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Field Adaptation of Some Introduced Wheat (*Triticum aestivum* L.) Genotypes in Two Altitudes of Tropical Agro-Ecosystem Environment of Indonesia

ADEEL ABDUL KARIM ALTUHAISH[1], MIFTAHUDIN[2*], TRIKOESOEMANINGTYAS[3], SUDIRMAN YAHYA[3]

[1]Plant Biology Graduate Program, Graduate School, Bogor Agricultural University, Darmaga Campus, Bogor 16680, Indonesia
[2]Department of Biology, Faculty of Mathematics and Natural Science, Bogor Agricultural University, Darmaga Campus, Bogor 16680, Indonesia
[3]Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Darmaga Campus, Bogor 16680, Indonesia

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Heat stress is a major environmental factor limiting wheat productivity in tropical regions such as Indonesia. The objective of this study was to investigate the adaptability of introduced wheat genotypes in tropical agro-ecosystems. Sixteen spring wheat genotypes were grown at two different altitudes i.e. low altitude (176 m asl) with an average temperature of 29.8 °C located at Leuwikopo Field Experimental Station, Bogor Agricultural University, Darmaga Bogor and high altitude (1100 m asl) with an average temperature of 20.6 °C at Cipanas Field Experimental Station (Ornamental Crop Research Station), Cianjur, West Java, Indonesia from July to November 2012. Plant height, number of tillers, flag leaf area, leaf angle, days to flowering, spike number per plant, empty spikelet number, grain weight per plant and 100 grain weight were observed following the standard methods. Heat susceptibility index was calculated based on grain weight per plant. The results showed that cultivation at a low altitude, hotter environment remarkably affected wheat growth and yield, as reflected in overall reduction of plant height, reduced number of tillers and leaf area, and ultimately reduced yield and yield components for most genotypes compared to the same measures taken at high altitude in lower temperatures. Plant growth before heading was similar in both locations, but the days to flowering was longer in high altitude than that in low altitude. High temperature stress in low altitude reduced the spike number/plant, grain weight/plant, 100 grain weight and increase number of empty spikelet/spike. Based on our results for heat susceptibility index, six genotypes, namely Sbr, Ymh, Astreb/Cbrd, Astreb/Ningma, H-20 and Nias, were characterized as heat tolerant genotypes.

Keywords: agro-ecosystem, heat stress, heat susceptibility index, high altitude, low altitude, wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) is indigenous to subtropical environments with an optimal growing temperature about 20 °C. Consumption and demand of wheat flour in Indonesia has increased recently by 6% from 2011 to 2012 and supply mostly depends on the imports (www.bataviase.co.id). This situation has prompted the government to adopt policies to develop and grow tropical wheat adapted to the Indonesian agro-ecosystem. However, growing wheat in Indonesia is difficult, mainly due to high temperature stress (heat stress) which can inhibit growth and reduce yield. The climate at high altitude regions differs greatly from that at low or mid altitude regions at the same latitude. Higher solar radiation and lower air temperature at high altitude regions are favorable environmental conditions for wheat production. Therefore, several wheat cultivars have been cultivated in high altitude region of Indonesian agro-ecosystem with temperature ranges between 15 to 20 °C, which are more favorable for growth and development of wheat. Nonetheless wheat cultivation in such regions must compete with other highly profitable horticultural crops (Handoko 2007). An alternative solution to avoid displacement of other crops at high altitudes is to cultivate wheat in low or mid altitude regions using wheat cultivars adapted to heat stress in tropical agro-ecosystems.

There are few reports comparing wheat growth and production at high vs. low altitudes in tropical area. Fujimura *et al*. (2009) studied the growth of spring wheat at high and low altitude and reported that total dry weight and matter production were significantly higher at the high altitude than that at

*Corresponding author. Phone/Fax: +62-251-8622833,
E-mail: miftahudin@ipb.ac.id

low altitude because of longer growth duration and higher crop growth rate at the high altitude. Heat stress is a major limiting factor for wheat growth and production in tropical and subtropical environments. Such stress can impose morphological, anatomical, and physiological changes that result in considerable yield reduction (Wahid *et al*. 2007). High temperature stress (> 30 ^{o}C) during the grain filling period is one of the major constrains in increasing wheat productivity in the tropics (Rane & Nagarajan 2004). To overcome this problem, time and effort is required to develop varieties that are tolerant to high temperature and to introduce them for cultivation in tropical agro-ecosystems. However, such introduced wheat varieties must be assessed in the field, testing outcomes at low or middle altitude area with those in a high temperature environment to evaluate their adaptability to tropical conditions. This study was conducted to investigate the adaptation of 16 introduced wheat genotypes to conditions in a low altitude tropical agro-ecosystem and to identify the varieties and potential genotypes that are best able to adapt to heat stress environment.

MATERIALS AND METHODS

Field Experiment. Field experiments were conducted under two altitudes representing two different tropical agro-ecosystem i.e. low altitude (176 m asl) with an average temperature of 29.8 ^{o}C located at Leuwikopo Field Experimental Station, Bogor Agricultural University, Darmaga Bogor and high altitude (1100 m asl) with an average temperature of 20.6 ^{o}C at Cipanas field experimental Station, Balai Penelitian Tanaman Hias (Ornamental Crop Research Station), Cianjur, West Java, Indonesia. The field experiments were conducted from July-November 2012. The field experimental design was a randomized complete block design with three replications using 16 wheat (*Triticum aestivum* L.) genotypes as shown in Table 1. Each plot size was 1.5 x 5 m with row to row spacing of 25 cm for a total of 48 experimental units in each locations. Standard recommended practices were followed throughout the growing season, for both fertilizer application as well as the general cultivation practices for wheat production.

Microclimate Data Collection. Microclimate data such as temperature, relative humidity and light intensity were recorded three times per day using a portable Lutron LM-8000 at both locations. Precipitation data was obtained from the Geophysic and Meteorological Agency in Darmaga Station, Bogor and Pacet Station, Cipanas, Indonesia.

Morpho-Physiological Traits of the Introduced Wheat. Observed traits, including plant height and number of tiller/plant, were collected randomly from 10 samples per plot for each genotypes. Flag leaf area was measured at the anthesis stage from 10 randomly picked samples per plant. Leaf length (LL) and maximum leaf width (LW) were measured and used to calculate leaf area (LA) using the following formula (Pourreza *et al*. 2009):

$$LA = 0.75 \times LL \times LW$$

Flag Leaf Angle. The angle between the flag leaf and the steam was measured using aprotactor at anthesis stage on the main tiller following the methods of Simon (1998).

Yield Component. At harvesting time, 10 plants per plot were randomly chosen from each altitude location to measure spike number per plant, number of empty spikelet's per spike, grain weight per plant and 100 grain weight. Days to flowering were calculated starting from the date of sowing until the date on which approximately 50% of the tillers produced spikes.

Table 1. The wheat genotypes and origin of wheat used in the experiment

Genotypes	Abbreviation	Origin
Munal	Munal	CIMMYT
Sbr*D/I/09/38	Sbr	CIMMYT
Sbd*D/I/09/142	Sbd	CIMMYT
Cndo/R143//Ente/Mex12/3AEGilopsSquarrosa(Taus)/4/	Cndo	CIMMYT
Waxwing*2 //Pbw343*2 /Kukuna	Waxwing	CIMMYT
Ymh/Tob//Mcd/3/Lira/4/Finsi/5/Babax/Ks93u76//Babax	Ymh	CIMMYT
Astreb*2/Cbrd	Astreb/Cbrd	CIMMYT
Astreb*2 /Ningma/9558,	Astreb/Ningma	CIMMYT
H-20	H-20	CIMMYT
S-03	S-03	Slovakia
S-08	S-08	Slovakia
S-09	S-09	Slovakia
Jarisa	Jarisa	Slovakia
Selayar	Selayar	Indonesia
Nias	Nias	Indonesia
Dewata	Dewata	Indonesia

Heat Susceptibility Index (HSI). The HSI was calculated based on grain weight per plant for each cultivar using the following formula (Fischer & Maurer 1978):

$$HSI = [1-(GYS/GYn)]/1-D$$

Where GYs is the grain weight mean of the cultivar under heat stress (low altitude) conditions and GYn is the grain weight mean of the cultivar under non-stress (high altitude) conditions. D is the ratio of the overall grain weight mean of all cultivars under heat stress to the overall grain weight mean of all cultivars in the non stress condition.

Statistical Analysis. A combined analysis variance was performed using MSTATC microcomputer program (MSTATC 1990). The means of the results of both treatments were compared using the Least Significant Difference (LSD) at 5% probability.

RESULTS

Environmental Conditions During the Crop Growth Period. Table 2 shows meteorological data, including average monthly temperature, relative humidity, rainfall, and light intensity during the crop growth period (August- October 2012) in two locations. It was observed that the mean temperature during the cropping season was lower in high altitude (20.6 ^{o}C) than that in low altitude (29.8 ^{o}C). However, the average monthly rainfall during the cropping season was about 1.5 times higher in low altitude (18.0 mm,) than that in high altitude (11.7 mm). The data showed that there was a decline of light intensity in low altitude from sowing to harvest while at high altitude it was increased from August to September then slightly declined from September to October particularly at the anthesis stage. Generally the mean of light intensity was higher in high altitude than low altitude.

Morpho-Physiological Traits of the Introduced Wheat. Wheat cultivated in our tropical agro-ecosystem environments showed significant difference on most growth traits among genotypes in the two different field locations (Table 3). For all genotypes, measures of plant height and number of tiller per plant were found to be significantly less at low altitude compared to that of high altitude.

Table 2. Monthly meteorological data during the cropping season (August to October 2012) at both locations

Months	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)		Light intensity (lux)	
	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude
August	29.8	20.5	74.0	74.9	11.3	7.2	10329.2	6410.8
September	29.7	20.1	76.0	75.4	19.3	12.1	8664.2	12735.4
October	29.9	21.2	81.0	79.7	23.5	15.8	7643.9	12616.1
Mean	29.8	20.6	77.0	76.6	18.0	11.7	8879.1	10587.5

Table 3. Mean of plant height, number of tiller per plant, flag leaf area, and flag leaf angle of introduced wheat in two different tropical agro-ecosystem environments

Genotypes	Plant height (cm)		Number of tillers/plant		Flag leaf area (cm^2)		Flag leaf angle (^{o})	
	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude
Munal	35.86 h	78.87cd	4.56h	17.6a	10.27j-l	22.64cf	16.54hi	39.54ab
Sbr	36.67h	72.87e	4.03h	12.67d-f	13.17i-l	24.52b-e	20.75e-i	33.17b-d
Sbd	36.92h	81.73bc	4.16h	15.5a-c	14.55h-l	30.93ab	21.90e-i	30.57b-e
Cndo	35.4h	62.93f	4.16h	12.43d-g	9.61kl	18.79e-i	22.67d-i	26.22c-h
Waxwing	34.9h	75.7de	4.36h	16.2ab	9.13l	21.34c-h	18.34hi	40.57ab
Ymh	36.77h	74.63de	4.4h	12.5d-f	9.07l	24.66b-e	16.84hi	39.53ab
Astreb/Cbrd	35.75h	61.53fg	4.33h	10.5fg	18.18ei	22.64c-f	17.60hi	29.94b-g
Astreb/Ningma	34.29h	56.43g	4.56h	9.833g	14.50h-l	19.57e-i	14.79i	30.42b-f
H-20	36.7h	82bc	4.36h	12.93c-f	27.76a-c	26.88a-d	21.37e-i	33.99bc
S-03	35.39h	85.4ab	4.03h	16.9ab	16.33f-k	22.62c-f	21.77e-i	30.83b-e
S-08	35.38h	74.73de	4.5h	14.53b-d	17.09f-j	20.75d-h	19.58g-i	30.19b-g
S-09	34.07h	77.1c-e	3.53h	13.13c-e	14.77g-l	21.64c-g	19.87f-i	39.22ab
Jarisa	34.38h	84.07ab	4.26h	18.07a	17.03f-j	27.18a-d	21.09e-i	25.66c-h
Selayar	34.11h	63.93f	3.967h	11.77e-g	12.95i-l	18.09e-i	15.96hi	25.10c-i
Nias	38.73h	60.3fg	4.3h	10.83e-g	18.8e-i	22.2c-f	22.78d-i	23.02d-i
Dewata	39.18h	87.37a	4.33h	16.1ab	21.2c-h	33.01a	23.00d-i	46.16a
Mean	35.91	73.72	4.24	13.84	15.28	23.59	19.67	32.75

Mean values sharing the same letter in the same column or row did not differ significantly with LSD test at $\alpha = 0.05$.

Plant height and number of tiller per plant were significantly different between the two altitude environments while significantly different only among genotypes at high altitude. For leaf area, results showed a significant difference in leaf area among different genotypes regardless of locations however, leaf areas were smaller overall at low altitude except for H-20 that had higher flag leaf area compared to the same genotype at high altitude. Even though there was reduced flag leaf area for the Nias genotype cultivars in low altitude compared to those in high altitude but there was no significant difference suggesting that this genotype had more stability under diverse environments. However, the leaf angle was not significantly different among genotypes at each locations (Table 3) except for Jarisa and Selayar genotypes in high altitude which showed a significant difference. In general, flag leaf angle was lower for plants grown at low altitude compared to those at high altitude.

Yield and Yield Component. Yield is the end result of many complex morphological and physiological processes that occurr during crop growth and development. A combined analysis of variance for our results revealed that yield and yield components severely decreased due to heat stress at low altitude (Table 4). Most of the tested genotypes produced lower spike number/plant at low altitude compared to the genotypes grown at high altitude. Meanwhile, wheat which was grown at high altitude showed variation in spike number/plant among genotypes. The highest spike number was recorded for Astreb/Cbrd in both locations. However, in the observations of empty spikelet/spike, there were significant differences among genotypes at both locations. High average daily temperature at low altitude caused significantly higher counts of empty spikelet number/spike compared to the same genotypes grown in a high altitude environment (Table 4). There were no significant differences in empty spikelet number/spike among genotypes grown at high altitude except for Jarisa which had a higher number of empty spikelet number/spike.

The combined analysis of variance revealed that grain weight/plant was very significantly affected by environment and by genotype for grain weight/plant (Table 4). The low altitude environment that represents heat stress resulted in substantial reduction in grain weight/plant due to reduction in spike number/plant and increased number of empty spikelet/spike (Table 4). The 100 grain weight was reduced significantly by high temperature increase at low altitude environment for all genotypes compared to those grown in the cooler high altitude environment indicating that such traits are highly affected by the interaction of each genotypes and their environment. However, the average of 100 grain weight was ranged between 1.51 to 2.61 g and 2.96 to 3.89 g at low and high altitude, respectively. The national variety Selayar had significantly higher 100 grain weight among all genotypes at low altitude but not higher than that same genotypes grown on high altitude condition.

Table 4. Mean of spike number/plant, empty spikelet/spike, grain weight/plant, 100 grain weight and days to flowering of introduced wheat in two different tropical agro-ecosystem environments

Genotypes	Spike number/plant		Empty spikelet number/spike		Grain weight/plant(g)		100 grain weight (g)		Days to flowering	
	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude	Low altitude	High altitude
Munal	4k	14a-c	6b-f	0.57l	1.04h	13.86ab	1.72i-k	3.89a	70c-e	74c-f
Sbr	5i-k	12cd	4e-i	1j-l	1.51h	11.92a-c	1.88i-k	3.17c-e	67e-i	71jk
Sbd	5i-k	11cd	5d-g	1j-l	1.63h	12.41bc	2.09hi	3.49bc	67f-j	72f-i
Cndo	6h-k	15ab	6b-e	1h-l	1.66h	12.73bc	1.77hi	3.81ab	66h-k	73
Waxwing	4k	13bc	7a-d	0.77kl	-	-	-	-	72c	75
Ymh	5i-k	8f-h	3f-k	1j-l	1.31h	8.48d-f	1.51k	3.40c	69d-g	76c
Astreb/Cbrd	6h-k	16a	3e-j	1i-l	2.68gh	13.54ab	1.99h-j	3.35cd	64j-l	70c-f
Astreb/Ningma	7f-i	12cd	5d-g	2g-l	2.15gh	6.85ef	1.61jk	2.97d-f	65h-l	69j-k
H-20	5i-k	7f-j	4d-g	1i-l	1.76h	7.04ef	1.70jk	3.82ab	70c-f	72fg
S-03	4j-k	11de	5.80c-f	0.93kl	1.07h	11.50b-d	2.28gh	3.49bc	64kl	67j-k
S-08	6g-k	11cd	6b-e	1h-l	1.15h	9.97c-e	2.57g	3.23c-e	65i-l	69hi
S-09	4jk	9ef	4e-h	0.87kl	1.10h	7.90ef	2.27gh	2.96ef	65h-l	69f-i
Jarisa	1l	12cd	8ab	6b-f	-	-	-	-	97a	81a
Selayar	4jk	11de	7a-c	1i-l	0.73h	9.80c-e	2.61fg	3.85ab	67f-j	69f-j
Nias	4k	9e-g	2g-l	1h-l	1.70h	5.26f	2.31gh	3.35cd	50p	66kl
Dewata	4k	16a	9a	0.87kl	0.91h	16.18a	1.79i-k	3.27c-e	67e-i	71eg
Mean	5	12	5	1	1.46	10.53	2.01	3.43	66	71

Mean values sharing the same letter in the same column or row did not differ significantly with LSD test at $\alpha = 0.05$.

Observed days to flowering results were significantly different between genotypes, at both locations (Table 4). It was also observed that all genotypes at the low altitude condition had shorter days to flowering compared to those in high altitude. The exeption to this was the Jarisa variety, which had longest measured days to flowering of all the tested genotypes, but whose days to flowering did not significantly differ in low vs. high altitude. This suggests a different response for this trait for the Jarisa variety. Days to flowering for all genotypes ranged from 50-97 and 66-81 days at low and high altitude, respectively. However, the shortest days to flowering was recorded for Nias at low altitude (50 days) among all genotypes compared to high altitude (66 days) as in Table 4. Early flowering seen in Nias at low altitude, probably exposed the plant to high temperature overall location and genotypes, and it could be due to effect of high temperature.

Heat Susceptibility Index. The heat susceptibility index has been commonly used in studies of various types of plants to measure the level of heat tolerance of a particular genotype. Based on grain weight/plant, heat susceptibility index values ranged from 0.78 to 1.14 among genotypes (Table 5). The genotypes Sbr, Ymh, Astreb/Cbrd, Astreb/Ningma, H-20, and Nias were relatively heat-tolerant (lowest heat susceptibility index), while Munal, Sbd, Cndo Waxwing, S03, S08, S03, Jarisa, Selayar, and Dewata were relatively heat-susceptible (higher heat susceptibility index) and thus can be identified as heat-sensitive.

Table 5. Grain weight mean, and heat susceptibility index for introduced wheat at low and high altitude

Genotypes	Grain weight(g)/plant		Heat susceptibility index (HSI)
	Low altitude	High altitude	
Munal	1.04	13.86	1.06
Sbr	1.51	12.15	0.99
Sbd	1.63	12.41	1.00
Cndo	1.66	12.73	1.00
Waxwing	0.69	13.78	1.09
Ymh	1.31	8.48	0.97
Astreb/Cbrd	2.68	13.54	0.92
Astreb/Ningma	2.15	6.85	0.79
H-20	1.76	7.04	0.86
S-03	1.07	11.50	1.04
S-08	1.15	9.96	1.01
S-09	1.03	7.90	1.00
Jarisa	0.01	3.02	1.14
Selayar	0.73	9.80	1.06
Nias	1.70	5.26	0.78
Dewata	0.87	16.18	1.08
Mean	1.31	10.28	0.99

DISCUSSION

Morpho-Physiological Traits of the Introduced Wheat. Different environmental conditions characterized the two locations where wheat varieties were cultivated in this study. Wheat genotypes grown under different environmental conditions produced diverse morphological and physiological responses which were reflected in the measure of yield and its component measures. In particular, temperature differed in each environment. The low altitude location represented a hot environment (29.8 ^{o}C mean temperature) which negatively affected wheat crops, as indicated by reduction in most morphological and agronomical measures for the tested wheat genotypes, compared to that of high altitude. We believe the difference in measured plant characteristics is due to differences in temperature at two altitude conditions. Low altitude associated with high temperature, caused an inhibition of plant growth indicated by reduction in plant height and tillers number/plant compared to high altitude. High temperatures can cause considerable pre- and post-harvest damages, including scorching of leaves and twigs, sunburn on leaves, branches and stems, leaf senescence and abscission, shoot and root growth inhibition and reduced yield (Wahid *et al*. 2007). Observed differences in plant height and tiller number in the introduced wheat genotypes studied in our research, may be due to high temperature stress (Al-Otayk 2010). Prior research has also reported reduced plant height under high temperature stress (Riazuddin *et al*. 2010). In order to improve grain yield/plant in the low-lying tropics, there is a need to develop high yielding wheat varieties which can produce higher plant height in low altitude under high temperatures. In this study, we observed that the number of tillers/plant was negatively affected by increased temperature, which indicated that survival of tillers in low altitude was adversely affected by higher temperature. In general, plants of all wheat genotypes grew faster with fewer numbers of tillers/plant under high temperature, whereas the same genotypes grew slowly with comparatively large numbers of tillers/plant at low temperature. Several reports suggests that the production and survival of tillers of wheat plants depends on genotype, spacing, agronomic and nutritional management practices, and also on environmental factors especially air temperatures (Longnecker *et al*. 1993). The reduction of tiller numbers/plant at low altitude is probably due to inhibition of the initiation and survival of tillers in wheat, during stand establishment, due to high temperature stress (Fischer 1985). This results in poor stand establishment and reduces the number of productive tillers and ultimately the final yield (Sattar *et al*. 2010).

Larger flag leaf area at later stages might contribute to higher rates of photosynthesis ultimately resulting in higher grain yields. In this research the flag leaf area varied among genotypes at both altitudes, and showed more reduction when grown in high temperature at low altitude. Genotypic difference in green leaf area duration in response to heat stress was also reported by Fischer *et al*. (1998). In that study, reduction in flag leaf area was caused by inhibition of cell division and by cell expansion under high temperature stress. High temperature-induced leaf senescence largely depends on membrane thermo-stability which varies with varietal tolerance. In heat tolerant cultivars, leaf senescence was reported to occur after significant grain growth, while in sensitive cultivars, leaf senescence occurred before substantial grain growth (Rahman *et al*. 2005). In our current study, leaf angle varied among genotypes, indicating that both genetic background and environment play a role in determining the slope of flag leaf during the growth period of plant. Flag leaf angle may be reduced to make the plant more erect, in order to reduce mutual shading and enable greater exposure to light through abaxial and adaxial surfaces (Dutta *et al*. 2002). This has an important effect for increasing wheat grain yield.

Yield and Yield Component. Yield and yield traits continue to be important in measuring the success of a genotype in heat-stressed environments. A genotype with stable and high yield across environments would be more suitable as a cultivar and also as a donor parent for further breeding in environments with high temperature. In this study, significant variation in yield and yield components among wheat genotypes occurred at both low altitude (heat stress) and high altitude (normal temperature) conditions, indicating that a wide range of pre-existing genetic variation exists. However at low altitude conditions, the number of spike/plant, grain weight/plant and 100 grain weight were reduced in low altitude compared to high altitude for most genotypes. By contrast the number of empty spikelets/spike was higher at low altitude. These results indicate that wheat growth in low altitude adversely affected by high temperature in contrast to wheat grown in a cooler, high altitude. High temperature stress disturbs the translocation of assimilates from the source to sink. Under low to moderate heat stress, a reduction in source and sink activities may occur leading to severe reductions in growth economic yield (Wahid *et al* . 2007). The results showed a reduction in spike numbers/plant at low altitude, caused by high temperature that results in poor stand establishment, reduced plant height and lower number of productive tillers, ultimately reducing the final yield (Sattar *et al*. 2010). However, the empty spikelet count was higher at low altitude compared to high altitude. The period of growth most sensitive to high temperature is the anthesis stage. This sensitivity occurs because spikelets begin to form in the spike from ridges, and a reduction in duration of emergence to double ridges caused a reduction on spikelet number (McMaster 1997). The number of empty spikelets/spike varied by genotype in our study, but in general were reduced at low altitude. This could be attributed to the harmful effects of high temperature on the grain filling process, causing plants to reach maturity before completion of grain filling (Menshawy 2007). Hamam *et al*. (2009) found significant variation in yield and yield components among wheat genotypes under normal and heat stress conditions. Individual grain weight, considered as one of the major contributors to yield, was also significantly influenced by temperature, with enhanced plant maturation causing reduction in grain growth duration (Rahman *et al*. 2005) and in production of smaller grains. Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of a crop. In this study the grain weight per plant showed reduction in all genotypes at low altitude compared with same genotypes in high altitude (Table 4). It is important to mention that there was significant difference between genotypes in both locations; an exception for Waxwing and Jarisa genotypes which did not produce any yield at the low altitude location because they are most sensitive to heat. This was particularly evident after anthesis as indicated by a high number of empty spikelets and fewer numbers of spikes/plant. Grain weight/plant and 100 grain weight/plant were reduced in genotypes grown at low altitude, which may have been affected by high temperatures during grain filling and associated with the number of spikes per plant. Starch accounts for 70% of wheat grain dry weight, and high temperature impedes starch deposition, one of the main causes of reductions in grain weight (Bhullar & Jenner 1986). However, high temperatures (up to 30/25 ^{o}C) after anthesis reduce yield largely through an effect on weight per grain, rather than on grain number (Wardlaw *et al*. 1989) and the effect appears to be directly on the grain itself. Our results thus are in agreement with Fujimura (2009) who stated that grain weight was significantly higher under normal temperature than in a higher temperature environment. Thus, similarly to his study of spring wheat, the majority of the reduction in grain yield in our study can be attributed to sink limitation given the similarities of the declines in grain number (Ferris *et al*. 1998). The weight of grains/plant are potentially determined by pollination time. However, high temperatures disturb the translocation from source to the sink and decreased pollen viability.

Days to flowering for genotypes showed wide variation as in Table 4. The genotypes at low altitude flowered early compared to those at high altitude. However, early flowering at low altitude could be one mechanism to escape from rising temperatures, in an attempt to complete its life cycle earlier in the season when air temperatures were lower and generally more favourable. This resulted in high yields from early flowering plants at low altitudes. It has been reported that for wheat plants, the duration from heading to maturity was also shortened by a high temperature (Fujimura 2009). On the other hand, Tewolde (2006) observed that wheat cultivars with early heading produced fewer total leaves per tiller, but retained more green leaves and lost fewer leaves to senescence at anthesis, than later-heading cultivars. During our study period, at low altitude, the plant had two types of stresses: high temperatures and high rainfall, particularly at anthesis period. Flowering behavior is closely related to the physiological condition of the plant and influenced by environmental factors specifically light intensity, photo period, temperature and water availability on the growth of plants (Glover 2007). Our results suggest that early days to flowering is an important and defining trait to effectively identify which wheat genotypes we tested are prone to high temperature stress during the post-heading period. The results indicated that the anthesis and maturity stages of Jarisa were periods of greatest sensitivity to high temperature, compared with the Nias variety, which was relatively tolerant to higher temperature stress. This result aligns with Araus *et al*. (2007) who stated that effect of environmental factors on the number of days required for the occurrence of different growth stages of wheat, varied by genotype. It was also reported that the low temperature and short photoperiod at high altitude might delay heading and maturity.

Heat Susceptibility Index (HSI). Yield and yield component have been widely used indicators of wheat tolerance to heat stress in the final phase of growth. In this study, observed variation in measures of heat susceptibility index among introduced wheat genotypes indicated different responses to environmental factors. The HSI has sometimes been represented as providing a measure of genotypic yield potential under heat stress (Al-Otayk 2010). Yang *et al*. (2002) showed a variation in the value of HSI between wheat, based on grain weight character of wheat. They reported that different genotypes exhibited different levels of tolerance, and no genotype was very tolerant. The results of our study are also in harmony with Al-Otayk (2010) who reported that there was a variety in HSI among genotypes as measured by grain yield. Therefore, stress tolerance of a genotype as defined by HSI, does not necessarily correlate with high yield potential. The difference of response of each genotypes to high temperature will be expected due to the difference between environmental origin of of the introduced genotypes (sub tropical environment) and the national varieties (tropical conditions).

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