academicJournals

Vol. 8(43), pp. 5315-5323, 7 November, 2013
DOI: 10.5897/AJAR11.1869
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Genotypic variation in yield in wheat to cold sensitive response at high altitude

B. B. BANDYOPADHYAY

G. B. Pant University of Agriculture and Technology, Hill Campus, Ranichauri, Tehri Garhwal Uttarakhand 249199, India.

Accepted 15 October, 2013

Low temperature becomes an important limitation for production of grains in wheat cultivars as altitude increases. An alteration of growth habit accompanied with changes in morphology of leaf, shoot and root characteristic and cool temperature induced sterility in florets seemed to be associated with yield loss. The extent of variability of these characters, their relationship and contribution to grain yield were examined among 9 wheat cultivars (viz., HPW 155, HPW 236, HPW 277, HS 473, SKW 323, Sonalika, VL 829, VL 832 and Local cultivar) at an elevation of 2100 m above mean sea level (msl) under field condition. The results revealed an increase in average growing degree x days for head emergence and number of days experiencing lower soil temperature than air temperature during anthesis both induced sterility in florets. An increase in thermal time at post anthesis grain filling period encouraged the production of grains. Grain yield did not show significant correlation with leaf, shoot and root characters. Susceptible cultivars, however, exhibited a greater percentage of sterile florets in population, low grain yield, high root to shoot ratio, less thickness of fresh leaves and less dry matter deposition. The varieties VL 829, HPW 236 and HS 473 showed superior in yield and higher tolerance to cool conditions at high altitude.

Key words: Wheat cultivars, high altitude, cold stress, floret sterility, grain yield.

INTRODUCTION

Extent of maturity period of standing wheat crop and its yield potential are the two major criteria for acceptance of cultivars fitted into a target environment or commonly followed crop rotation in higher elevation areas. In India mostly spring wheat cultivars are grown except in some cooler parts in the Himalayas (Kumar and Mishra, 2006) where cultivation of winter wheat is generally practiced. Less ability to sustain cold stress condition at different phases of growth (Salfer and Rawson, 1994) produces appreciable variation in grain yield (Huner et al., 1981; Korner and Larcher, 1988; Boese and Huner, 1990) among spring wheat cultivars. Effect of timing and severity of cold increases the risk of reduced seed set among wheat genotypes. Sudden exposure to low temperature greatly increases the chances of injury. At high altitude and exposure to sub-optimal low temperature conditions many cultivars alter their growth habit to a rosette pattern with short leaf and minimal stem elongation, while new growth resume in the early spring and heading comes when the stress condition has been alleviated. It is assumed that alteration in the morphology of leaf, shoot and root characteristics (Equiza et al., 1997, 2001) and cool temperature induced sterility in florets (Subedi et al., 1998) are possibly correlated with reduced yield potential among these spring wheat cultivars in tropical mountain areas. Introgression of genes from winter wheat into spring wheat cultivars has enabled to enhance 8% of yield (Nanda and Sohu, 1998). In the

E-mail: bbbandyopadhyay@rediffmail.com.

absence of physiological marker due emphasis has not been paid in conventional breeding method to develop early maturing cold tolerant breeding lines for wheat cultivars suitable for this region. Genetic adaptation to colder temperatures is associated with high-altitude chilling resistance (Taiz and Zeiger, 1998). In the present investigation cold sensitivity response of wheat genotypes was examined for their relative degree of association amongst different physiological components characters, their contribution to grain yield and development of fertile and sterile spikes on the main shoot under field conditions at an exposure to cool temperature at high altitude.

MATERIALS AND METHODS

Wheat plant follows a hierarchal pattern of growth indicating that development of organ differentiation and growth depends not only on current environmental condition but on the size and growth of previously formed organs (Austin, 1993). Alternatively it can be stated that growth and development of wheat cultivars determine by the influence of both current and previous environmental conditions at growing site. Persistence of cool climatic condition for a prolong period of time at nearby areas of higher altitude and/or high fall of rain induces cold stress on wheat plant and reduces genetic differences among cultivars. The cold sensitive response of wheat cultivars was examined among 8 improved genotypes (HPW 155, HPW 236, HS 473, SKW 323, Sonalika, VL 832, HPW 277, and VL 829) and one locally collected (land race) genotype, recommended for cultivation on high altitude under early sown condition. The experiment was conducted on high hill (2100 msl) at Ranichauri (78°24$^{/}$N and 30°18$^{/}$E) in the Himalayan mountain. The seeds of the 8 improved genotypes were supplied by All India Coordinated Wheat and Barley Improvement Project (ICAR). The seeds of 6 wheat cultivars and three remaining other genotypes were sown in 3 replications on 7-10-2003 and 7-10-2006 respectively assuming that the planting of seeds using same date and same management of field conditions would exhibit a uniform trend in grain production at high altitude at the test location in different testing years for wheat genotypes. Standard agronomic practices were followed along with recommended dose of fertilizer, insecticides and pesticides were applied to maintain normal growth and development of the crop. Twenty five healthy seedlings were randomly selected from each population of the wheat cultivar for recording the observations for leaf, shoot and root characters. Seedlings were harvested at the third expanded leaf stage. Shoot length (SL, cm.), root length (RL, cm.), ratio between root and shoot length [(R:S)L], shoot fresh weight (SFW, g), root fresh weight (RFW, g), ratio between fresh weight of root and shoot [(R:S)W] of individual seedling were measured. The area of the fully expanded third leaf (LA, cm.^{2}) was measured (by an electrically operated leaf area meter) on individual seedling and their fresh weights (LFW) were recorded. Dry-weight (LDW, g) of the third leaf was determined after completely drying over-night at 70°C of each leaf sample. Specific leaf areas per unit mass of fresh (LA/LFW, cm^2 g$^-$) and dry weight (LA/LDW, cm^2 g^{-1}) of third leaf were estimated separately. It was presumed that the lower the values of LA/LFW and LA/LDW the greater would be the thickness of the fresh leaf with more deposition of transient dry matter in the leaf (Lu and Neumann, 1999).

The number of spikes with normal fertile florets and normal growth of seed (FS), partially sterile florets with impaired seed growth (PS) and chilling induced sterile florets (SS) were determined by the presence and absence of seeds in each population and were expressed as a percentage of total number of florets present on a spike. The physiological limitation of grain development after anthesis was determined by development of impaired seed growth on spikes. Numbers of florets developing on individual fertile, partially sterile and cold-induce sterile spikes (F_{FS}, F_{PS}, F_{SS} respectively) on the main shoot of wheat cultivars were counted separately. Observation was taken on seed number (S_{FS}, S_{PS}), 100 seed weight (SW_{FS}, SW_{PS}) and grain yield (GY_{FS}, GY_{PS}) from fertile and partially sterile spikes respective to each cultivar. Effect of timing and severity of cold at different stages of crop growth were studied on four phenological phases which included (i) the time interval between date of sowing and days of heading, (ii) date of head emergence and days to anthesis, (iii) post head emergence period of 45 days after date of head emergence and (iv) post anthesis grain filling period of 25 days past the date of anthesis. Cumulative values of growing degree days (GDD; also called as thermal times) was estimated by subtracting the base temperature form daily average air temperature at respective phenological stages of crop growth. The base temperature from seedling to heading, heading to anthesis and anthesis to maturity were considered 3, 5 (Angus et al., 1981) and 8°C (Slafer and Rawson, 1995) respectively.

Observations related to phenological parameters were recorded on days to heading (DH), thermal time for days to head emergence (TDH), average GDD during heading (ATDH), number of days experiencing low soil temperature than air temperature during heading (STDH), days to anthesis (DA), thermal time for anthesis (TDA), average GDD during anthesis (ATDA), number of days experiencing lower soil temperature than air temperature during anthesis (STDA), thermal time for grain filling (TGF), average GDD during grain filling (ATGF), number of days experiencing lower soil temperature than air temperature during grain filling (STGF), thermal time for post head emergence period of 45 days after date of head emergence (T45), average GDD for post head emergence period (AT45) and number of days experiencing lower soil temperature than air temperature during post head emergence period (ST45). The number of days experiencing low soil temperature (at 10 cm. depth) was counted by comparing the air temperature recorded on that day at respective phenophases of crop growth. Field data were pooled together and were subjected to compute the analysis of variance (Burton and Devane, 1953) on 36 characters by assuming that wheat cultivars would experience a uniform eco-physiological response for growth in both years and their inter-character association was estimated through correlation analysis (Al–Jibouri et al., 1959). Significant association between two characters was determined by *t* – test. The association of those characters that exhibited significant correlation for grain yield (GY_{FS}), fertile (FS) and sterile (SS) spikes of main shoot were subjected to path analysis (Dewey and Lu, 1959). Relative changes in contribution of direct and indirect effect of individual characters to SS, FS and GY_{FS} were estimated through separate analysis.

RESULTS AND DISCUSSION

The state of acclimation is of physiological and ecological significance for the successful establishment of crops. An understanding of climatic factors controlling flowering and seed production is, therefore, needed to delineate the environment suitable for expansion of sowing areas of spring wheat cultivars on high altitude and for persistence of seed production in farm practice. A comparison of meteorological data (Table 1) between the two test years revealed that minimum temperature did not rise above 3.5°C during the 46th to 6th (in 2003 to 2004) and 52th to

Table 1. Temperature (°C) and rain fall (mm) experienced during 2003 to 2004 and 2006 to 2007 at experimental site.

Year	Temperature (°C) and rainfall (mm)	Meteoroligical week												
		40	41	42	43	44	45	46	47	48	49	50	51	52
2003-2004	Maximum temp.	23.0	22.0	22.3	20.0	20.5	19.5	14.3	16.7	15.7	15.3	13.0	11.7	10.2
	Minimum temp.	9.4	8.3	8.1	7.0	7.1	5.3	3.5	2.7	1.8	2.4	2.1	0.0	-0.6
	Rainfall	0.0	0.0	0.0	0.0	0.0	0.0	14.8	2.6	0.0	0.0	48.4	3.3	8.6
2006-2007	Maximum temp.	23.7	22.4	20.7	18.0	20.0	19.6	17.7	16.2	14.9	13.7	13.7	15.5	14.4
	Minimum temp.	12.6	12.4	9.1	7.9	8.1	8.1	7.0	4.6	2.5	4.6	2.5	3.8	2.6
	Rainfall	0.0	1.6	40.0	0.9	0.0	0.0	0.0	3.4	0.0	25.6	29.4	0.0	0.0

Year	Temperature (°C) and rainfall (mm)	Meteoroligical week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2003-2004	Maximum temp.	12.0	13.3	12.5	8.3	9.1	12.2	15.4	17.4	19.4	20.2	21.8	25.1	22.7	24.7	26.2
	Minimum temp.	-0.1	1.0	1.2	-0.9	1.3	2.9	5.3	5.9	7.9	8.3	11.4	13.3	9.9	11.9	13.4
	Rainfall	0.0	0.0	5.2	86.3	30.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
2006-2007	Maximum temp.	13.1	11.9	11.9	17.0	16.2	11.7	7.0	14.8	11.6	15.5	13.0	19.9	21.7	23.6	23.3
	Minimum temp.	0.4	0.1	0.6	4.3	4.7	2.8	-0.6	3.3	2.6	4.5	3.0	7.3	10.8	10.5	12.4
	Rainfall	0.0	0.0	0.0	0.0	0.7	86.0	58.7	2.4	68.0	3.4	80.9	10.2	0.0	0.0	0.0

11th (in 2006 to 2007) meteorological week (Figure 1). The post-winter period of growth in spring wheat cultivars suffered from cold stress under early planting of seeds in 2006 to 2007 mostly due to continuous fall of winter-rain, which had extended till the end of March. Otherwise the climatic condition after emergence of seedlings from field remained uniform in both years. The time of head emergence, which is a measure of genetic variation and of synchrony within each genotype in a specific environment, varied between two years at this elevation (Table 2). Most of the cultivars evaluated during 2003 to 2004 showed an early termination of vegetative growth. Head emergence of Local cultivars during 2006 to 2007 also fell within the range of the time period observed on 2003 to 2004 amongst the early-maturing genotypes under available moisture level in the soil and same management conditions of field. It was presumed that trivial differences in flowering ability caused by variation in cold sensitive response among genotypes and possibly synergistic interaction on genotype and environment between two years. The results of this investigation suggested that the qualitative differences in growth habit among spring wheat genotypes not only depend on physiological stimulus and its evocation at the apex of flowering but on genes governed earliness and vernalization requirement of plant (Akerman and MacKey, 1949; Stelamakh, 1990). About 70 to 75% differences in total length of wheat life cycle seem to be controlled by these genes (Stelamakh, 1981). The reducing effect of vernalization requirement in spring wheat cultivars had exposed the plants to grow at most sensitive stage of its growth in cooler climatic condition on high hill during winter in both years.

Mean performances of wheat genotypes (Table 2) showed that both Sonalika and local cultivars, on respective years, experienced relatively high average thermal time for head emergence (ATDH) with less average GDD at post flowering period (ATGF and AT45) and maximum number of days for low soil temperature than air temperature at anthesis (STDA) and at post head emergence period of 45 days (ST45) while minimum number of days for low soil temperature was recorded at days to heading (STDH) and grain filling (STGF) period. The comparison between Sonalika and Local cultivars revealed that the later was the most susceptible wheat genotype to cool temperature as indicated by the presence of maximum number of sterile (SS) and partially sterile spikes (PS) in population, less number of fertile florets (F_{FS}) on spike and low grain yield (GY_{FS} and GY_{PS}). It was, therefore, apparent that the higher the number of days forlow soil temperature than air temperature during anthesis (STDA) and at post head emergence period of 45 days (ST45) the higher would be the development of cool temperature induced sterile spikes in population, which in turn reduced the physiological efficiency of grain production among spring wheat cultivars at high hills.

Analysis of variance (Table 3) appeared significant for all characters except F_{PS} and SW_{PS}. This suggested that considerable variation was observed among these characters in spring wheat genotypes when exposed to sub-optimal low temperature on high hills. The correlation

Table 2. Mean performance of 9 wheat genotypes for 36 characters evaluated on 2003- 2004 and 2006-2007.

Characters*	Wheat genotypes								
	2006-2007		2003-2004						
	Local	HSPW277	VL 829	SKW 323	HPW 236	HS 473	HPW 155	VL 832	Sonalika
DH	104.66	126.33	140.66	108.00	112.33	108.00	108.00	103.66	91.00
TDH	791.31	911.61	961.63	709.30	721.83	709.30	709.30	695.76	646.70
ATDH	7.86	7.22	6.83	6.56	6.34	6.56	6.56	6.70	7.10
STDH	49.66	63.33	67.33	32.33	33.00	32.33	32.33	30.33	23.00
DA	20.00	20.00	20.00	25.00	23.33	25.00	25.00	25.00	20.00
TDA	75.60	58.16	83.40	38.20	58.58	38.20	38.20	21.75	24.70
ATDA	3.78	2.90	4.16	1.52	2.52	1.52	1.52	0.86	1.23
STDA	13.33	5.00	5.33	3.66	3.00	3.66	3.66	5.00	10.00
TGF	-15.15	78.58	18.60	94.80	11.87	94.80	94.80	76.63	-15.15
ATGF	-0.60	3.14	7.43	4.73	5.45	4.73	4.73	3.82	-0.62
STGF	5.66	7.33	13.00	4.33	7.00	5.00	5.00	4.00	3.00
T45	60.45	137.08	268.41	133.00	177.31	133.00	133.00	98.38	9.15
AT45	1.33	3.04	5.98	2.95	3.93	2.95	2.95	2.18	0.20
ST45	19.00	12.33	18.33	8.66	10.00	8.66	8.66	9.00	13.00
F_{FS}	14.00	20.33	20.33	21.33	20.66	20.33	20.66	21.33	18.00
F_{PS}	17.00	20.00	20.66	25.33	20.00	21.33	19.66	22.33	18.00
S_{FS}	4.00	45.33	44.66	47.33	53.33	54.66	45.00	52.00	49.33
S_{PS}	2.66	39.33	37.33	43.33	22.00	30.66	40.33	46.00	43.66
SW_{FS}	15.0	28.6	28.3	27.6	34.0	31.6	25.6	27.0	29.0
SW_{PS}	9.0	20.3	19.0	15.6	17.3	16.3	20.6	18.6	18.6
FS	6.85	76.16	74.80	94.86	97.43	83.73	77.80	68.32	59.70
PS	26.30	8.53	8.37	2.43	1.64	1.61	3.73	7.31	4.60
SS	66.84	15.30	16.81	2.65	0.83	14.59	18.36	24.30	35.53
GY_{FS}	9.00	129.46	227.73	130.80	181.33	172.73	116.10	141.00	143.26
GY_{PS}	3.40	80.00	88.73	40.33	39.53	55.33	83.63	87.46	81.80
SL	8.23	7.10	7.90	7.90	8.09	9.00	9.16	8.50	9.50
RL	5.23	5.03	5.33	2.50	2.83	2.66	3.83	5.00	5.66
(R : S) L	0.63	0.70	0.67	0.31	0.34	0.29	0.41	0.57	0.59
SFW	0.06	0.04	0.05	0.04	0.07	0.08	0.08	0.05	0.06
RFW	0.08	0.05	0.07	0.02	0.05	0.05	0.06	0.05	0.06
(R : S) W	1.19	1.25	1.23	0.50	0.69	0.79	1.13	1.03	1.30
LA	20.66	22.33	21.66	24.00	24.66	25.00	24.33	23.33	23.00
LFW	0.38	0.41	0.40	0.53	0.52	0.51	0.50	0.44	0.43
LA/LFW	58.89	53.54	54.10	45.27	46.58	48.39	48.71	52.35	52.66
LDW	0.03	0.04	0.05	0.10	0.10	0.07	0.07	0.06	0.04
LA/LDW	538.98	536.20	363.16	226.33	231.30	323.36	324.76	351.66	526.60

*DH= Days to head emergence, TDH= Thermal time for head emergence, ATDH= Average thermal time for head emergence, STDH= number of days for low soil temperature than air temperature during head emergence, DA= Days to anthesis, TDA= Thermal time for anthesis, ATDA= Average thermal time for anthesis, STDA= Number of days for low soil temperature than air temperature during anthesis, TGF= Thermal time for grain filing (that is, period of 25 days after anthesis), ATGF= Average thermal time for grain filling, STGF= Number of days for low soil temperature than air temperature during grain filling, T45= Thermal time for post head emergence period (that is, 45 days after date of head emergence), AT45= Average thermal time at post head emergence period, ST45= Number of days for low soil temperature than air temperature at post head emergence period, FFS= number of florets on fertile spike, FPS¬= Number of florets on partially sterile spike with impaired seed growth, SFS = Number of seed on fertile spikes, SPS= Number of seeds on partially sterile spike with impaired seed growth, SWFS = 1000 Seed weight for fertile spike, SWPS= Seed weight for partially sterile spike with impaired seed growth, FS = Percent of fertile spike, PS = Percent of partially sterile spike with impaired seed growth, SS = Percent of cool induced sterile spike, GYFS Grain yield for fertile spike, GYPS= Grain yield for partially sterile spike with impaired seed growth, SL= Shhot length, RL= Root length, (R : S) L= ratio of root:shoot length, SFW= Fresh weight of shoot, RFW= Fresh weight of root, (R : S) W= Ratio of root: shoot fresh weight, LA= Leaf area, LFW= Fresh weight of leaf, LA/LFW= Specific leaf area per unit mass of leaf fresh weight, LDW=Dry weight of leaf, LA/LDW= Specific leaf area per unit mass of leaf dry weight.

coefficient values (Table 3) revealed that FS constituted significant association with 27 characters, while PS and SS showed significant correlation with 10 and 25 characters respectively. GY_{FS} had significant relation with 15 characters. GY_{PS} , on the contrary, exhibited strong significant association with five combinations. A perusal of results on correlation analysis revealed that 12 combinations appeared significant for GY_{FS}, FS and SS.

Table 3. Analysis of variance of characters and their correlation coefficient values with different nature of spikes and grain yield of wheat cultivars at high altitude.

Characters	ANOVA			Correlation coefficient values				
	Source of variance[#]			Nature of spike			Grain yield procured from different nature of spike	
	Replication	Genotypes	Error	Fertile with normal seed (FS)	Partially sterile with impaired seed growth (PS)	Cool induced sterile with no seeds (SS)	Fertile (GY_{FS})	Partially sterile and impaired seed growth (GY_{PS})
DH	24.93	613.64**	15.84	0.269	0.025	-0.331	0.406*	0.198
TDH	249.83	34319.13**	269.08	-0.086	0.234	-0.014	0.177	0.135
ATDH	0.10	0.65**	0.03	-0.870**	0.511**	0.785**	-0.517**	-0.234
STDH	6.37	746.73**	5.24	-0.181	0.330	0.055	0.074	0.052
DA	0.95	18.98**	0.95	0.485*	-0.349	-0.406*	0.070	0.054
TDA	381.05	1405.40*	162.08	-0.168	0.317	0.045	0.120	-0.244
ATDA	0.92	4.13**	0.36	-0.251	0.364	0.121	0.093	-0.214
STDA	13.814	98.87**	18.02	-0.860**	0.400*	0.827**	-0.487**	-0.290
TGF	456.96	11846.24**	732.75	0.671**	-0.352	-0.625**	0.617**	0.283
ATGF	0.59	21.66**	1.13	0.724**	-0.397*	-0.666**	0.598**	0.269
STGF	0.48	26.12*	3.43	0.122	-0.053	-0.117	0.429*	0.132
T45	1579.61	15701.68**	1244.27	0.518**	-0.201	-0.516**	0.563**	0.164
AT45	0.79	7.80**	0.60	0.518**	-0.200	-0.517**	0.562**	0.165
ST45	4.459	51.20**	7.63	-0.591**	0.274	0.570**	-0.093	-0.163
F_{FS}	5.77	16.41*	4.06	0.790**	-0.310	-0.788**	0.543**	0.422*
F_{PS}	2.25	17.67	6.17	0.485*	-0.224	-0.468*	0.151	0.046
S_{FS}	7.14	715.37**	9.73	0.862**	-0.600**	-0.732**	0.623**	0.526**
S_{PS}	12.70	577.89**	74.32	0.523**	-0.354	-0.449*	0.297	0.764**
SW_{FS}	0.69	0.83*	0.30	0.676**	-0.141	-0.736**	0.623**	0.250
SW_{PS}	0.15	0.37	0.23	0.428*	-0.104	-0.458*	0.324	0.726**
FS	131.33	2162.80**	78.97	1.00	-0.564**	-0.913**	0.633**	0.351
PS	113.51	176.88	100.06	-0.564**	1.00	0.178	-0.437*	-0.249
SS	434.34	1185.18**	181.86	-0.913**	0.178	1.00	-0.538**	-0.295
GY_{FS}	451.13	10653.13**	1823.96	0.633**	-0.437*	-0.538**	1.00	0.476**
GY_{PS}	133.76	2624.74*	901.24	0.511**	-0.249	-0.295	0.476*	0.178
SL	0.30	1.67*	0.17	-0.041	-0.100	0.097	-0.011	0.270
RL	0.30	4.90*	0.74	-0.523**	0.235	0.507**	-0.062	0.238
(R : S) L	0.001	0.079*	0.008	-0.499**	0.259	0.467*	-0.059	-0.147
SFW	0.00003	0.00072*	0.00012	0.057	-0.045	-0.046	0.069	-0.039
RFW	0.000003	0.00080*	0.00014	-0.535**	0.265	0.507**	0.006	0.344
(R : S) W	0.09	0.24**	0.01	-0.486**	0.189	0.486**	-0.093	0.216
LA	0.77	6.33**	1.27	0.614**	-0.601**	-0.435*	0.286	-0.041
LFW	0.005	0.098*	0.004	0.676**	-0.515**	-0.551**	0.219	0.271
LA/LFW	3.21	34.48**	1.37	-0.605**	0.322	0.562**	-0.101	-0.124
LDW	0.000016	0.00195*	0.000009	0.705**	-0.433*	-0.626**	0.282	-0.030
LA/LDW	158.97	46581.86**	73.70	-0.706**	0.402*	0.644**	-0.345	0.096

**, * Significant at 1 and 5% level of probability; [#] df for replication, genotype and error are 2,8 and 16 respectively.

Different nature of spike (FS, PS, and SS) showed significant correlation with GY_{FS} at different magnitude and direction. FS and GY_{FS} registered positive significant association with TGF, ATGF, T45 and AT45. This indicated that an increase in percent of fertile florets in population and favourable air temperature during post head emergence and grain filling period encouraged the production of grain yield at high altitude. Direct proportionate significant positive association of ATDH and STDA with PS and SS and significant inverse relation to FS and GY_{FS} suggested that average thermal time during head emergence (ATDH) and number of days

Table 4. Correlation coefficient values of different phonological parameter and yield component traits of wheat cultivars.

Character	ATDH	STDA	TGF	ATGF	STGF	T45	AT45	F_{FS}	S_{FS}	S_{PS}	SW_{FS}	SW_{PS}
DH	-0.080	-0.360	0.785**	0.695**	0.856**	0.877**	0.878**	0.278	0.072	0.014	0.193	0.058
ATDH		0.741**	-0.615**	-0.696**	-0.047	-0.458*	-0.458*	-0.754**	-0.792**	-0.410*	-0.496**	-0.030
STDA			-0.715**	-0.780**	-0.085	-0.551**	-0.551**	-0.715**	-0.754**	-0.419*	-0.623**	-0.241
TGF				0.985**	0.687**	0.956**	0.956**	0.600**	0.491**	0.233	0.374	0.046
ATGF					0.569**	0.915**	0.915**	0.638**	0.539**	0.262	0.378	0.052
STGF						0.790**	0.790**	0.172	-0.036	-0.146	0.118	-0.182
T45							1.000**	0.443*	0.277	0.035	0.270	-0.053
AT45								0.443*	0.278	0.037	0.270	-0.053
F_{FS}									0.712**	0.565**	0.565**	0.272
S_{FS}										0.658**	0.673**	0.337
S_{PS}											0.192	0.764**
SW_{FS}												0.202

*, * Significant at 1 and 5% level of probability.

for low soil temperature than air temperature at anthesis (STDA) possibly controlled the fertility factors of florets and physiological ability of grain production among wheat cultivars (Wiegand and Cuellar, 1981) at high altitude. The association of DA with FS and SS indicated that eco-physiological constraints possibly induced variation in development of fertile and sterile floret of spring wheat cultivars under hierarchial mode of growth at DA on high altitude. The correlation between ATDH with STDA appeared positive and significant (Table 4). A perusal of data revealed that high average thermal time for head emergence (ATDH) and greater number of days for low soil temperature than air temperature at days to anthesis (STDA) reduced the development of potential sink capacity (that is, F_{FS}, S_{FS} and SW_{FS}) among wheat cultivars. ATDH and STDA also established strong significant relation to leaf, shoot and root characters at different magnitude and direction (Table 5). This suggested that low soil temperature possibly exerted its influence on reducing root hydraulic conductivity (Kramer, 1983. Fennell and Markhart, 1997) and subsequently induced water deficit in shoot (Fennell et al., 1990) and affected the growth of grains on spike through arresting the normal physiological activities of plants. Changes in R:S ratios thus became necessary in controlling the stress factors associated with low temperature and limited supply of water during crop growth (Wlison, 1988). Inter character association revealed that a strong relation existed among leaf, shoot and root characters (Table 6). It was, therefore, apparent that wheat cultivars with FS possessed greater tolerance capacity to cold stress and encouraged the production of grain yield at high hills through adjusting its morphological characters of leaf, shoot and root characters and through commensurate increase in sink attributes. This study, therefore, indicated that cultivars with fertile spikes was characterized by expanded leaf area with greater thickness and weight of fresh leaf couple with transient deposition of more dry matter and relatively less root system (length and weight). Smaller R:S ratios seemed to exhibit adaptive potential to cold stress situation as it was observed more frequently among winter cultivars than in spring cultivars (Equiza et al., 2001; Subedi et al., 1998). None of the parameters related to leaf, shoot and root characters, however, exhibited significant association with GY_{FS} and GY_{PS}.

The path coefficient analysis (Table 7) revealed that ATDH and STDA had significant positive correlation and contributed direct positive effect to SS. This indicated that development of cool temperature induced floret sterility in wheat cultivars increases through a concomitant increase in average GDD during head emergence and number of days for low soil temperature than air temperature at anthesis. TGF, T45 and FS appeared as major indirect contributor for establishing desired correlation of SS with other characters. The residual effect (R^2 = 0.1055) indicated that 89.45% variability on chilling induced floret sterility on spike in wheat population could be explained effectively through involving 12 common characters. The consideration of leaf, shoot and root characters in path analysis seemed to explain more details about variability in wheat population. The direct positive effect and positive significant correlation of AT45, GY_{FS} and ATGF to FS and their major indirect contribution through other characters suggested that an increase in average thermal time during post head emergence and grain filling period and the ability for producing high grain yield at high altitude indicated the presence of fertile florets on spike in wheat population. Residual effect (R^2 = 0.0186) suggested that 98.14% variability on development of fertile florets on spike in wheat population could be explained effectively through involving these characters.

Path analysis for GY_{FS} indicated that those characters (viz., TGF and FS) that discouraged the development of sterile floret on spike of main shoot at an exposure to cool climatic condition had showed their ability to enhance higher grain yield in wheat population. Residual effect (R^2 = 0.1230) indicated that the association of 12 characters had enabled to explain 87. 70% variability on grain yield procured from normal fertile spikes.

Table 5. Correlation of leaf, shoot and root characters with different phonological parameters and yield component traits of wheat cultivars.

Character	DH	ATDH	STDA	TGF	ATGF	STGF	T45	AT45	F_{FS}	S_{FS}	S_{PS}	SW_{FS}	SW_{PS}
SL	-0.588**	-0.167	0.087	-0.304	-0.243	-0.437*	-0.398*	-0.397*	-0.024	0.154	0.154	0.045	0.275
RL	0.102	0.540**	0.489**	-0.257	-0.358	0.185	-0.160	-0.159	-0.285	-0.293	-0.049	0.166	0.237
(R:S)L	0.303	0.591**	0.446*	-0.151	-0.271	0.328	-0.027	-0.026	-0.271	-0.331	-0.082	-0.178	0.182
SW	-0.232	-0.238	-0.025	-0.013	0.047	-0.105	-0.001	-0.001	-0.125	-0.026	-0.247	0.003	-0.166
RW	0.008	0.422*	0.543**	-0.249	-0.313	0.238	0.105	-0.104	-0.449*	-0.469*	-0.412*	-0.205	-0.136
(R:S)W	0.108	0.531**	0.471*	-0.265	-0.360	0.228	-0.188	-0.187	-0.268	-0.295	0.004	-0.169	0.302
LA	-0.233	-0.704**	-0.504**	0.258	0.376	-0.261	0.097	0.094	0.407*	0.615**	0.303	0.350	0.104
LFW	-0.237	-0.770**	-0.593**	0.292	0.415*	-0.276	0.142	0.140	0.441*	0.561**	0.190	0.339	-0.078
LA/LFW	0.205	0.696**	0.563**	-0.267	-0.370	0.241	-0.151	-0.150	-0.404*	-0.417*	-0.061	-0.266	0.238
LDW	-0.021	-0.789**	-0.656**	0.488**	0.592**	-0.062	0.363	0.362	0.487*	0.494*	0.128	0.292	-0.220
LA/LDW	-0.090	0.835**	0.716**	-0.617**	-0.715**	-0.044	-0.480*	-0.480*	-0.551**	-0.526**	0.181	-0.298	0.175

**, * significant at 1 and 5% level of probability.

Table 6. Correlation coefficient values of leaf, shoot and root characters of wheat cultivars.

Character	RL	(R:S)L	SW	RW	(R:S)W	LA	LFW	LA/LFW	LDW	LA/LDW
SL	0.097	-0.209	0.511**	0.311	0.204	0.202	0.153	-0.089	-0.033	-0.018
RL		0.950**	-0.458*	0.454*	0.847**	-0.586**	-0.775**	0.798**	-0.769**	0.710**
(R:S)L			-0.582**	0.362	0.793**	-0.632**	-0.815**	0.828**	-0.769**	0.724**
SW				0.455*	-0.144	0.326	0.326	-0.260	0.221	-0.246
RW					0.654**	-0.379*	-0.533**	0.581**	-0.566**	0.498**
(R:S)W						-0.502**	-0.742**	0.818**	-0.820**	0.753**
LA							0.893**	-0.603**	0.680**	-0.593**
LFW								-0.896**	0.879**	-0.785**
LA/LFW									0.885**	0.812**
LDW										-0.957**

**, *Significant at 1 and 5% level of probability.

Table 7. Direct (diagonal) and indirect (off diagonal) effect of path analysis on wheat cultivars at high altitude for cold induced sterile spikes (SS), normal fertile spikes (FS) and grain yield (GY_{FS}) obtained from normal fertile spikes.

Character	ATDH	STDA	TGF	ATGF	T45	AT45	F_{FS}	S_{FS}	SW_{FS}	FS	GY_{FS}	r^2 (SS)
ATDH	0.049	0.067	1.192	-2.190	51.102	-50.648	0.049	0.235	0.074	1.216	-0.363	0.785**
STDA	0.036	0.091	1.385	-2.455	61.479	-60.932	0.046	0.224	0.091	1.202	-0.342	0.827**
TGF	-0.030	-0.065	-1.938	3.100	-106.668	105.719	-0.039	-0.146	-0.053	-0.938	0.433	-0.625**
ATGF	-0.034	-0.071	-1.909	3.147	-102.094	101.185	-0.041	-0.160	-0.055	-1.054	0.420	-0.666**
T45	-0.022	-0.050	-1.853	2.880	-111.578	110.585	-0.028	-0.082	-0.038	-0.724	0.395	-0.516**
AT45	-0.022	-0.050	-1.853	2.880	-111.578	110.585	-0.028	-0.082	-0.038	-0.724	0.394	-0.517**
F_{FS}	-0.037	-0.065	-1.163	2.008	-49.429	48.989	-0.065	-0.211	-0.083	-1.104	0.381	-0.780**
S_{FS}	-0.039	-0.068	-0.951	1.696	-30.907	30.742	-0.046	-0.297	-0.093	-1.205	0.437	-0.732**
SW_{FS}	-0.027	-0.062	-0.790	1.328	-32.804	32.512	-0.041	-0.210	-0.132	-0.945	0.437	-0.736**
FS	-0.042	-0.078	-1.300	2.373	-57.797	57.283	-0.051	-0.256	-0.089	-1.398	0.444	-0.913**
GY_{FS}	-0.025	-0.044	-1.195	1.882	-62.818	62.149	-0.035	-0.185	-0.082	-0.885	0.702	-0.538**
R^2 = 0.1055												
Character	**ATDH**	**STDA**	**TGF**	**ATGF**	**T45**	**AT45**	**F_{FS}**	**S_{FS}**	**SW_{FS}**	**SS**	**GY_{FS}**	**r^2 (FS)**
ATDH	0.004	-0.057	1.448	-1.666	28.356	-28.416	-0.080	-0.068	0.009	-0.214	-0.186	-0.870**
STDA	0.003	-0.077	1.683	-1.867	34.114	-34.186	-0.076	-0.065	0.011	-0.226	-0.175	-0.860**
TGF	-0.002	0.055	-2.355	2.358	-59.189	59.314	0.064	0.042	-0.006	0.170	0.222	0.671**
SS	-0.103	0.124	-3.204	3.504	-51.523	51.686	0.122	0.139	-0.155	-1.938	0.810	-0.538**

Table 7. Contd.

ATGF	-0.003	0.060	-2.319	2.393	-56.651	56.771	0.068	0.046	-0.006	0.182	0.215	0.754**
T45	-0.002	0.042	-2.251	2.190	-61.913	62.044	0.047	0.023	-0.004	0.141	0.202	0.518**
AT45	-0.002	0.042	-2.251	2.190	-61.913	62.044	0.047	0.024	-0.004	0.141	0.202	0.518**
F_{FS}	-0.003	0.055	-1.413	1.527	-27.427	27.485	0.106	0.061	-0.010	0.213	0.195	0.790**
S_{FS}	-0.003	0.058	-1.156	1.290	-17.150	17.248	0.076	0.086	-0.011	0.200	0.224	0.862**
SW_{FS}	-0.002	0.053	-0.960	1.010	-18.202	18.241	0.067	0.061	-0.015	0.201	0.224	0.676**
SS	0.003	-0.063	1.471	-1.594	31.947	-32.077	-0.083	-0.063	0.011	-0.273	-0.193	-0.913**
GY_{FS}	-0.002	0.037	-1.453	1.431	-34.857	34.869	0.057	0.053	-0.009	0.147	0.360	0.633**

R^2 = 0.0186

Character	ATDH	STDA	TGF	ATGF	T45	AT45	F_{FS}	S_{FS}	SW_{FS}	FS	SS	r^2 (GY_{FS})
ATDH	-0.131	0.111	-3.153	3.662	-45.731	45.787	0.118	0.150	-0.119	-1.847	0.635	-0.517**
STDA	-0.097	0.150	-3.665	4.104	-55.017	55.085	0.112	0.143	-0.145	-1.826	0.669	-0.487**
TGF	0.081	-0.107	5.127	-5.183	95.457	-95.574	-0.094	-0.093	0.086	1.424	-0.506	0.617**
ATGF	0.091	-0.117	5.050	-5.262	91.363	-91.475	-0.100	-0.102	0.089	1.601	-0.539	0.598**
T45	0.060	-0.082	4.901	-4.815	--.850	-99.973	-0.069	-0.052	0.062	1.099	-0.418	0.563**
AT45	0.060	-0.082	4.901	-4.815	99.850	-99.973	-0.069	-0.052	0.062	1.099	-0.418	0.562**
F_{FS}	0.099	-0.107	3.076	-3.357	44.233	-44.288	-0.157	-0.135	0.133	1.677	-0.631	0.543**
S_{FS}	0.104	-0.113	2.517	-2.836	27.658	-27.792	-0.112	-0.189	0.149	1.830	-0.592	0.623**
SW_{FS}	0.074	-0.104	20.091	-2.220	29.356	-29.392	-0.099	-0.134	0.211	1.435	-0.596	0.623**
FS	0.114	-0.129	3.440	-3.968	51.722	-51.786	-0.124	-0.163	0.142	2.123	-0.739	0.633**

R^2 = 0.1230, **, * significant at 1 and 5 % percent level of probability.

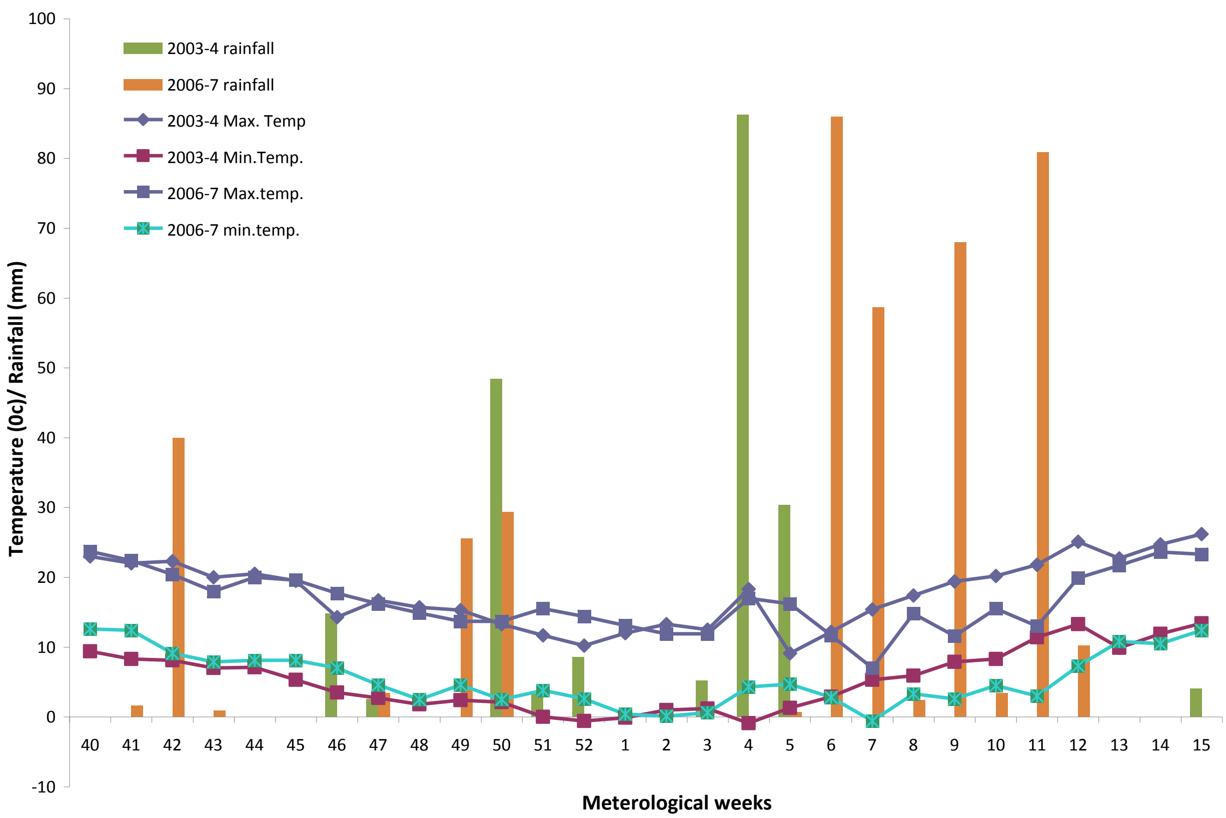

Figure 1. Maximum, minimum temperature and rain fall data at experimental site over wheat growing season.

Consideration of leaf, shoot and root characters and various physiological parameters related to photosynthetic processes (Levitt, 1980; Hurry and Huner, 1991) might be required to explain more details variability on grain yield in wheat cultivars produced under field condition at an exposure to sub-optimal low temperature on hills.

The results of this investigation revealed that in spite of establishing superiority on yield VL 829 was found sensitive to cold as indicated by the delay in timing of head emergence, development of sterile florets on spikes and physiological limitation of grain growth (that is, impaired seed growth) after anthesis. High percent of fertile florets was observed in HPW 236 and HS 473. Onthe contrary, the development of high percent of sterile florets on spike and physiological limitation of grain growth after anthesis was observed in Local cultivar. It was presumed that location specific adaptation of cultivar and possible synergistic interaction between genotype and cool environment had reduced the potential of physiological ability to produce yield by Local genotype at high altitude at an exposure to sub-optimal low temperature (Figure 1). Sonalika and VL 832 appeared as moderately susceptible cultivars to cold. VL 829, HPW 236 and HS 473 were found suitable for cultivation under cold stress situation at high hills. Further investigation would be required to obtain more precise information in regard to sensitive reaction of spring wheat cultivars upon cold stress and grain yield variation at high altitude.

REFERENCES

Akerman A, MacKey J (1949). Forsok till stegrande av varvetets avkastning. II Korsnonger mellan var-oh hostvete: Beskrivning Svalofs Ellavarvete. Sveiges Utsaderforeningen Tidskrift 59:105-117 (Swedish).

Al–Jibouri HA, Miller PA, Robinson HF (1959). Genotypic and environmental variances and covariances in upland cotton cross of interspecific origin. Agron. J. 51:633-666.

Angus JF, Makanzie DH, Morton R, Schafer CA (1981). Phasic development in field crops: ii. Thermal and photoperiodic requirement of spring wheat. Field Crops Res. 4:269-283.

Austin RB (1993) Augmenting yield-based selection. In: Palnt Breeding: Principles and Practices (Eds) Hayward MD, Bosemark NO and Romagosa I. published by Chapman & Hill. London, pp. 391-405.

Boese SR, Huner NPA (1990). Effect of growth temperature and temperature shift on spinach leaf morphology and photosynthesis. Plant Physiol. 94:1830-1836.

Burton GW, Devane EM (1953). Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. Agron. J. 45:478-481.

Dewey DR, Lu KH (1959). A correlation and path coefficient analysis of components of crested grass seed production. Agron. J. 51:515-518.

Equiza MA, Mirave JP, Tgnetti JA (1997). Differential root versus shoot growth inhibition and its relation with carbohydrate accumulation at low temperature in different wheat cultivars. Ann. Bot. 80:657-663.

Equiza MA, Mirave JP, Tgnetti JA (2001). Morphological, anatomical and physiological responses related to differential shoot vs. root growth inhibition at low temperature in spring and winter wheat. Ann. Bot. 87:67-76.

Fennell A, Markhart AHIII (1997). Rapid acclimation of root hudraulic conductivity at low temperature. J. Exp. Bot. 49:879-884.

Fennell A, Li PH, Markhart A, HIII K (1990). Influence of air and soil temperature on Water relations and freezing tolerance of spinach (Spinacia oieracea). Physiol. Planterum 78:85-56.

Huner NPA, Palta JP, Li PH, Carter JV (1981). Anatomical changes in leaves of Puna rye in response to growth at cold hardening temperatures. Botanical Gazzet 142:55-62.

Hurry VM, Huner NPA (1991). Low growth temperature affects a differential inhibition of photosynthesis in spring and winter wheat. Planta Physiologium 96:491- 497.

Korner CH,Larcher W (1988). Plant life in cold climates. In : Long S.P. and Woodward, F.L. (Eds) Plant and temperature. Symposia of the Society for Experimental Biology, Cambridge: The Company of the Biologist Limited.

Kramer PJ (1983). Water relations of plants. New York. Academic Press

Kumar J, Chatrath R, Mishra B (20060. Winter wheats as donors of higher productivity traits. Indian J. Plant Genetic Resour. 19 (2):245-252.

Levitt J (1980). Response of plants to environmental stress Vol I. Chilling, freezing and high temperature stress. New York, Academic Press.

Lu Z, Neumann PM (1999). Low cell wall extensibility can limit maximum leaf growth rates in rice. Crop Sci. 39:126-130.

Nanda GS, Sohu VS (1998). Breeding methodologies for wheat improvement. In :Nayar et.al. (eds) Wheat pathology. Genetics and breeding for resistance, 199. Advance course 14 -17 September 1998. DWR, Regional Station, Flowerdale, Shimla, India. pp. 51-60.

Salfer GA, Rawson HM (1994). Sensitivity of wheat phasic development to major environmental factors: A re-examination of some assumptions made by physiologist and modelers. Austr. J. Plant Physiol. 21:393-426.

Salfer GA, Rawson HM (1995). Base and optimum temperatures vary with cultivar and stage of development in wheat. Plant Cell. Environ. 18:1-9.

Stelamakh AF (1981). Genetics of growth habit and duration of life cycle in common wheat. Selectsija I Semenovodstvo (Kiev) 48:8-15. (Russian).

Stelamakh AF (1990). Geographic distribution of Vrn genes in land races and improved varieties of spring bread wheat. Euphytica 45:113-118.

Subedi KD, Floyed CN, Budhathoki CB (1998). Cold temperature-induced sterility in spring wheat (Triticum aestivum L) at high altitudes in Nepal: Variation among cultivars in response to sowing date. Field Crops Res. 55:141-151.

Taiz L, Zeiger E (1998). Stress physiology. In : Plant Physiology (second edition). Sinauer Associates. Inc. Publisher. Sunderland. Massachusetts. U.S.A. pp. 725-757.

Wiegand CL, Cuellar JA (1981). Duration of grain filling and Kernel weight of wheat as affected by temperature.Crop Sci. 21:95-101. oieracea). Physiol. Planterum 78:85-56.

Wlison JB (1988). A review of evidence on the control of shoot : root ratio, in relation to models. Ann. Bot. 75:533-539.