeiba taken in trend over time 30-75 days after sowing with an interval of 15 days. The results showed that an increase in number of leaves at 30-45 days in the first sowing date, and then it decreased gradually at 60-75 days at both locations.

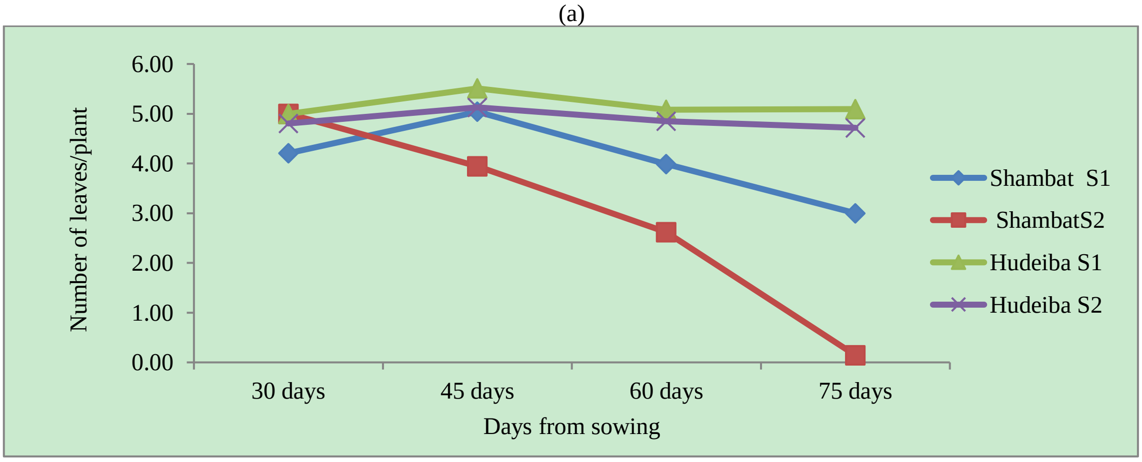
Table 7 Scores of 12 genotypes of wheat for leaf waxiness, and number of tillers/plant at two different sowing dates (Sl and S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Genotype	Leaf waxiness						Number of tillers plant^{-1}					
	Shambat			Hudeiba			Shambat			Hudeiba		
	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean
1	2.7^{a}	2.3^{a}	2.5^{A}	0.0^{i}	0.3^{h}	0.2^{D}	0.5^{ef}	0.4^{ef}	0.5^{B}	1.1^{fg}	1.8^{ab}	1.4^{ABC}
14	3.0^{a}	2.7^{a}	2.8^{A}	0.3^{h}	0.3^{h}	0.3^{CD}	2.3^{a}	0.7^{ef}	1.5^{AB}	1.5^{d}	1.9^{a}	1.7^{A}
16	2.7^{a}	3.0^{a}	2.8^{A}	2.7^{b}	3.0^{a}	2.8^{A}	1.2^{d}	0.4^{ef}	0.8^{AB}	1.3^{e}	1.5^{d}	1.4^{ABC}
33	3.0^{a}	3.0^{a}	3.0^{A}	2.3^{c}	2.7^{b}	2.5^{A}	0.6^{ef}	0.3^{f}	0.4^{B}	1.0^{g}	1.6^{cd}	1.3^{ABCD}
41	3.0^{a}	3.0^{a}	3.0^{A}	2.7^{b}	2.3^{c}	2.5^{A}	1.4^{cd}	0.8^{e}	1.1^{AB}	1.5^{d}	1.8^{ab}	1.7^{AB}
53	3.0^{a}	3.0^{a}	3.0^{A}	1.3^{e}	1.0^{f}	1.2^{B}	0.7^{ef}	0.6^{ef}	0.6^{B}	1.8^{ab}	1.5^{d}	1.7^{AB}
56	3.0^{a}	3.0^{a}	3.0^{A}	2.3^{c}	2.3^{c}	2.3^{A}	0.4^{ef}	0.5^{d}	0.4^{B}	1.2^{ef}	1.7^{bc}	1.4^{ABC}
63	2.3^{a}	3.0^{a}	2.7^{A}	1.7^{d}	1.0^{f}	1.3^{B}	2.3^{a}	1.2^{d}	1.7^{B}	0.8^{h}	1.6^{cd}	1.2^{BCD}
67	2.7^{a}	2.3^{a}	2.5^{A}	0.7^{g}	1.3^{e}	1.0^{BC}	1.4^{cd}	0.7^{ef}	1.1^{AB}	0.6^{i}	1.1^{fg}	0.8^{d}
83	2.7^{a}	3.0^{a}	2.8^{A}	0.0^{i}	0.3^{h}	0.2^{D}	1.7^{bc}	0.8^{e}	1.2^{AB}	0.9^{gh}	1.1^{fg}	1.0^{CD}
86	2.7^{a}	2.7^{a}	2.7^{A}	1.0^{f}	1.0^{f}	1.0^{BC}	1.9^{b}	0.8^{e}	1.4^{AB}	1.3^{e}	1.6^{cd}	1.5^{ABC}
95	2.7^{a}	3.0^{a}	2.8^{A}	1.7^{d}	1.3^{e}	1.5^{BD}	1.5^{cd}	1.5^{cd}	1.5^{AB}	0.7^{hi}	1.9^{a}	1.3^{ABC}
Mean	2.8^{a}	2.8^{a}	2.8^{A}	1.4^{a}	1.4^{a}	1.4^{B}	1.3^{a}	0.7^{b}	1.0^{A}	1.1^{a}	1.6^{b}	1.4^{B}
CV %	14.2			41.1			76.3			28.0		

Means within column or row followed by the same letter(s) are not significantly different at ≤ 0.05 probability level according to Duncan's Multiple Range test.



(a)



(b)

Fig. 1 Effect of sowing date (S1 and S2) on (a) plant height and (b) number of leaves plant^{-1} at two locations (Shambat and Hudeiba) at 30-75 days from sowing, during the growing season 2012/2013.

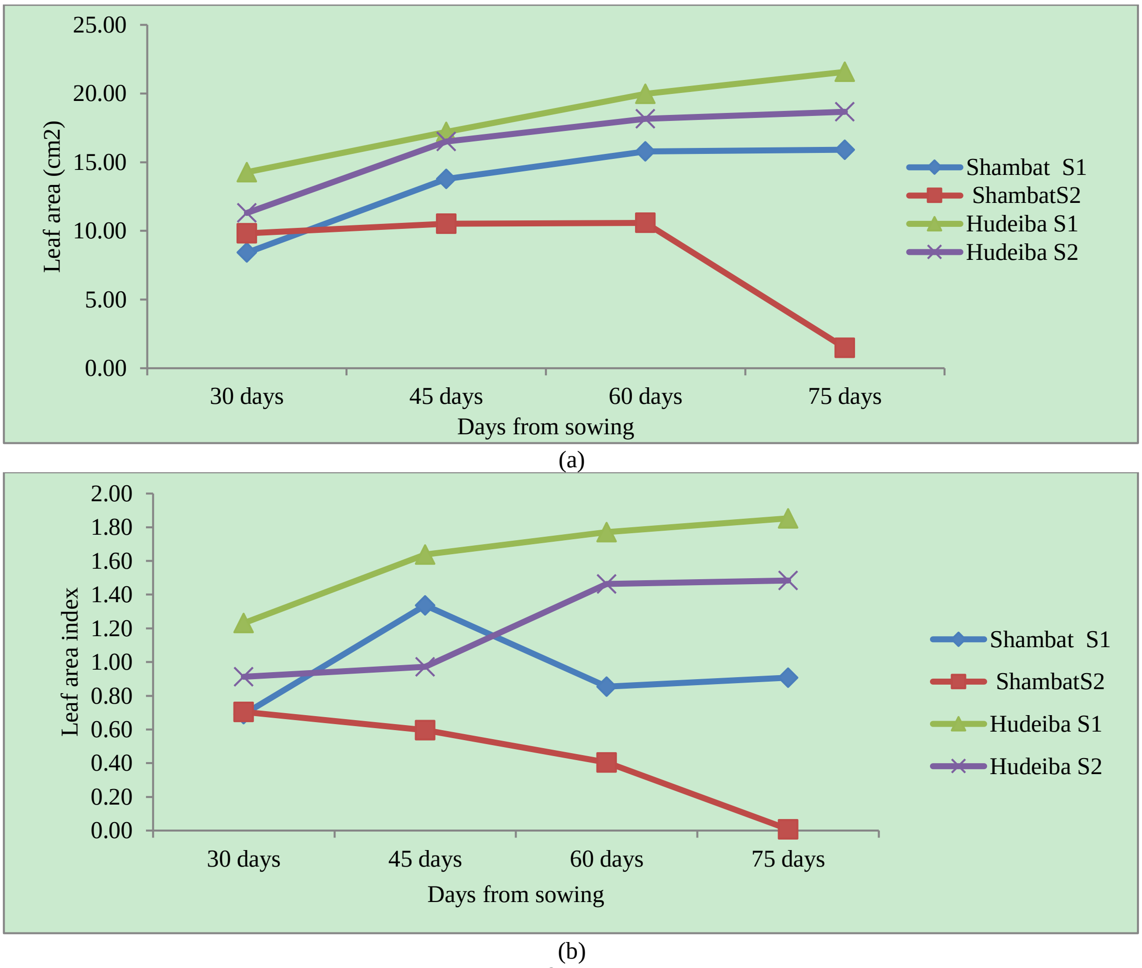


Fig. 2 Effect of sowing date (S1 and S2) on (a) leaf area (cm^2) and (b) leaf area index at two locations (Shambat and Hudeiba) at 30-75 days from sowing during the growing season 2012/2013.

Results also showed continuous rapid decrease in number of leaves in the second sowing date at Shambat after 30 days; until almost all genotypes lost their leaves at 75 days.

The number of leaves reached a maximum at 45 days from sowing in the second sowing date at Hudeiba; then decreased shortly till 60 days, after that it was decreasing at a minimum rate till 75 days.

3.4.8 Leaf Area Plant^{-1}

Fig. 2a illustrates the mean values for leaf area (cm^2) for the two sowing dates (S1 and S2) at two locations Shambat and Hudeiba taken in trend over time 30-75 days after sowing, with an interval of 15 days. The results showed that the mean values of leaf area in the first sowing date were higher than in the second one at both locations. The mean values were higher at Hudeiba than at Shambat. The decrease of leaf area was clearly observed in the second sowing date at Shambat after 60 days from sowing until it reached its least values at 75 days from sowing.

3.4.9 Leaf Area Index

The mean values for leaf area index for the two sowing dates (S1 and S2) at two locations Shambat and Hudeiba taken in trend over time 30-75 days after sowing with an interval of 15 days are illustrated in Fig. 2b. The results showed that the mean values of leaf area index in the first sowing date were higher than in the second one at both locations, and were higher at Hudeiba than at Shambat. The leaf area index in the second sowing date at Shambat decreased rapidly and the mean values were almost near zero at 75 days from sowing.

3.4.10 Number of Tillers Plant^{-1}

The mean values of number of tillers plant^{-1} were higher at Hudeiba than at Shambat. Mean values of number of tillers were higher in the first sowing date at Shambat, while they were higher in the second sowing date at Hudeiba. Genotype (63) had the maximum mean number of tillers at Shambat, whereas genotype (14) had the maximum number of tillers at Hudeiba. Grand means for this trait were 1.0 at Shambat and 1.4 at Hudeiba (Table 7).

3.4.11 Plant Biomass (g)

Mean values for plant biomass (g) were higher at Hudeiba than at Shambat, results also showed that means for this trait were higher in the first sowing date than in the second one at Shambat. Genotype (95) had the maximum mean plant biomass at Shambat, while genotype (16) had the maximum one at Hudeiba. Grand means of locations were 3.6 (g) and 4.6 (g) at Shambat and Hudeiba, respectively (Table 8).

3.4.12 Harvest Index

The mean values for harvest index range was 40%-50% at Shambat and 30%-40% at Hudeiba. Grand means for this trait ranged between 30%-40% at Hudeiba and Shambat, respectively (Table 8).

3.5 Effect of Sowing Date on Production

3.5.1 Yield in Tons/Ha

Table 9 shows that the mean values for yield in tons/ha were higher in the first sowing date than in the second sowing date. Genotype (14) had the maximum mean yield in tons/ha at both locations, while genotype (53) scored the minimum mean yield at both locations. Range of grand means at locations was 1.76-1.88 tons/ha (Table 9).

Table 8 Plant biomass (g) and harvest index of 12 genotypes of wheat, at two different sowing dates (S1 and S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Genotype	Plant biomass						Harvest index					
	Shambat			Hudeiba			Shambat			Hudeiba		
	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean	Sl	S2	Mean
1	3.5^a	2.5^a	3.0^A	4.6^a	5.1^a	4.9^A	30^a	50^a	40^A	40^a	30^a	40^A
14	6.0^a	2.4^a	4.2^A	4.1^a	4.3^a	4.2^A	40^a	40^a	40^A	40^a	40^a	40^A
16	4.5^a	2.2^a	3.3^A	4.7^a	5.6^a	5.2^A	50^a	50^a	50^A	40^a	40^a	40^A
33	3.3^a	2.2^a	2.7^A	4.1^a	5.4^a	4.7^A	40^a	50^a	50^A	40^a	40^a	40^A
41	5.2^a	3.1^a	4.1^A	5.4^a	4.6^a	5.0^A	50^a	40^a	50^A	40^a	50^a	40^A
53	3.7^a	2.2^a	2.9^A	5.4^a	3.7^a	4.5^A	40^a	40^a	40^A	30^a	30^a	30^A
56	2.9^a	2.4^a	2.6^A	4.9^a	4.8^a	4.8^A	50^a	50^a	50^A	30^a	40^a	40^A
63	5.2^a	3.0^a	4.1^A	3.6^a	4.8^a	4.2^A	40^a	40^a	40^A	30^a	40^a	40^A
67	5.7^a	2.5^a	4.1^A	3.7^a	4.2^a	3.9^A	50^a	40^a	50^A	30^a	40^a	40^A
83	5.5^a	2.2^a	3.8^A	4.0^a	4.8^a	4.4^A	40^a	40^a	40^A	40^a	30^a	30^A
86	4.5^a	2.8^a	3.7^A	4.8^a	5.1^a	5.0^A	50^a	50^a	50^A	30^a	30^a	30^A
95	6.0^a	3.5^a	4.7^A	3.4^a	5.0^a	4.2^A	40^a	40^a	40^A	40^a	30^a	30^A
Mean	4.6^a	2.6^a	3.6^B	4.4^a	4.8^a	4.6^A	50^a	40^a	50^A	40^a	30^a	40^B
CV (%)	36.2			21.4			27.6			13.1		

Means within column or row followed by the same letter(s) are not significantly different at ≤ 0.05 probability level according to Duncan's Multiple Range test.

Table 9 Mean yield (tons/ha) of 12 genotypes of wheat at two different sowing dates (S1 and S2) and two locations (Shambat and Hudeiba) during the growing season 2012/2013.

Genotype	Yield (t/ha)					
	Shambat			Hudeiba		
	S1	S2	Mean	S1	S2	Mean
1	2.39^a	1.01^a	1.70^A	2.69^a	1.03^j	1.89^{ABC}
14	2.46^a	1.59^a	2.02^A	2.48^b	2.25^{cd}	2.37^A

16	2.50^{a}	1.19^{a}	1.84^{A}	1.69^{g}	2.36^{bc}	2.03^{AB}
33	2.50^{a}	1.39^{a}	1.94^{A}	1.94^{f}	1.98^{e}	1.96^{AB}
41	2.29^{a}	1.26^{a}	1.78^{A}	2.45^{b}	1.42^{h}	1.93^{AB}
53	2.45^{a}	0.72^{a}	1.59^{A}	1.68^{g}	0.71^{k}	1.19^{C}
56	2.22^{a}	1.34^{a}	1.78^{A}	1.97^{e}	2.06^{cde}	2.02^{AB}
63	2.21^{a}	1.27^{a}	1.74^{A}	1.93^{f}	2.15^{cde}	2.04^{AB}
67	2.27^{a}	0.94^{a}	1.60^{A}	1.99^{e}	0.89^{jk}	1.44^{BC}
83	1.94^{a}	0.97^{a}	1.46^{A}	2.04^{e}	1.58^{gh}	1.81^{ABC}
86	2.43^{a}	1.41^{a}	1.92^{A}	2.20^{cd}	2.11^{cde}	2.15^{AB}
95	2.46^{a}	1.01^{a}	1.74^{A}	1.85f	1.73^{fg}	1.79^{BC}
Mean	2.34^{a}	1.18^{b}	1.76^{B}	2.08^{a}	1.69^{b}	1.88^{A}
C.V	21.3			27.8		

Means within columns or rows followed by the same letter(s) are not significantly different at ≤ 0.05 probability level according to Duncan's Multiple Range test.

4. Discussion

The terminal heat stress affected both the vegetative and reproductive traits and the effect was more severe during the reproductive stage. These results are in accordance with those reported by Khan et al. [8]. In this study the high temperature that prevailed during the late stages of plant growth had significantly and adversely affected many vegetative traits resulting in yield reduction. The significant adverse effect of late sowing at both locations was more severe at Shambat than Hudeiba, for most of the studied traits.

The results revealed that all genotypes reached 50% booting earlier in Shambat than in Hudeiba. However, higher temperature at late sowing reduced days to 50% booting at both locations. Although, there were no large differences in temperature between Shambat and Hudeiba, therefore this might be attributed to the fact that there was higher relative humidity at Hudeiba compared to Shambat. Likewise, days to 50% anthesis were significantly reduced by late sowing, however, the reduction was more pronounced in Shambat than Hudeiba. Similar results were concluded by Balla et al. [9], who stated that heat stress speeds up the commencement of anthesis, thereby decreasing grain yield by affecting the number of spikes per spikelet. Also, other researchers e.g. Arshad et al. [2] and Lohani et al. [3] found that heat stress during reproductive stage affects anthesis, pollen viability and grain setting, photosynthesis, grain filling rate and duration, and ultimately, crop yields.

The observed significant interaction between genotypes and sowing dates for days to 50% booting, 50% anthesis shows differential response of genotypes to variation in prevailing conditions (e.g., temperature and relative humidity) between the two locations. This can be attributed to high temperature at Shambat during booting stage at the late sowing date that reduced the life span and hastened the beginning of reproductive stage. This variation may be due to relatively lower temperatures or higher relative humidity (data not shown) during anthesis of the late sown crop at Hudeiba, as genotypes passed through cooler temperatures, and were associated with late flowering. These results agree with the findings of Balla et al. [9], who reported 16% and 20% reduction in days to anthesis and days to maturity, respectively, under heat stress.

There was highly significant difference for days to 95% maturity among the genotypes in both Shambat and Hudeiba. This indicates that this trait is highly affected by genetical factors. This significant sowing date × genotype interaction effect observed for days to 95% maturity indicates the differential response of genotypes to the sowing dates. Similar findings were reported by Balla et al. [9]. The general trend was that delay in planting date decreased the average number of days to 95% maturity by exposure to high temperature towards the end of the growing season. Significant differences were reported in plants reactions to heat stress depending on the length and intensity of the heat as well as the growth stage at the stress period [1].

Sowing date, location and genotype exhibited significant effects on plant height measured at different stages. The observed reduction and differences in plant height due to late sowing and location may be attributed to increase in temperature and other environmental conditions between locations. In support of these findings, Balla et al. [9] reported that under heat stress the plant height was reduced up to 12%. Several authors reported on the negative effect of high temperature on seed germination, poor field establishment plant growth and yield traits in terms of plant biomass, productive tillers and number of grains per plant [1, 8].

In this study, low leaf area enhanced by higher temperature, caused reduction in green coverage at later stages of 10 and 20 days after anthesis in heat tolerant genotypes and the trend was common for all the genotypes. There was a decrease in number of leaves and leaf area index due to elevated temperatures in the late sowing date [10]. These results are in accordance with the findings of Bergkamp et al. [11] that attributed yield losses, resulting from high temperatures, to faster leaf senescence thereby shortened grain filling period. High temperature influences the photosynthetic activity of wheat plants by affecting various physiological processes [12] resulting in lower grain filling. Heat stress was so severe at Shambat that almost all genotypes had a leaf area index near zero at maturity. It is reported that high temperature has a strong effect on leaf duration rates with decreased leaf elongation [13]. Results showed significant sowing date × genotype interaction effect. Cultivar Imam produced the highest leaf area index at both locations while, genotype 33 produced the lowest leaf area index at Shambat and genotype 53 produced the lowest one at Hudeiba. This may be referred to genotype × environment variations for this trait. The decline in LAI following the flag leaf stage might be ascribed to aging of leaves, leaf senescence and thermal stress at later growth stages. It is reported that heat stress reduces leaf area and decreases photosynthesis rate, among others, through reduction in chlorophyll content and chlorophyll degradation, resulting in lower amount of photosynthetic products transportation to grains eventually reducing yield [14].

The non-significant differences between the sowing dates, for number of tillers may be due to other factors rather than delayed sowing, such as genotype, environment, agronomic and nutritional management practices, or may be because the heat stress timing significantly influences the reproductive tiller number [9]. The results of this study are supported by findings stating increased tiller number in wheat plants exposed to heat stress during early developmental stages [9, 15]. In contrast, reports show that spike formation and tillering were adversely affected by exposure to high temperatures during flowering and grain filling stages [16]. This confirms that the effects of heat stress depend on the developmental stage of the crop and the occurrence and duration of the heat stress episode [15].

The results showed that there were significant differences between the two sowing dates and two locations for plant biomass because of increase in temperature in the second sowing date at Shambat rather than at Hudeiba, similar reductions in plant biomass under heat stress were reported by Khan et al. [17]. They also reported that the rate of plant development is accelerated by high temperature, where the reproductive stage starts much earlier than under optimum temperatures, leading to less biomass accumulation.

Heat stress hinders the morphological and physiological developmental processes in wheat leading to great yield losses [18]. Wheat grain yields can be significantly reduced when exposed to temperature (> 35 °C) for a short period of time [19]. The induced terminal heat stress in the present study caused a reduction of 35% in yield. A similar reduction of yield due to heat stress was reported by Poudel et al., [20]. The different sowing dates caused significant variations in the yield of wheat and other characters as the temperature increased at the end of the growing season. In wheat, heat stress usually decreases growth stage duration from emergence to anthesis [14]. When temperatures are high between anthesis and early grain filling, which is very sensitive to high temperatures, grain yield is decreased because of the reduction in sink size as well as time to capture resources [21].

Higher temperature hastens the crop growth and initiation of reproductive stage than normal. Shortened period of grain filling, impaired development of grains, decreased grain number and grain weight in wheat crop under heat stress were reported [22]. This indicates that reproductive characters depend on vegetative characters for example, days to flowering and days to maturity and this is because any delay in sowing date of wheat hastens the days of flowering and maturity by shortening the period between flowering and leaf loss due to high temperature at the end of the growing season. Different studies demonstrate that delayed sowing increases the impact of terminal heat stress on wheat yield [23].

There was significant sowing date × genotype interaction for grain yield. Some genotypes performed better than others, but generally all genotypes produced low grain yield when grown in December. Genotypes 1 and 53 exhibited relatively the highest yields under favorable conditions; however, they had shown the lowest ones under late sowing, at both locations, indicating their specific adaptability only to favorable environments. Genotypes 14 and 53 had the maximum and minimum yields under terminal heat stress at both locations, respectively. Genotype 14 out-yielded the check variety Imam and had the advantage over others by its relatively higher and similar yields under both sowing dates and both locations, indicating its stability and wide adaptation across extreme environments. These results are supported by the findings of Ubadhyaya and Bhandari [24] who reported significant differences in yield in response to heat stress between wheat genotypes.

5. Conclusion

The findings of this study have demonstrated that wheat yields decrease when planting time is delayed and this may be attributed to shortened crop development with low dry matter accumulation. This shows that early planting of wheat increased season length through increasing number of days to anthesis and consequently number of days to physiological maturity. Therefore, early planting of wheat should be recommended for areas with short winter duration like Shambat. Moreover, the genotypes exhibited large variation in their response to heat stress imposed at late sowing, indicating the possibility of improving this trait genetically. Genotype 56 was the earliest in maturity at both locations; therefore, it can be recommended for cultivation south of Khartoum. Genotype 14 could be selected as the most potential heat-tolerant, stable across contrasting environments (optimum vs. late sowing), and had relatively better yield under terminal heat stress compared to the heat-tolerant check variety, Imam. Therefore, genotype 14 could be identified as widely-adapted and recommended for high-temperature, non-traditional areas of wheat production in Central Sudan.

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