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Full Length Research Paper

Study of influence of temperature regimes on germination characteristics and seed reserves mobilization in wheat

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In a laboratory, experiment germination characteristics and seed reserves mobilization of wheat cultivars were evaluated at three temperature regimes (16, 26 and 36°C). Four heat tolerant cultivars (Gourab, Sourav, Kanchan and Shatabdi) and two heat sensitive cultivars (Sonora and Kalyansona) were used as study materials. Germination characteristics expressed as rate of germination, coefficient of germination and germination vigor index, increased with an increase in temperature. The shoot dry weight and shoot to root dry weight ratio, increased with increasing temperature. But in root dry weight, the highest values were found to be 26°C compared to 16 and 36°C temperature. The dry matter distributed in shoot and the respiratory loss, increased with increasing temperature in all the cultivars. But these increments were greater at 16 - 26°C than those at 26 - 36°C. Therefore, temperature had a profound effect on seed metabolic efficiency (SME). At moderate temperature (26°C), all the cultivars showed the highest SME than the lowest (16°C) and highest temperatures (36°C). Heat tolerant cultivars attained higher SME (2.55 - 2.88 g/g) than those of heat sensitive cultivars (Sonora and Kalyansona) (2.00 - 2.1 g/g).

Key words: Wheat, temperature, germination, seed metabolic efficiency.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a thermosensitive cool season crop. It is predominantly produced and consumed in densely populated tropical and subtropical regions of developing world. The optimum temperature for wheat is 15 - 18°C (Chowdhury and Wardlaw, 1978) while moderate high temperature (25 - 32°C) for longer duration and very high temperature (33 - 44°C) for a shorter period are very common in the tropical and subtropical environments particularly during grain filling period (Marcellos and Singh, 1972; Dhadhwal, 1998; Stone and Nicolas, 1994; Pausen, 1994). Heat stress is also a common abiotic factor responsible for reducing wheat yields in about 40% which encomposes 36 million hectares (Fisher and Bayerlee, 1991). To overcome this acute problem, scientists are trying to develop heat tolerant varieties of wheat. In the recent years, plant scientists have given attention to physiological and metabolic characteristics to evaluate heat tolerance of wheat genotypes which determine yield of this crop. But before initiating a crop improvement programme, it is desirable to have a prior knowledge about the magnitude of variability present in the existing varieties in respect of particular physiological or metabolic characteristics.

Seed germination and seedling establishment are

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important characteristics for wheat which could provide advantages to heat tolerant cultivars over heat sensitive ones. This may be dependent on their ability to utilize seed reserves more efficiently (Rao and Sinha, 1993). Germination and seed reserves mobilization may vary in different temperature regimes (Penning de Vries et al., 1979) because temperature is a modifying factor in germination since it can influence the rate of water and other substrates supply, necessary for plant growth and development (Wanjura and Buxtor, 1979). The magnitude of variation in seed reserves mobilization may also vary in different genotypes and higher seed metabolic efficiency (SME) is a desirable character under water stress environments when emergence is delayed due to insufficient soil moisture. Genotypes having higher SME would not run out the substrates before germination. But the studies on germination characteristics and seed reserves mobilization in relation to heat tolerance are very limited. Therefore, the present study was undertaken to elucidate heat tolerance of wheat. We have investigated germination characteristics and seed reserves mobilization of wheat cultivars and examine their variability in seed metabolic efficiency during germination in different temperature regimes.

MATERIALS AND METHODS

The experiment was carried out in two factors completely randomized design with three replications in the Plant Pathology Laboratory of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The treatment factors A and B were:

A. Three germination temperatures (low, moderate and stressful) of 16, 26 and 36°C.
B. Six wheat cultivars of which four (Gourab, Sourav, Kanchan and Shatabdi) were heat tolerant (HT) and the rest two (Sonora and Kalyansona) were heat sensitive (HS).

Seed placement for germination

Before placement of seed for germination, the seeds of a cultivar were thoroughly mixed and moisture percentage was determined gravimetrically using a portion of the seeds, the remaining seeds were used for the experiment. Individual weight of 30 seeds for each genotype was taken and was placed sequentially according to the marking on filter paper soaked with water in sterilized petridishes. Then the petridishes were kept in seed germinator (WTB-Binder, Germany) at 16, 26 and 36°C. For each temperature, three batches of Petri dishes each containing 30 seeds was used. Water was added to the petridishes when necessary.

Rate of germination, co-efficient of germination and germination vigor

Germination was counted at 24-h interval and continued up to the 5th day (120 h). A seed was considered germinated as plumule and radicle came out and was larger than 2 mm long. The rate of germination was calculated (Krishnasamy and Seshu, 1990).

Rate of germination *(%)*

$$= \frac{\text{No. of seed germinated at 48h}}{\text{No. of seed germinated at 120h}} \cdot 100$$

Co-efficient of germination and vigor index was calculated using the following formulae (Copeland, 1976):

Co-efficient of germination =

$$\frac{100(A_1 + A_2 + - - - - - - + A_n)}{A_1T_1 + A_2T_2 + - - - + A_nT_n}$$

$$\text{Vigor index} = \frac{A_1}{T_1} + \frac{A_2}{T_2} + - - - - - - - - + \frac{A_n}{T_n}$$

where: A = Number of seeds germinated, T = Time (days) corresponding to A and
n = No. of days to final count.

Shoot and root length, dry matter partitioning

At 5th day after placement for germination, five seedlings from each Petri dish were sampled, shoot and root length of individual seedling was recorded manually with scale. Then shoot, root and remaining seeds were dried separately at 70°C for 72 h and weight was recorded. The mean length (cm) and dry weight was calculated for each treatment combination.

Seed metabolic efficiency (SME)

Seed metabolic efficiency in the present study is defined as the amount of shoot and root dry matter (g) produced from 1 unit (g) of dry seed weight that was respired. Thus the higher the value of seed metabolic efficiency (SME), the higher the efficiency of seed as more seed reserves would be used for producing roots and shoots.

Amount of seed material respired (SMR) was calculated as:

SMR = SDW- (SHW +RTW +RSW)

Where: SDW = Seed dry weight before germination, SHW = Shoot dry weight, RTW = Root dry weight and RSW = Remaining seed dry weight.

Seed metabolic efficiency (SME) was calculated using the following formula (Rao and Sinha, 1993):

$$SME = \frac{SHW + RTW}{SMR}$$

Statistical analysis

The findings were analyzed by partitioning the total variance with the help of computer using MSTAT program. The treatment means was compared using Duncan's Multiple Range Test (DMRT).

Table 1. Rate of germination, co-efficient of germination and germination vigor index in different wheat cultivars as influenced by temperature regimes.

Cultivar	Temperature (°C)	Rate of germination (%)	Co-efficient of germination (%)	Germination vigor index
Gourab	16	27.62 g	25.45 def	14.60 e
	26	59.75 d	27.45 abcd	20.32 d
	36	87.70 abc	28.32 ab	23.55 bc
Sourav	16	27.54 g	25.68def	15.64 e
	26	65.08 d	27.55 abcd	20.56 d
	36	89.45 abc	29.05 a	24.88 ab
Kanchan	16	25.74 g	24.29 f	15.44 e
	26	63.14 d	27.14abcd	19.68 d
	36	93.15 ab	28.21 abc	25.47 ab
Shatabdi	16	33.74 fg	26.38 bcde	15.18 e
	26	62.32 d	27.53 abcd	21.38 cd
	36	94.82 a	29.2 a	27.30 a
Sonora	16	41.99 ef	24.45 ef	16.11 e
	26	64.44 d	27.44 abcd	20.98 cd
	36	83.07 c	28.487 ab	24.82 ab
Kalyansona	16	42.88 e	26.10 cdef	16.37 e
	26	60.96 d	27.35 abcd	21.40 cd
	36	84.32 bc	28.35 ab	21.92 cd
CV (%)		6.09%	3.08%	5.46%

Mean followed by the same letter(s) did not differ significantly at 5 % level by DMRT.

RESULTS

Germination characteristic

The rate of germination, co-efficient of germination and germination vigour index of six wheat cultivars are presented in Table 1. Results showed that all the three germination characteristics were significantly influenced by the interaction of temperature regimes and wheat cultivars. At 16°C, all the cultivars showed the lowest rate of germination (25.74 - 42.88%). In this temperature (16°C) cultivar Kalyansona showed the highest (42.88%) rate of germination which was at par with cultivar Sonora (41.99%). Whereas, cultivar Kanchan had the lowest (25.74%) rate of germination. With increasing temperature, all the cultivars showed an increasing trend of rate of germination. Therefore, at temperature of 36°C, all the cultivars reached their highest level (83.07 - 94.82%) rate of germination. At high temperature (36°C) cultivar Shatabdi showed the highest rate of germination (94.82%) which was statistically similar to cultivars Gourab, Sourav and Kanchan. Whereas, cultivar Sonora attained the lowest rate of germination (83.07%). However, at temperature of 26°C, all the cultivars showed a moderate rate of germination (59.75 - 65.08%).

Co-efficient of germination was increased with an increase in temperature. The lowest co-efficient of germination (24.29 - 26.38%) was found at 16°C. At the lowest temperature (16°C) cultivar Kanchan showed the lowest co-efficient of germination (24.29%) whereas, cultivar Sourav had the highest co-efficient of germination (26.38%). However, the overall highest co-efficient of germination (29.20%) was found in cultivar Shatabdi at 36°C temperature.

In germination vigour indices, all the cultivars showed an increasing trend as temperature increases. At temperature of 16°C, all the cultivars showed the lowest values of germination vigour index (14.60 - 18.67) which increased to moderate level (19.68 - 21.40) at 26°C and then to the highest level (21.92 - 27.30) at 36°C in all the cultivars. Therefore, cultivar Shatabdi showed the highest germination vigour index at 36°C and cultivar Gourab had

Table 2. Length of shoot and root of wheat seedlings as influenced by temperature regimes.

Cultivar	Temperature (°C)	Length (cm)		
		Shoot	Root	Shoot:Root
Gourab	16	2.14 e	4.27 jk	0.51 f
	26	7.46 ab	9.56 bc	0.78 de
	36	7.74 ab	6.11 gh	1.26 a
Sourav	16	2.47 e	4.55 jk	0.55 f
	26	7.27 abc	10.53 a	0.68 def
	36	7.7 ab	7.73 de	0.99 ab
Kanchan	16	2.06 e	4.35 jk	0.49 f
	26	6.28 cd	10.06 ab	0.61 ef
	36	7.06 abc	6.46 fg	1.08 ab
Shatabdi	16	2.67 e	5.25 i	0.50 f
	26	6.70 bc	10.73 a	0.62 ef
	36	7.90 a	7.07 ef	1.13 ab
Sonora	16	2.50 e	3.22 l	0.77 de
	26	6.78 abc	8.08 d	0.84 cd
	36	5.30 d	4.94 ij	1.07 ab
Kalyansona	16	2.48 e	4.14 k	0.60 ef
	26	7.03 abc	9.13 c	0.76 de
	36	6.60 bc	5.56 hi	1.18 ab
CV (%)		8.49%	4.49%	10.28%

Mean followed by the same letter(s) did not differ significantly at 5 % level by DMRT.

the lowest value of germination vigour index at 16°C temperature. However, the germination vigour indices increased to a greater extent as the temperature rose from 16 - 26°C, while in further increase in temperature up to 36°C, the increment was lower.

Length of shoot and root of wheat seedling

Effect of temperature on the length of shoot and root of wheat seedling is shown in Table 2. The interaction of temperature and wheat cultivar on length of shoot and root of wheat seedlings and their ratio (shoot : root) were significant. The shoot lengths were increased as temperature increases in all cultivars except cultivars Sonora and Kalyansona. At 16°C, all the cultivars showed their lowest shoot length (2.14 - 2.67 cm). In this lowest temperature (16°C), the value of shoot length of all cultivars were statistical similar. From 16 - 26°C, all the cultivars (Gourab, Sourav, Kanchan, Shatabdi, Sonora and Kalyansona) increased their shoot length and thereafter, at 36°C, Gourab, Sourav, Kanchan and Shatabdi continued their increasing trend in shoot length, but the remaining two cultivars Sonora and Kalyansona decreased their shoot length. Therefore, cultivar Shatabdi showed the highest shoot length (7.90 cm) and cultivar Sonora attained the lowest shoot length (5.30 cm) at the highest temperature (36°C).

In root length, all the cultivars attained their lowest value (3.22 - 5.27 cm) at 16°C and it was increased at moderate temperature of 26°C (8.08 - 10.73 cm) but thereafter, decreased at highest temperature (36°C) (4.94 - 7.73 cm). However, at moderate temperature (26°C) Shatabdi attaind the overall highest root length (10.73 cm), whereas, Sonora had the lowest (8.08 cm) root length.

The ratio of shoot to root length was increased as temperature increases in all the cultivars. These ratios were lowest at 16°C (0.49 - 0.77), moderate at 26°C (0.61 - 0.84) and highest at 36°C (0.99 - 1.26). However, at 36°C, cultivar Gourab attained the highest shoot to root length ratio (1.26) and cultivar Sourav had the lowest

Table 3. Dry weight of shoot and root of wheat seedlings as influenced by temperature regimes.

Cultivar	Temperature (°C)	Dry weight (mg/seedling)		
		Shoot	Root	Shoot:Root
Gourab	16	1.18 g	2.5 hi	0.46 e
	26	5.66 cdef	5.66 b	1.0 d
	36	6.45 bcd	4.26 e	1.38 c
Sourav	16	1.03 g	2.06 jk	0.51 e
	26	5.56def	5.13cd	1.08 d
	36	6.66 bc	4.10 e	1.62 ad
Kanchan	16	1.0 g	2.26 ij	0.44 e
	26	6.0 cde	5.43 bc	1.10 d
	36	7.1 b	4.33 e	1.61 ad
Shatabdi	16	1.6 g	2.63 h	0.61 e
	26	6.4 bcd	6.10 a	1.01 d
	36	8.06 a	5003 d	1.45 bc
Sonora	16	0.77 g	1.80 k	0.44 e
	26	4.66 f	4.10 e	1.13 d
	36	5.16 ef	3.4 g	1.51 bc
Kalyansona	16	0.90 g	1.90 k	0.47 e
	26	5.0 ef	4.43 e	1.13 d
	36	5.3 ef	3.73 f	1.79 a
CV (%)		9.44	3.92	11.74

Mean followed by the same letter(s) did not differ significantly at 5% level by DMRT.

value (0.99) in shoot to root length ratio.

Dry weight of shoot and root of wheat seedling:

Dry weight of shoot and root of wheat seedlings were influenced significantly by the interaction of temperatures and cultivars. The dry weight of shoot and root of six wheat cultivar seedlings at different temperature regimes is presented in Table 3. Results showed that shoot dry weight was increased as temperature increases in all the cultivars. There existed significant variations among wheat cultivars in shoot dry weight at different temperature regimes. At 16°C, the shoot dry weights were lowest (0.77 - 1.60 mg) than those of 26°C (4.66 - 6.40 mg) and 36°C (5.16 - 8.06 mg). Therefore, at 16, 26 and 36°C, Shatabdi attained the highest shoot dry weight (1.6, 6.4 and 8.06 mg, respectively) and cultivar Sonora had the lowest value (0.77, 4.66 and 5.16 mg, respectively) of shoot dry weight.

In case of root dry weight, highest values were found at moderate temperature (26°C) and it was reduced significantly both at 16 and 36°C in all the cultivars. The lowest root dry weight (1.80 mg) was found in Sonora at 16°C and the highest root dry weight was found in Shatabdi at 26°C. The shoot to root dry weight ratios were increased as temperature increases in all the cultivars. However, at 36°C, Kalyansona showed the highest (1.79) shoot to root dry weight ratio, whereas, Gourav had the lowest (1.38) shoot to root dry weight ratio.

Seed dry matter distribution

The percent dry matter distribution at five days after placement for germination in six wheat cultivar as influenced by temperature regimes is presented in Table 4. The wheat cultivars under study showed significant variations for dry matter accumulation in shoot and root, the amount of dry matter loss during respiration and dry matter remained in seed at 5th day after placement of

Table 4. Seed dry matter distribution (%) at 5 days after placement for germination in different wheat cultivars as influenced by temperature regimes.

Cultivar	Temperature (°C)	Distribution of seed dry matter (%)			
		In shoot	In root	Respired	Remaining seed
Gourab	16	2.63 gh	5.58 g	6.78 hi	85.00 ab
	26	13.13 f	12.74 bc	9.41 fg	64.71 c
	36	13.99 ef	9.26 f	14.62 d	62.20 cd
Sourav	16	2.45 gh	4.90 g	8.16 gh	84.48 ab
	26	14.12 def	13.03 bc	10.44 ef	62.40 cd
	36	15.22 cd	9.37 f	18.21 c	57.20 def
Kanchan	16	2.16 gh	4.87 g	6.16 i	86.80 a
	26	13.43 f	12.16 cd	9.82 f	64.57 c
	36	16.26 bc	9.94 ef	17.72 c	56.04 ef
Shatabdi	16	3.54 g	5.82 g	7.47 hi	83.16 ab
	26	14.64 de	13.95 ab	9.93 f	61.47 cde
	36	17.99 a	11.22 de	17.19 c	53.60 f
Sonora	16	2.55 gh	5.52 g	11.54 e	80.37 b
	26	16.50 b	14.52 a	14.77 d	54.20 f
	36	18 a	12.10 cd	30.83 a	39.04 g
Kalyansona	16	2.42 gh	5.11 g	9.17 fg	83.29 ab
	26	14.30 def	12.64 bcd	15.50 d	41.94 g
	36	14.76 de	10.30 ef	22.78 b	52.14 f
CV (%)		4.46 %	6.31 %	5.16 %	

Mean followed by the same letter(s) did not differ significantly at 5% level by DMRT.

germination at 16, 26 and 36°C. The amount of seed reserves respired was increased (6.16 -30.83%) as temperature increases (16 - 36°C) in all cultivars. These increments were observed more at 26 - 36°C than at 16 - 26°C in all the cultivars. At high temperature (36°C), among the cultivars, the heat sensitive cultivar Sonora showed significantly, highest (30.83%) respiratory loss, which was followed by other heat sensitive cultivar Kalyansona (22.78%). Whereas, heat tolerant cultivar Gourab showed the lowest value (14.62%) in respiratory loss. Other heat tolerant cultivar Sourav, Kanchan and Shatabdi showed moderate and statistically similar respiratory loss (17.19 - 18.21%) at high temperature (36°C).

In shoot development, the dry matter distributed in shoot was increased with an increase in temperature in all the cultivars. But the magnitude of increments was different among the cultivars. The lowest dry matter distribution to shoot (2.16 - 3.54%) was found at 16°C, which increased at 26°C (13.13 - 16.50%) then at 36°C to highest level (13.99 - 18.00%) in all the cultivars. Therefore, these increments were greater at 16 - 26°C than those at 26 - 36°C. However, at high temperature (36°C), Shatabdi and Sonora showed significantly, the highest (17.99 and 18.00%, respectively) and Gourab had the lowest (13.99 %) dry matter distribution to shoot.

In root development, the amount of dry matter accumulated in root was increased only from 16 - 26°C and thereafter, decreased at 26 - 36°C in all the cultivars. Among the cultivars, Sonora showed the highest proportion of dry matter distribution (14.52%) to root at moderate temperature (26°C) . Whereas, the lowest value (4.87%) was obtained by Kanchan at the lowest temperature (16°C).

Seed metabolic efficiency

The seed metabolic efficiency (SME) of six cultivars at different temperature regimes is presented in Figure 1. Results showed that temperature had a profound effect on seed metabolic efficiency in all the cultivars. At

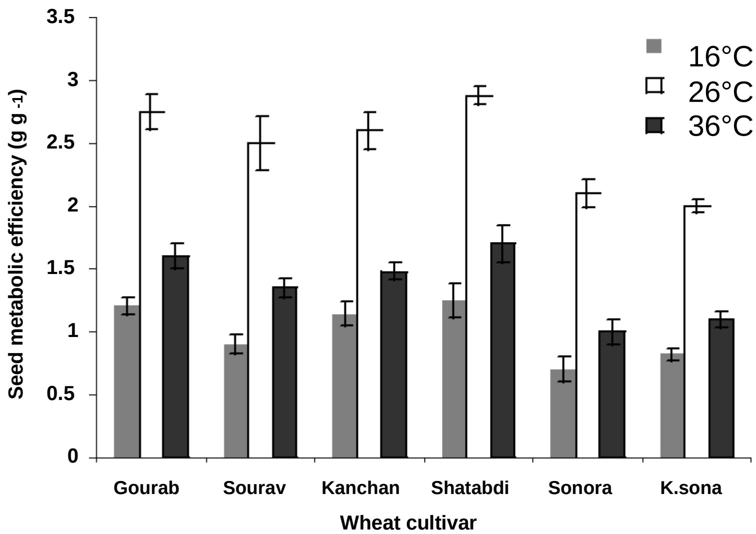

Figure 1. Seed metabolic efficiency in wheat cultivars as influenced by temperature.

moderate temperature (26°C) all the cultivars showed the highest SME than those at the lowest (16°C) and highest temperaure (36°C). At 26°C, the heat tolerant cultivar Shatabdi attained the highest SME (2.88 g/g) which was closely followed by other heat tolerant cultivars Gourab (2.75 g/g), Sourav (2.50 g/g) and Kanchan (2.60 g/g). Whereas, heat sensitive cultivar Kalyansona showed the lowest SME (2.00 g/g) which was followed by other heat sensitive cultivar Sonora (2.1 g/g). In the lowest (16°C) and highest (36°C) temperature, the heat tolerant cultivars (Gourab, Sourav, Kanchan and Shatabdi) also maintained their supremacy over heat sensitive cultivars (Sonora and Kalyansona) in seed metabolic efficiency.

DISCUSSION

All the germination characters viz: Rate of germination, co-efficient of germination and germination vigour index of all the six wheat cultivars, showed an increasing trend as temperature increases from 16 - 36°C. At 16°C, all the cultivars showed their lowest germination characters. However, Shatabdi had the highest rate of germination (94.82%), co-efficient of germination (29.20%) and germination vigour index (27.30) at 36°C. Faster speed of germination at higher temperature might be due to rapid hydrolysis and mobilization of seed reserves through higher alpha amylase activity at higher temperature. The close relation between germination of wheat seed and alpha amylase activity at various temperatures was reported by Sultana et al. (2000). Hasan et al. (2004) also found the increased speed of germination (rate of germination, co-efficient of germination and germination vigour index) with increasing temperature from 15 - 35°C of different wheat genotypes at various degrees.

At 16 - 26°C temperatures all the cultivars increased their shoot length and thereafter, at 36°C, the heat tolerant cultivars Gourab, Sourav, Kanchan and Shatabdi continued their increasing trend, but the two heat sensitive cultivars Sonora and Kalyansona had a decrease in shoot length. The root length was increased with increasing temperature of about 26°C, but thereafter, decreased at 36°C in all the cultivars. HT cultivar Shatabdi had the highest and HS cultivar Sonora and showed the lowest performance in shoot and root lengths. The increasing ratio of shoot to root length with increasing temperature regimes, indicated that root was more affected than the shoot at high temperature. Hasan et al. (2004) also reported that from a low temperature to high temperature (15 to 35°C), the shoot length and shoot to root length ratio of wheat seedlings showed an increasing tendency, but root length was increased at low to moderate temperature.

Shoot dry weight and ratio of shoot to root dry weight were increased with increasing temperature from 16 - 36°C in all the cultivars but in root dry weight, the highest values were at the moderate temperature (26°C) and it was decreased both at 16 and 36°C in all the cultivars. The increasing shoot to root dry weight ratios with increasing temperature indicated that root dry weights were reduced, but shoot dry weights were increased at high temperature. Results from other studies (Hasan et al., 2004) indicated that shoot dry weight of wheat seedling was significantly increased with increasing temperature (15 - 35°C). They also found that shoot to root dry weight ratio was increased as temperature increases in the different wheat genotypes. All these findings support the results of present study.

At 5th day after the placing of seed for germination at different temperature regimes (16, 26 and 36°C), all the cultivars increased the loss of seed reserves due to respiration as temperature increases from 16 - 36°C. At the highest temperature, HS cultivar Sonora and HT cultivar Gourab showed the highest (30.83%) and lowest (14.62%) respiratory loss, respectively. In shoot development, the dry matter distribution in shoot, all the cultivars increased their percentge dry matter distribution in shoot as temperature increases from 16 - 36°C. But in root development, the amount accumulated by dry matter in root was increased from 16°C to about 26°C and thereafter, decreased at 36°C in all the cultivars. These results demonstrated that the optimum temperature for root development (growth) was lower compared to that for shoot development. Therefore, root failed to continue to increase the accumulation of dry matter at high temperature (36°C), while the shoot was able to continue to gain dry matter by showing higher temperature optima than root. Results from Rao and Sinha (1993) studies with different genotypes of sorghum, reported that the amount of seed reserves respired was increased from 20 - 30°C. Sikder and Ahmed (2007) also found that root of seedlings of different wheat varieties failed to continue to increase dry matter at higher temperature (32°C), but at 25°C, all the varieties increased their root dry weight compared to temperature at 18°C. Whereas, the shoot was able to continue to gain dry weight from 180°C to about 320°C. Hasan et al. (2004) also found that the amount of seed reserves respired and dry matter accumulation in shoot were increased over a larger increased in temperature (from 15 - 35°C). But the dry matter accumulation in root was increased over a smaller increase in temperature (from 15 - 25°C) and thereafter, decreased at 35°C. These results are in close agreement with those of the present study.

Temperature had tremendous effect on seed metabolic efficiency (SME) in all the six wheat cultivars and at moderate temperature (26°C), all the cultivars showed their highest SME than those of the lowest (16°C) and the highest (36°C) temperature (Figure 2). It was also observed that heat tolerant cultivars (Gourab, Sourav, Kanchan and Shatabdi) showed higher SME than those of heat sensitive cultivars (Sonora and Kalyansona) at all the temperature regimes. The lowest SME at 16°C suggested that at lower temperature, substrate respiration was not linked to building useful plant parts (shoot and root) and could lead to thermal dissipation of respiratory energy by an alternate oxidase pathway or cyanide resistant pathway (Henry and Nyns, 1975; Day et al., 1980). Again at high temperature (36°C), reduction in SME may be attributed to inability to accumulate respiratory product to shoot and root of wheat seedlings.

Generally shoot and root growth of HS cultivars in terms of length and dry weight were more affected than those of HT cultivars at high temperature. Seed metabolic efficiency of HS cultivars was also affected to a greater extent than those of HT cultivars under higher temperature.

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