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Thermal Unit Requirement and Grain Yield of Wheat under Non-Irrigated Dry Warmer Condition

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Authors' contributions

This work was carried out in collaboration between both authors. Author SKP performed the experiment, collected the data, analyzed the data, wrote the manuscript and critically revised the manuscript. Author SS planned and designed the experiment, wrote the protocol, coordinated and revised the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted with four wheat genotypes (BARI Gom 28, BARI Gom 29, BAW 1177 and ESWYT 29) and two growing conditions (well water and non-irrigated water stress) during November, 2015 to March, 2016 at research field of Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The experiment was carried out to investigate the effect of non-irrigated dry warmer condition on growing degree days (GDD), phenothermal index (PTI), heat use efficiency (HUE) and grain yield and also to assess the relation of grain yield with HUE of wheat genotypes. The results revealed that there was an increasing trend of GDD requirement from early to later stages and finally, the highest GDD requirement was observed at harvest maturity stage for all genotypes under both growing conditions. For attaining different phenological stages the maximum GDD requirement was observed in ESWYT 29 under well water conditions, whereas minimum GDD requirement for that was observed in BARI Gom 29 under water stress condition. Non-irrigated water stress reduced PTI in maximum cases of different phenophases but there was minimum variation in PTI between the two growing conditions. Non-irrigated water stress also reduced the grain yield and HUE in all wheat genotypes. The highest grain yield (4.20 t ha^{-1}) and HUE (3.89 kg ha^{-1} ℃ day^{-1}) based on grain yield was observed in BAW 1177 under well water condition, while the lowest grain yield (2.06

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t ha^{-1}) and HUE (1.92 kg ha^{-1} ℃ day^{-1}) was observed in ESWYT 29 under water stress condition. The results of the present investigation also revealed that there was a strongly positive linear relationship between HUE and grain yield of wheat genotypes.

Keywords: Wheat; water deficit stress; growing degree days; phenothermal index and heat use efficiency.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a thermo-sensitive, long-day crop, grown extensively throughout the world. Its global production reaches 757.6 million tons per year with an annual consumption of 734 million tons [1]. Global climate changes are increasingly affecting wheat yields and raising future food security concerns. Temperature and drought stress due to climate change are causing substantial reductions in global wheat yields. To increase and sustain wheat yields the understanding and genetic dissection of quantitative traits, especially those related to yield and stress tolerance, are required [2,3]. Phenological development from sowing to maturity is related to accumulation of heat units above threshold or below which no growth occurs [4]. To reach a particular phenophase of plant a quantified accumulated heat unit is required. Under stress condition, most of the crops try to finish their developmental phases within a shorter period of time [5,6]. Several research findings noticed that temperature below (<10°C) or above (>25°C) the optimum (12-25°C) alter phenology, growth and development and finally reduce the yield of wheat varieties [5]. Air temperature based indices, *viz.,* growing degree days, phenothermal index, photothermal units and heliothermal units have been used to describe changes in phenological behavior and growth parameters [7]. Heat use efficiency quantification is necessary for a crop yield potential assessment in different growing conditions [8]. The drought and heat stresses may occur simultaneously under natural environments and cause huge crop losses. Irrigation can play a potential role as an adaptation strategy to offset heat impacts. Dryland wheat yields are estimated to decrease about 8% for every 1℃ increase in temperature, where irrigation can completely offset this negative impact [9]. Irrigation potentially reduces heat stress [10] by offsetting the additional evapotranspiration demand due to higher temperature [11] and by cooling the canopy temperature [12]. For instance, when transpiration rate is low in wheat plants under drought stress conditions, the canopy temperatures of plants at both vegetative and anthesis stages were higher than in plants under control conditions [13]. Other researchers also reported higher canopy temperature under non-irrigated wheat compared to irrigated wheat [14,15,16]. Therefore, a question rise does the higher temperature prevails at crop canopy due to non-irrigated dry warmer condition affect the heat unit requirement and yield of wheat or not. Keeping the above facts in mind, the present investigation was carried out to study the thermal unit requirement and its effects on yield of wheat genotypes under non-irrigated water stress condition.

2. MATERIALS AND METHODS

2.1 Location and Duration

The experiment was conducted at the research field of Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh during November, 2015 to March, 2016. The experimental field is located at 25º39′ N latitude and 88º41′ E longitude with an elevation of 37.58 meters above the sea level and under the Agro-ecological zone Old Himalayan Piedmont Plain (AEZ-1).

2.2 Experimental Design and Layout

The experiment was laid out in a split plot design and replicated thrice. The unit plot size was 3 m × 2 m having a plot to plot and block to block distance of 0.75 m and 1 m, respectively. Two growing conditions: a) well water (irrigation was given at crown root initiation, anthesis and grain filling stages) and b) water stress (no irrigation) were placed in main plots, whereas four wheat genotypes (BARI Gom 28, BARI Gom 29, BAW 1177 and ESWYT 29) were placed randomly in sub plots.

2.3 Sowing of Seeds and Intercultural Operations

Seeds were sown on 29 November, 2015 at the rate of 120 kg ha^{-1} in rows of 20 cm apart. Slight irrigation was given after sowing to facilitate uniform germination. Recommended production technology of wheat was followed and necessary intercultural operations were done accordingly.

2.4 Collection of Weather Data

The daily meteorological data were collected from Agro-meteorological Centre of Wheat and Maize Research Institute, Nashipur, Dinajpur. Relative humidity and mean air temperature during growing periods of wheat are presented in the Fig. 2 and total mean air temperature received by different wheat genotypes during sowing to harvest maturity are presented in the Fig. 3 as Appendix.

2.5 Calculation of Accumulated Thermal Units

The growing degree days and phenothermal index for consecutive phenophases and the heat use efficiency based on grain yield were calculated according to the formulae [17].

1. Growing degree days (GDD) = $\sum [(T_{max} + T_{min})/2 - T_b]$; T_b = Base temperature = 10℃
2. Phenothermal index (PTI) = GDD ÷ Growth days
3. Heat use efficiency (HUE) = Grain yield (kg/ha) ÷ GDD

2.6 Data Recorded on Grain Yield

The grains were separated by threshing plot wise and then sun dried and weighed. The grain yield was adjusted to 12% moisture using a moisture meter and the means were recorded.

2.7 Statistical Analysis

The collected data were analyzed by partitioning the total variance using the STATA program (small STATA 12.0), and the treatment means were compared using Tukey's test.

3. RESULTS AND DISCUSSION

3.1 Growing Degree Days (℃ days)

The combined effect of genotypes and growing conditions significantly influenced the growing degree days (GDD) requirement of wheat to attain the different phonological stages except the physiological maturity stage (Tables 1 and 1a). The results showed that the lowest heat unit (GDD) requirement was observed in tillering stage but there was an increasing trend of heat unit (GDD) requirement in the later stages (booting, heading, anthesis, physiological maturity and harvest maturity) and finally, the highest GDD requirement was observed for attaining the harvest maturity stage for all the wheat genotypes under both well water and water stress conditions. Among the different treatment combinations, for attaining tillering stage the maximum GDD requirement was observed in BARI Gom 28 (231.90) which was statistically similar to that of BARI Gom 29, whereas for attaining others phenological stages the maximum GDD requirement was observed in genotype ESWYT 29 (539.76 for booting, 583.10 for heading, 646.80 for anthesis, 1038.00 for physiological maturity and 1093.40 for harvest maturity stage) under well water condition. For attaining tillering stage, the minimum GDD requirement was observed in ESWYT 29 (202.90) under water stress condition which was statistically at par with that of other three genotypes under both growing conditions except BARI Gom 28 and BARI Gom 29 under well water condition. The minimum GDD requirement for attaining other phenological stages was observed in genotype BARI Gom 29 (438.50 for booting, 474.30 for heading, 540.10 for anthesis, 860.60 for physiological maturity and 1043.66 for harvest maturity) under water stress condition. Non-irrigated water stress reduced GDD requirement in three wheat genotypes (BARI Gom 29, BAW 1177 and ESWYT 29) for attaining different phenological stages, increased GDD requirement in BARI Gom 28 for attaining anthesis and harvest maturity and maintain similar GDD requirement in BARI Gom 28 for attaining physiological maturity. However, under well water condition, the genotypes BARI Gom 28 and BARI Gom 29 had the highest and statistically similar GDD requirement (231.90) for attaining tillering stage, whereas the genotype ESWYT 29 had the highest GDD requirement for attaining other phenological stages (539.76 for booting,583.10 for heading, 646.80 for anthesis, 1038.00 for physiological maturity and 1093.40 for harvest maturity). Under well water condition, the lowest and statistically similar GDD requirement (208.40) was observed in genotypes BAW 1177 and ESWYT 29 for attaining tillering stage, while for attaining other phenological stages, the lowest GDD requirement was observed in BARI Gom 28 (453.40 for booting, 492.60 for heading, 549.70 for anthesis, 876.60 for physiological maturity and 1049.33 for harvest maturity). Under water stress condition, again the genotypes BARI Gom 28 and BARI Gom 29 had the highest and statistically similar GDD requirement (208.40) for attaining tillering stage, whereas the genotype ESWYT 29 had the highest GDD requirement for attaining other phenological stages (521.90 for booting, 560.40 for heading, 631.26 for anthesis, 1007.80 for physiological maturity and 1074.73 for harvest maturity). Under water stress condition, the lowest and statistically similar GDD requirement was observed in genotypes BAW 1177 (197.10) and ESWYT 29 (202.90) for attaining tillering stage, while for attaining other phenological stages, the lowest GDD requirement was observed in genotype BARI Gom 29 (438.50 for booting, 474.30 for heading, 540.10 for anthesis, 860.60 for physiological maturity and 1043.66 for harvest maturity). GDD explains the direct impact of temperature on crop growth and development as every crop needs a certain amount of GDD to enter its next crop stage. The different responses to GDD requirement for attaining different phenological stages might be due to differences in their genetic constitution of different wheat genotypes. The higher heat units (GDD) requirement for well water condition than the water stress condition was probably due to longer period for all the phenological stages in the well water condition. At stress condition, GDD requirement was reduced in wheat genotypes but in some cases especially the genotype BARI Gom 28 showed increased in GDD requirement for attaining different phenological stages. It might be due to that all the genotypes significantly decreased the requirement of days for attaining different phenological stages at water stress condition. As a result, the definite days required to attain certain phenophase at well water condition were not similar to the definite days required to attain certain phenophase at water stress condition. As the air temperature varying day to day, the mean air temperature during different growing stages of BARI Gom 28 at well water condition might be less compared to the mean air temperature during different growing stages at water stress condition resulted in more GDD requirement. These results are in harmony with those obtained by Ali et al. [18]. These results are also

Table 1. Growing degree days at different phenological stages of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Growing degree days (℃ days) at		
		Tillering	Booting	Heading
BARI Gom 28	Well water	231.90a	453.40bc	492.60de
	Water stress	208.40b	467.50bc	491.90de
BARI Gom 29	Well water	231.90a	474.30b	525.56cd
	Water stress	208.40b	438.50c	474.30e
BAW 1177	Well water	208.40b	476.50b	530.90bc
	Water stress	197.10b	461.50bc	511.70cd
ESWYT 29	Well water	208.40b	539.76a	583.10a
	Water stress	202.90b	521.90a	560.40ab
Level of significance		0.05	0.05	0.05
CV (%)		6.58	5.63	7.32

In a column, Means followed by the same letter(s) did not differ significantly at 5% level by Tukey

Table 1a. Growing degree days at different phenological stages of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Growing degree days (℃ days) at		
		Anthesis	Physiological maturity	Harvest maturity
BARI Gom 28	Well water	549.70de	876.60	1049.33c
	Water stress	560.40cde	876.60	1060.06bc
BARI Gom 29	Well water	572.13bcd	908.10	1079.26ab
	Water stress	540.10e	860.60	1043.66c
BAW 1177	Well water	594.50b	951.68	1079.26ab
	Water stress	583.10bc	924.20	1060.06bc
ESWYT 29	Well water	646.80a	1038.00	1093.40a
	Water stress	631.26a	1007.80	1074.73ab
Level of significance		0.05	NS	0.01
CV (%)		6.89	2.91	6.81

In a column, Means followed by the same letter(s) did not differ significantly at 5% level by Tukey.
^{NS}Not significant at the 5% probability level

Table 2. Phenothermal index at different phenological stages of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Phenothermal index (℃ day day^{-1}) at		
		Tillering	Booting	Heading
BARI Gom 28	Well water	8.92a	6.98	7.04
	Water stress	8.02b	7.42	7.23
BARI Gom 29	Well water	8.59ab	7.30	7.40
	Water stress	8.02b	7.07	6.98
BAW 1177	Well water	8.02b	7.11	7.17
	Water stress	8.21ab	6.99	7.11
ESWYT 29	Well water	8.02b	7.20	7.48
	Water stress	8.12ab	7.15	7.28
Level of significance		0.05	NS	NS
CV (%)		3.70	3.69	3.17

In a column, Mean followed by the same letter(s) did not differ significantly at 5% level by Tukey.
^{NS}Not significant at the 5% probability level

Table 2a. Phenothermal index at different phenological stages of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Phenothermal index (℃ day day^{-1}) at		
		Anthesis	Physiological maturity	Harvest maturity
BARI Gom 28	Well water	7.23	8.68	9.29
	Water stress	7.47	8.77	9.46
BARI Gom 29	Well water	7.53	8.99	9.55
	Water stress	7.30	8.52	9.24
BAW 1177	Well water	7.43	8.98	9.38
	Water stress	7.38	8.89	9.38
ESWYT 29	Well water	7.70	9.27	9.43
	Water stress	7.61	9.16	9.19
Level of significance		NS	NS	NS
CV (%)		3.12	3.38	3.06

^{NS}Not significant at the 5% probability level

on line with those reported by Roy et al. [19], Wahid et al. [20] who reported that wheat genotypes differed in their GDD requirement and stress condition reduced GDD requirement in wheat compared to normal growing condition.

3.2 Phenothermal Index (℃ day day^{-1})

The combined effect of genotypes and growing conditions was significant on phenothermal index of wheat at tillering but not significant for attaining other phenological stages (Tables 2 and 2a). Among the different phenophases, the highest PTI was observed during physiological maturity to harvest maturity stage, while the PTI was lowest during tillering to booting stage. Among different treatment combinations the maximum PTI was observed under well water condition in genotype BARI Gom 28 at tillering (8.92), in genotype ESWYT 29 at heading (7.48), anthesis (7.70) and physiological maturity (9.27) and in genotype BARI Gom 29 at harvest maturity stage (9.55), while at booting the maximum PTI was observed under water stress condition in BARI Gom 28 (7.42). The minimum PTI was observed under water stress in BARI Gom 29 (6.98 and 8.52, respectively) at heading and physiological maturity stages, in genotype ESWYT 29 (9.19) at harvest maturity stage and in genotype BARI Gom 28 (8.02) at tillering stage, whereas minimum PTI was observed under well water condition in genotype BARI Gom 28 (6.98 and 7.23, respectively) at booting and anthesis stages. Non-irrigated water stress reduced PTI in maximum phenophases but there was minimum variation in PTI between the two growing conditions. BARI Gom 28 showed increased in PTI under water stress and it was due to increased GDD under water stress in BARI Gom 28 as the PTI is expressed as growing degree days per growth days. GDD was increasing with plant age as the growth duration was lower at the initial stages and then increased with plant age. As a result, at the later stages the values of PTI were closer between the two growing conditions. The results of the present study indicate that changes in the air temperature even for a short period are reflected in the PTI during the individual growth stages. The difference in PTI for different growth stages also indicates that the accumulated heat unit could be utilized for studying biomass accumulation pattern at different phenophases which ultimately influences the crop productivity. Differences between wheat varieties for PTI were also noted by Sourour et al. [21]. The phenothermal index is affected by the growing conditions and cultivars [22] which support the results of the present study. Researcher also mentioned that the stress condition affected the PTI in wheat [23].

3.3 Heat Use Efficiency (kg ha^{-1} ℃ day^{-1})

Heat use efficiency of wheat was significantly influenced by the combined effect of genotypes and growing conditions (Table 3). The combined effect of wheat genotypes and growing conditions revealed that among the different treatment combinations the maximum HUE (3.89) was found in genotype BAW 1177 under well water condition followed by HUE (3.73) found in genotype BARI Gom 28 under similar growing condition. On the other hand, minimum HUE (1.92) was found in genotype ESWYT 29 under water stress condition. From the results it was observed that at well water condition all the genotypes were more efficient in using heat compared to water stress condition. Non-irrigated water stress significantly reduced the HUE in all genotypes compared to water stress condition. The different magnitude of reduction of HUE was 31.37% in BARI Gom 28, 15.01% in BARI Gom 29, 14.39% in BAW 1177 and 34.47% in ESWYT 29. However, under well water condition genotype BAW 1177 had significantly highest HUE followed by that of BARI Gom 28, while ESWYT 29 had the lowest HUE. Under non-irrigated water stress condition, again the genotype BAW 1177 had the highest HUE and the genotype ESWYT 29 had the lowest HUE, while BARI Gom 28 and BARI Gom 29 had the moderate but statistically similar HUE. The results of the present study regarding HUE showed that all the wheat genotypes used heat more efficiently under well water condition than those of non-irrigated water stress condition. The higher HUE under well water condition compared to water stress condition was might be due to that well watered plants performed all the physiological activities normally and successfully and increased different physiological activities by using accumulated heat units more efficiently which resulted in higher grain yield consequently higher HUE. The results are in close agreement with those of Ali et al. [18], Roy et al. [19] who mentioned that the stress condition reduced heat use efficiency in wheat in different magnitude. Differential behavior of durum wheat genotypes for HUE could be attributed to their genetic potential reported by Sourour et al. [21].

3.4 Grain Yield

The interaction effect of genotypes and growing conditions significantly influenced the grain yield of wheat (Table 4). The results showed that, among different treatment combinations the maximum grain yield was found in genotype BAW 1177 (4.20 t ha^{-1}) under well water condition, whereas the minimum grain yield was found in genotype ESWYT 29 (2.06 t ha^{-1}) under non-irrigated water stress condition. However, under well water condition, genotype BAW 1177

Table 3. Heat use efficiency of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Heat use efficiency	
		kg ha^{-1} ℃ day^{-1}	Reduction (%) over well water condition
BARI Gom 28	Well water	3.73ab	31.37
	Water stress	2.56d	
BARI Gom 29	Well water	3.33bc	15.01
	Water stress	2.83d	
BAW 1177	Well water	3.89a	14.39
	Water stress	3.33bc	
ESWYT 29	Well water	2.93cd	34.47
	Water stress	1.92e	
Level of significance		0.01	-
CV (%)		1.36	-

In the column, Means followed by the same letter(s) did not differ significantly at 5% level by Tukey gave the maximum grain yield which was followed by that of BARI Gom 28 (3.91 t ha^{-1}), while the minimum grain yield was recorded in genotype ESWYT 29 (3.20 t ha^{-1}) which was followed by that of BARI Gom 29 (3.59 t ha^{-1}). Non-irrigated water stress significantly reduced the grain yield in all wheat genotypes but the degree of reduction was different for different genotypes. Maximum reduction in grain yield was observed in genotype ESWYT 29 (35.63%), while minimum reduction was observed in BAW 1177 (15.95%) and other two genotypes showed reduction in grain yield by 30.69% in BARI Gom 28 and by 17.83% in BARI Gom 29. Under non-irrigated water stress condition, again the genotype BAW 1177 produced the maximum grain yield (3.53 t ha^{-1}) and genotype ESWYT 29 produced the minimum grain yield. Water stress hampers the different physiological processes as well as growth and development of plants that results in low dry matter accumulation. Non-irrigated water stress drastically reduced different yield components of wheat which ultimately reduced final grain yield. Findings mentioned by other researcher [24,25,26] also showed that water stress reduced grain yield in wheat compared to control which support the results of the present study.

3.5 Relation of Grain Yield with Heat Use Efficiency

Heat use efficiency and grain yield of wheat genotypes maintained a strongly positive linear relationship (r^2=0.994) between them (Fig. 1). The results revealed that the genotype with higher HUE produced higher grain yield, while the genotype with lower HUE produced lower grain yield. It indicated that the grain yield of wheat genotypes increased with the increment of HUE and decreased with the decreasing of HUE. The higher yield resulted from higher HUE probably due to the genotype with higher HUE accumulated heat more efficiently and increased physiological activities that confirmed higher grain yield.

Table 4. Grain yield of wheat genotypes as influenced by growing conditions

Wheat genotypes	Growing conditions	Grain yield	
		t ha^{-1}	Reduction (%) over well water condition
BARI Gom 28	Well water	3.91ab	30.69
	Water stress	2.71d	
BARI Gom 29	Well water	3.59bc	17.83
	Water stress	2.95d	
BAW 1177	Well water	4.20a	15.95
	Water stress	3.53bc	
ESWYT 29	Well water	3.20cd	35.63
	Water stress	2.06e	
Level of significance		0.05	-
CV (%)		6.17	-

In the column, Means followed by the same letter(s) did not differ significantly at 5% level by Tukey

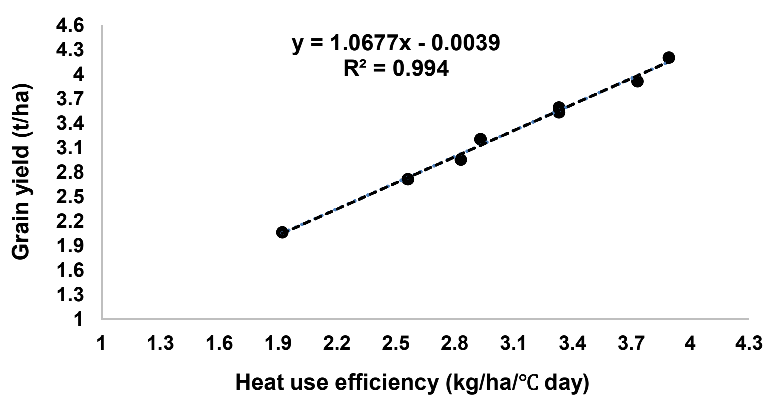

Fig. 1. The relation of grain yield with heat use efficiency of wheat genotypes

4. CONCLUSIONS

From the results of the study it can be concluded that non-irrigated water stress lowered the GDD requirement and PTI in maximum cases. Water deficit stress also reduced the HUE and grain yield and there was a strongly positive linear relationship between heat use efficiency and grain yield in all wheat genotypes. Among the four genotypes, ESWYT 29 required higher GDD, while BAW 1177 was better regarding PTI, HUE and grain yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

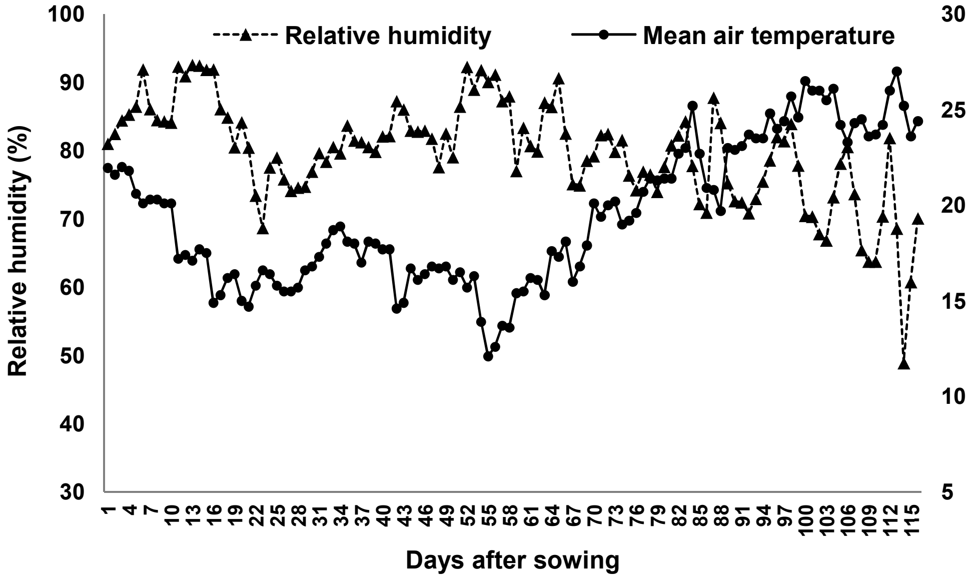

Fig. 2. Relative humidity and mean air temperature during growing periods of wheat genotypes

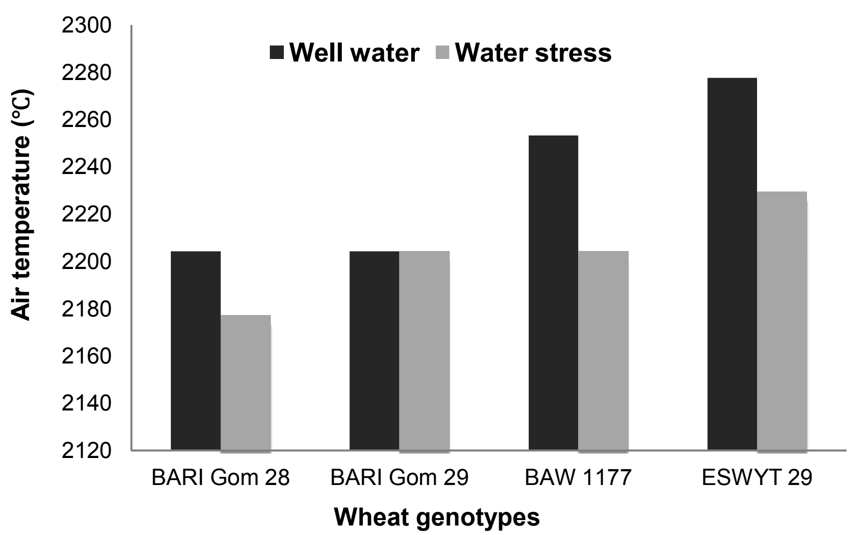

Fig. 3. Total mean air temperature received by different wheat genotypes during sowing to harvest maturity

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