Journal of Agrometeorology 21 (3) : 270-281 (September 2019)

Assessing impact of thermal units on growth and development of mustard varieties grown under optimum sown conditions

M.R. ISLAM[1], M.A. ALAM[2], MOHD. MOSTOFA KAMAL[3], R. ZAMAN[4], AKBAR HOSSAIN[5*], ALHARBY, H.[6], BAMAGOOS, A.[6], MOHD. FAROOQ[7,8,9], J. HOSSAIN[10], C. BARUTCULAR[11], F. ÇIG [12] and AYMAN EL SABAGH[13*]

[1]*Agronomy Division, Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Ishwardi, Pabna, Bangladesh;* [2] *Plant Breeding Division, RARS, BARI, Ishwardi, Pabna, Bangladesh;*

[3] *Research Fellow, Centre for Crop Health, University of Southern Queensland, Australia;*

[4] *Agricultural engineering Division, RARS, BARI, Ishwardi, Pabna, Bangladesh;*

[5]*Bangladesh Wheat and Maize Research Institute, Dinajpur-5200, Bangladesh;*

[6]*Department of Biological Sciences, Faculty of Science, King Abdulaziz University 21589 Jeddah, Saudi Arabia*

[7]*Department of Crop Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud-123, Oman*

[8]*The UWA Institute of Agriculture and School of Agriculture & Environment, The University of Western Australia, Perth WA 6001, Australia* [9]*Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan;*

[10] *Pulses Research Centre, BARI, Ishwardi, Pabna, Bangladesh;*

[11]*Department of Field Crops, Faculty of Agriculture, Cukurova University, Turkey*

[12]*Department of Field Crops, Faculty of Agriculture, Siirt University, Turkey;*

[13]*Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, 33156 Kafrelsheikh, Egypt;*

***Corresponding authors:** *ayman.elsabagh@agr.kgr.kfs.edu.eg, tanjimar2003@yahoo.com*

ABSTRACT

Thermal unit indices have a strong correlation with the phenology, growth and yield of crops and can be effectively used to select suitable crop cultivars for specific environmental conditions especially temperature. In this study, four mustard varieties (*viz.,* 'BARI Sharisha-14', 'BARI Sharisha-15', 'BARI Sharisha-16' and 'Tori-7') were grown in two consecutive growing to assess the impact of thermal unit indices on crop growth and development, and to select the suitable variety for better yield under optimum sowing condition. Thermal unit indices *viz.,* growing degree-day (GDD), helio-thermal units (HTU), pheno-thermal index (PTI) and heat use efficiency (HUE) were estimated from daily temperature and sunshine hours. Role of GDD on different growth indicators and seed yield (SY) were estimated through association and dependence of the traits. Significant variations in studied genotypes were observed for different traits. Among the studied varieties, 'BARI Sharisha-16' produced higher dry matter and seed yields (1.82 t ha^{-1}) while accumulated maximum GDD at different growth stages. A strong positive association was obtained between GDD and the studied traits. Thermal unit indices had a strong influence in attaining different phenophases and other growth indicators. Therefore, results suggest that those indices could be used for growth prediction; further 'BARI Sharisha-16' is expected to use heat energy more efficiently for increasing the seed yields which indicated that the crop can perform better under global warming scenarios.

***Keywords* :** Growth, mustard, phenology, thermal indices, yield

Mustard is one of the major winter oilseed crops grown across the globe. While it requires cool and dry weather for optimal growth and development. It is sensitive to changes in weather and hence climate change could have a significant impact on its production. In existing practice, a greater part of the vegetative phase is completed when the temperature is relatively high, but during flowering, the temperature is low and later on as the crop reaches maturity, the temperature and photoperiod gradually increase (Nanda *et al.,* 1995). Prevailing weather conditions during the whole crop growing season have a direct association with the phenological developments in the crop plants, which modulate yield formation (Akhter *et al.,* 2016). The morpho-physiological developments are markedly influenced by air temperature during different phenological stages (Srivastava *et al.,* 2005); more importantly, the sensitivity of crop plants increases in winter season due to increase in temperature and greater uncertainties in rainfall (Mall *et al.,* 2004). Boomiraj *et.al* (2010) reported that high temperature combined with erratic rains adversely affect the growth and development in every stage of the crop and cause considerable yield losses by increasing physiological disorder along with an infestation of aphids, white rust, downy mildew and stem rot. Singh *et al.* (2009) also reported stronger correlation of maximum temperature, minimum temperature and average relative humidity with developmof alternaria blight and white rust disease in mustard. While Singh *et al.* (2014) reported that an increase in temperature during the flowering stage of wheat increase pollen sterility that leads to reduce the seed yield wheat. Gill *et al.* (2007) reported that maximum temperature, minimum temperature, relative humidity and sunshine hours had good correlation with the yield of Brassica species.

There are wide variations in the thermal heat unit indices requirement by different mustard varieties (Singh et al., 2014). Crop growth and development are often correlated with thermal unit indices, like growing degree days (GDD), photo-thermal units (PTU), helio-thermal units (HTU), pheno-thermal index (PTI) and heat use efficiency (HUE). These indices relate temperature and sunshine hours to crop growth and dry matter production that can be used effectively for prediction of growth, phenology and yield of crops based on weather parameters (Kingra and Prabhjyot-kaur, 2013; Singh *et al.,* 2014). The concept of thermal unit indices of different varieties may be useful to formulate the recommendation for a specific area on the basis of their local weather condition (Akhter *et al.,* 2016). Among the above indices, GDD is an essential tool that used to identify the adverse effect of temperature and also find out the timing of different biological process (McMaster and Wilhelm, 1997, Ll *et al.,* 2012). For instance, Srivastava and Balkrishna (2003) reported that phenological developmental pattern of mustard regulates its yield and the former is regulated by environmental variables, which could be explained on the basis of GDD. Warthington and Hatchinson (2005) also noticed that rather than the calendar method, all growth and developmental stages of the crop may be estimated more accurately through GDD. However, adaptation strategies, such as planting suitable varieties can also help in reducing impacts of climate change to some extent (Aggarwal, 2008; Bal and Minhas, 2017). Therefore, this study was undertaken to evaluate the performances of different mustard varieties in relation to phenology, growth, thermal unit indices and final grain yield; as well as to select the suitable candidates that fit well in rice-based cropping system of South-Asia including Bangladesh, India and Pakistan under changing the climate.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in two consecutive winter seasons of 2013 and 2014 at the Regional Agricultural Research Station, Ishwardi, Pabna (24.03° N; 89.05° E; 16 masl), Bangladesh. The experimental site belongs to the agro-ecological zone of the High Ganges River Floodplain (AEZ#11).

Soil characteristics and weather data

Experimental soil was analysed before sowing wheat in the first year (Table 1). Soil pH was measured in soil/water (1:2, w/v) using a glass electrode pH meter. Organic carbon was determined by the Walkley and Black oxidation method (Walkley and Black, 1935), total nitrogen (N) by the micro Kjeldhal method (Jackson, 1958), phosphorus (P), potassium (K), sulphur (S) and zinc (Zn) by a modified Hunter's method (BARC, 1984), and boron (B) was estimated colorimetrically by the Azomethine-H method (Sippola and Ervio, 1977).

The textural class of the experimental was clay loam, having 28.5% field capacity. Whereas soil pH was 7.2, organic matter was 1.05%, total nitrogen was 0.06%, available phosphorus was11µg ml^{-1}, available potassium was 0.12 meq100g^{-1} and available sulphur, boron and Zinc was 13, 0.19 and 2.0 µg ml^{-1}. Based on the critical levels, all of these nutrients were above the critical levels except total N and B. Indicated that fertility status in experimental soil was good (Table 1).

Seasonal weather data for the study period were recorded during the experimental period and are given in Fig 1.

Experimental design and treatments

The experiment was laid out in a randomized complete block design with three replications. Four mustard varieties *viz*., 'BARI Sharisha-14', 'BARI Sharisha-15', 'BARI Sharisha-16' and 'Tori-7'were used in this study.

Crop management

The crop was sown on November 6 during 2013 and 2014 in plots measuring 7 m × 5 m in 30 cm spaced rows keeping the plant to plant distance of 5 cm. The crop was harvested from 05 to 28 February 2014 and 2015 depending on the maturity of different varieties used. The crop was fertilized with 138-36-50-32-2.5-2.5 kg N-P-K-S-Zn-B ha^{-1}, respectively. Half nitrogen and all other fertilizers were

Table 1: Initial soil physical and chemical properties of experimental soil

Items	Soil texture (clay loamy)			% Field capacity	pH	OM (%)	N (%)	P (µg ml^{-1})	K (meq100^{-1} soil)	S (µg ml^{-1})	B (µg ml^{-1})	Zn (µg ml $^{-1}$)
	Sand (18.6%)	Silt (32.0%)	Clay (49.4%)									
Initial soil				28.5	7.2	1.05	0.06	11.00	0.12	13.00	0.19	2.0
Critical level	-	-	-		-	-	0.12	10.00	0.12	10.00	0.20	0.60

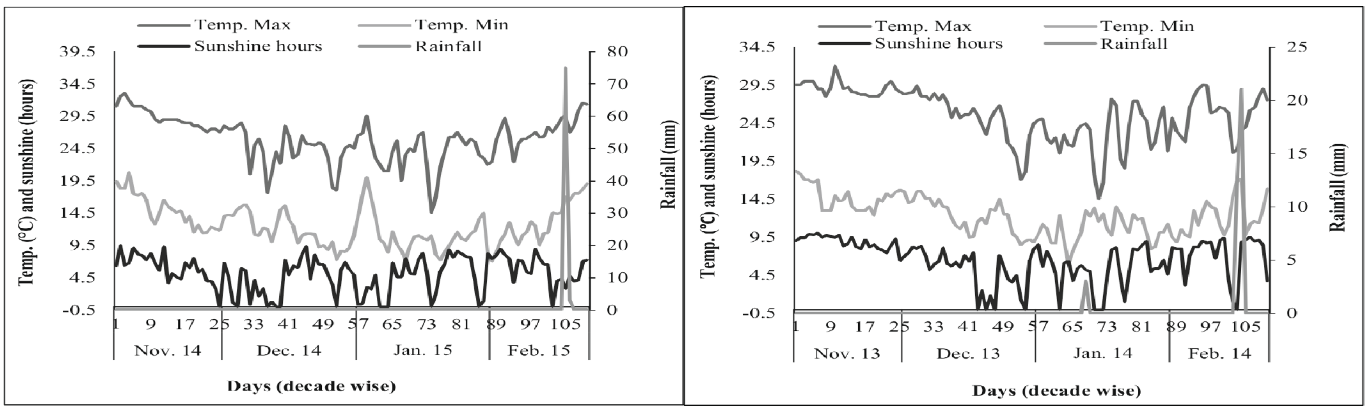

Fig. 1: Decade (weekly) wise temperatures and sunshine hours during the crop growth period in both years

Table 2: Crop phenology (pooled) at different growth phases of mustard studied during *rabi* season of 2013-14 and 2014-15

Varieties	Days required to-										
	RS	BIS		FIS		FFS		YCS		RiS	
	Particular	Particular	Cum.	Particular	Cum.	Particular	Cum.	Particular	Cum.	Particular	Cum.
BARI Sharisha-14	22	3	25	5	30	2	32	49	81	5	86
BARI Sharisha-15	22	5	27	6	33	3	35	48	83	5	88
BARI Sharisha-16	23	10	33	5	38	6	44	56	102	8	110
Tori-7	16	4	20	5	25	2	27	49	76	6	82
Mean	20.5		26.25		.35		34.5		85.25		91.25
SD	3.00		5.38		5.06		7.14		10.90		12.74

SD=Standard deviation, RS=Rosette stage, BIS=Bud initiation stage, FIS=Flower initiation stage, FFS=50% flowering stage, YCS=Yellowing of capsule stage, RiS= Ripening stage.

applied as a basal dose. Remaining nitrogen was top-dressed during the flowering stage. Weeds were controlled by manual hoeing 15 days after emergence. A post sowing irrigation was done for proper germination and seedling establishment. The subsequent irrigations were applied at 20-25 days after sowing (DAS) (pre-flowering stage) and 50-55 DAS (pod development stage) during both the years. To protect the crop from the aphid (*Lypaphis erysimi*) infestation, dimethoate (Tafgor 40 EC) was sprayed at 0.02% during vegetative and pod development stage.

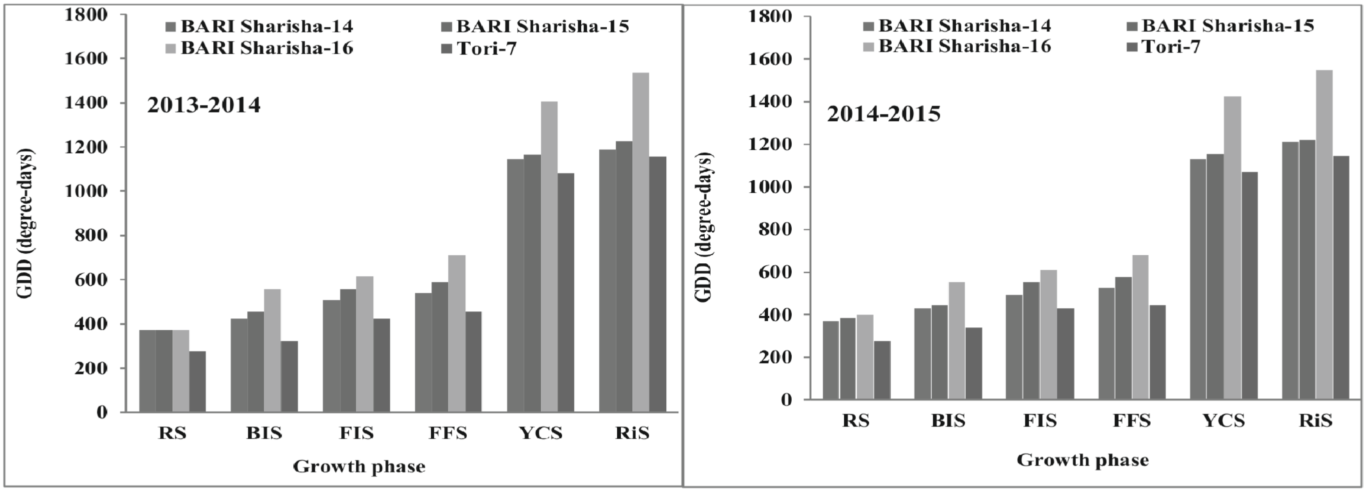

Fig. 2: GDD (degree-days) requirement of mustard varieties at different phenophases in both years

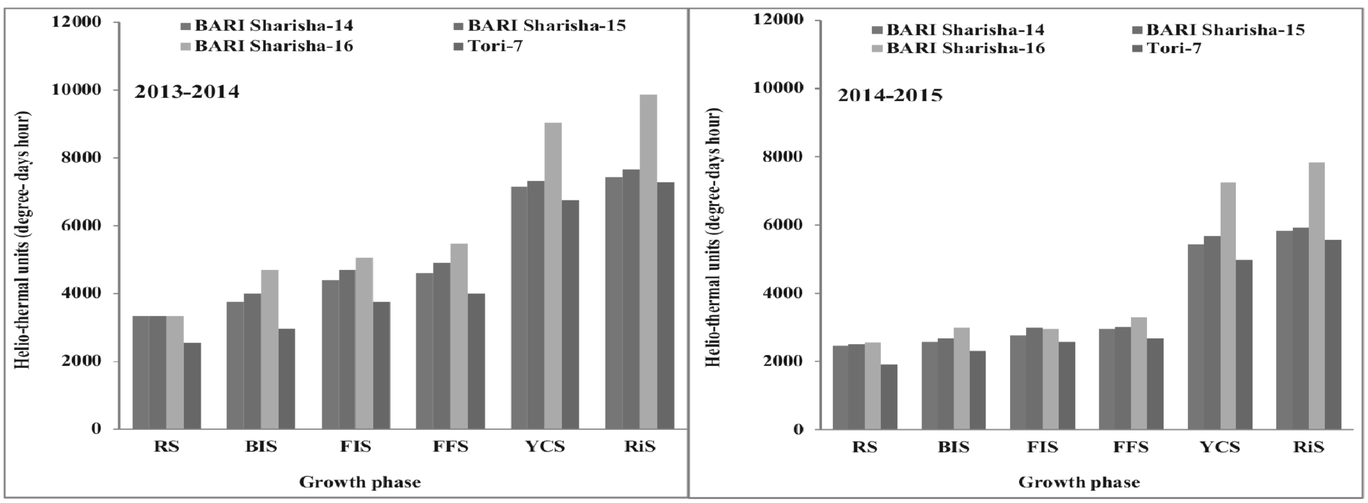

Fig. 3: Helio-thermal units (degree-days hour) requirement of mustard varieties at different phenophases in both years

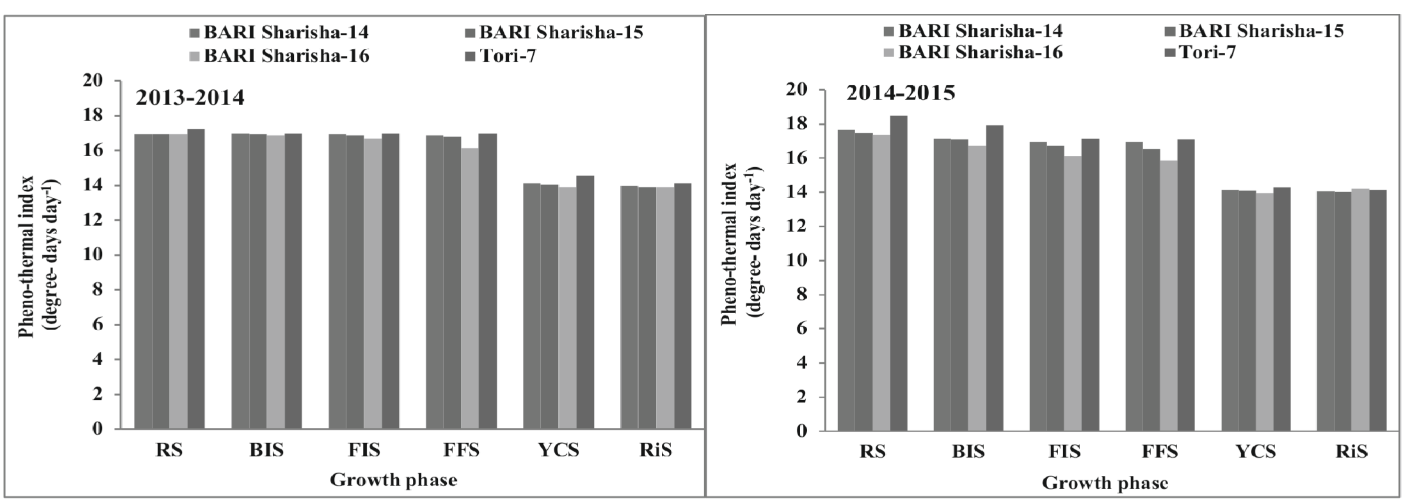

Fig. 4: Pheno-thermal index (degree-days day^{-1}) requirement of mustard varieties at different phenophases in both years

Table 3: Growth indices (viz., LAI & CGR) (pooled) at different growth phases of mustard studied during *rabi* season of 2013-14 and 2014-15

Variety	Leaf Area Index (LAI)				Crop Growth Rate (CGR)					
	RS	BIS	FIS	FFS	RS	BIS	FIS	FFS	YCS	RiS
BARI Sharisha-14	0.30	0.81	0.83	0.88	0.66	4.71	8.45	11.01	7.77	3.44
BARI Sharisha-15	0.23	0.74	0.77	0.87	0.52	3.43	7.68	9.11	7.56	5.05
BARI Sharisha-16	0.39	1.83	2.31	3.30	0.96	7.72	11.56	15.60	15.03	12.29
Tori-7	0.19	0.27	0.39	0.35	0.67	2.58	4.44	5.18	4.62	2.72
Mean	0.28	0.91	1.08	1.35	0.70	4.61	8.03	10.23	8.75	5.87
Vg	0.04**	2.59**	4.27**	10.53**	0.21**	30.38**	51.22**	112.34**	117.82**	115.34**
LSD(0.05)	0.01	0.08	0.08	0.20	0.10	0.50	0.43	0.66	0.63	0.82
CV (%)	5.39	6.59	5.56	11.97	10.85	8.53	4.24	5.15	5.71	11.04

**Significant at 1% level. Vg=Variance due to genotype, LSD=Least significant difference, CV=Coefficient of variation, RS=Rosette stage, BIS=Bud initiation stage, FIS=Flower initiation stage, FFS=50% flowering stage, YCS=Yellowing of capsule stage, RiS= Ripening stage.

Data recording

The whole life cycle of mustard varieties were categorized into six different growth stages *viz*., rosette stage (four leaves in clear nodes), bud initiation stage (appearance of first reproductive bud), flowering stage (fully open first flower), 50% flowering stage (flower open in 50% coverage of the plots), yellowing of capsules stage (appearance of yellow colour in capsules i.e., physiological maturity) and ripening stage (yellow to straw colour in capsules i.e., harvesting maturity). Plant samples were collected at all these phenophases to record dry matter accumulation, crop growth rate (CGR) and leaf area index (LAI). At maturity, five plants were hand-harvested randomly from each experimental unit, from which plant height, capsule/plant, capsule length, and seeds/capsule were determined. The number of capsules/plant and seeds/capsule were counted from 20 randomly selected capsules after hand threshing.

Calculating different thermal unit indices

Growing degree days (GDD), helio-thermal units (HTU), pheno-thermal index (PTI) and heat use efficiency (HUE) were calculated at different phenological stages according to Singh *et al.* (2014). GDD were computed with 5°C as the base temperature on the basis of daily mean temperature from the following equation:

$$\text{GDD (Growing day degree)} = \frac{\sum (T_{max} + T_{min})}{2} - T_b$$

where, T_{max}= Maximum temperature, T_{min}= Minimum temperature and T_b= base temperature of mustard.

HTU (degree-days hours) of successive growth phases were calculated on the basis of GDD and sunshine hours by using the following formula:

$$\text{HTU} = [\text{GDD}] \times \text{Duration of sunshine hours}$$

The duration of sunshine hours per day of successive growth phases was calculated by the following equation:

$$\text{The duration of sunshine hours} = \frac{\text{Total bright sunshine hours of the phases}}{\text{Duration of the phase}}$$

PTI (degree-days day^{-1}) was calculated using the following equation:

$$\text{PTI} = \frac{\text{GDD}}{\text{Growth day}}$$

Heat use efficiency (HUE) (kg ha^{-1} degrees-day) was calculated with the help of the following equation:

$$\text{HUE} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{GDD}}$$

Table 4: Dry matter partitioning (pooled) at different growth phases of mustard studied during *rabi* season of 2013-14 and 2014-15

Variety	RS		BIS		FIS		FFS		YCS		RiS	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Stem	Fruit	Stem	Fruit
BARI Sharisha-14	9.88	4.46	21.16	7.38	37.77	33.92	41.76	52.28	175.79	310.72	183.36	317.80
BARI Sharisha-15	8.06	3.14	15.24	13.25	32.42	27.40	32.97	45.46	181.98	271.16	200.22	279.13
BARI Sharisha-16	16.19	4.62	74.23	31.94	95.45	57.64	128.09	31.89	620.45	544.60	664.79	612.39
Tori-7	7.10	3.27	11.86	8.98	18.00	16.51	19.45	25.79	86.87	197.60	95.67	206.26
Mean	10.31	3.87	30.62	15.39	45.91	33.87	55.57	63.86	266.27	331.02	286.01	353.89
Vg	100.3	3.6	5159.7	767.6	6961.7	1816.8	14529.0	13099.5	345833.3	134828.8	395194.3	191017.1
F test	**	**	**	**	**	**	**	**	**	**	**	**
LSD (0.05)	0.91	0.44	3.17	0.68	4.78	3.48	7.97	2.74	7.28	16.12	16.98	11.42
CV (%)	7.03	9.01	8.22	3.50	8.27	8.17	11.40	3.41	2.17	3.87	4.72	2.57

**Significant at 1% level. Vg=Variance due to genotype, LSD=Least significant difference, CV=Coefficient of variation, RS=Rosette stage, BIS=Bud initiation stage, FIS=Flower initiation stage, FFS=50% flowering stage, YCS=Yellowing of capsule stage, RiS= Ripening stage.

Table 5: Performance (pooled) of mustard varieties for yield and its attributes studied during *rabi* season of 2013-14 and 2014-15

Varieties	PH (cm)	CPP (no.)	SPC (no.)	CL (cm)	TSW (g)	SY (t/ha)
BARI Sharisha-14	82.26	65.68	29.52	4.76	3.32	1.44
BARI Sharisha-15	105.18	93.68	22.89	5.10	3.08	1.40
BARI Sharisha-16	184.22	7.20	16.32	3.98	4.52	1.82
Tori-7	64.99	86.41	15.82	4.67	2.52	1.12
Mean	109.16	113.38	21.14	4.63	3.36	1.44
Vg	16649.63**	24591.44**	249.67**	1.34**	4.26**	0.49**
LSD(0.05)	5.91	4.35	1.94	0.26	0.22	0.10
CV (%)	4.30	3.05	7.29	4.40	5.23	5.54

**Significant at 1% level. Vg=Variance due to genotype, LSD=Least significant difference, CV=Coefficient of variation, PH=Plant height, CPP=Capsule per plant, SPC=Seed per capsule, CL=Capsule length, TSW=Thousand seed weight, SY=Seed yield.

Table 6: Association of GDD with growth indicating traits and SY based on pooled data studied during *rabi* season of 2013-14 and 2014-15

	FFS data			RiS data		
	LAI	Leaf dry matter	Stem dry matter	Capsule dry matter	CGR	SY
GDD	0.85	0.82	0.99	0.99	0.99	0.93

GDD=Growing degree day, LAI=Leaf area index, FFS=50% flowering stage, RiS= Ripening stage, CGR=Crop growth rate, SY=Seed yield.

Table 7: Association of different studied traits among mustard varieties based on pooled data studied during rabi season of 2013-14 and 2014-15.

	CPP	SPC	CL	TSW	SY
PH	0.95*	-0.35	-0.75	0.95*	0.94*
CPP		-0.60	-0.86	0.86	0.82
SPC			0.53	-0.12	0.04
CL				-0.78	0.69
TSW					0.99**

*Significant at 5% level, **Significant at 1% level. PH= Plant height, CPP = Capsules per plant, SPC = Seed per capsule, CL = Capsule length, TSW = Thousand seed weight, SY = Seed yield.

Statistical analyses

The data were subjected to variance analysis using the computer statistical software package MSTAT-C (Freed *et al.,* 1989). The means separations were done by LSD at 0.05 levels of probability when the F value was significant. MS Excel software program was used for the graphical description.

RESULTS AND DISCUSSION

Temperature scenario and thermal unit indices

The temperature, as well as sunshine hours, are important weather elements for crop response towards growth and development. The temperature scenario along with sunshine hours was depicted in Fig 1. The maximum temperature (T_{max}) ranges from 14.5 - 32 °C and 14.5 - 33 °C, while the minimum temperature (T_{min}) varied from 6 to 18.2°C and 7 to 20.8 °C during the crop season (November-February), respectively, in 2013-2014 and 2014-2015. In both the years, the highest T_{max} was recorded in 1st decade of the growing period and lowest T_{min} was in 7th decade both the years. However, longest sunshine hours were also observed at 1st decade (weekly) of the crop cycle. The temperature (T_{max} and T_{min}) and sunshine hours gradually decreased from 1st decade to 5th decade and thereafter, it increased.

Crop phenology

For advancement from one growth stage to another, the plant requires a specific time and amount of heat unit (measured in terms of growing degree days, GDD). The total life cycle of mustard were divided into six distinct growth phases (i.e., Rosette stage (RS), bud initiation stage (BIS), flowering initiation stage (FIS), 50% flowering stage (FFS), yellowing of capsules stage (YCS) and Ripening stage (RiS)) was varied among the varieties. The duration to reach at different growth phases were presented in Table 2. 'BARI Sharisha-16' took maximum time as compared to other varieties to attain these stages. It required 23, 33, 38, 44, 102 and 110 days, respectively which was followed by 'BARI Sharisha-15' (22, 27, 33, 35, 83 and 88 days, respectively). 'BARI Sharisha-14' taking 22, 25, 30, 32, 81 and 86 days for attaining those stages while 'Tori-7'cultivar took minimum days (16, 20, 25, 27, 76 and 82 days, respectively). It was evident from the observations that 'Tori-7'had the shortest life cycle whereas, 'BARI Sharisha-16' had the longest one as it took more time to complete all growth stages, more specifically bud initiation and yellowing of capsules stages.

In both the years, the higher GDD was accumulated in 'BARI Sharisha-16' during all the phenophases starting from

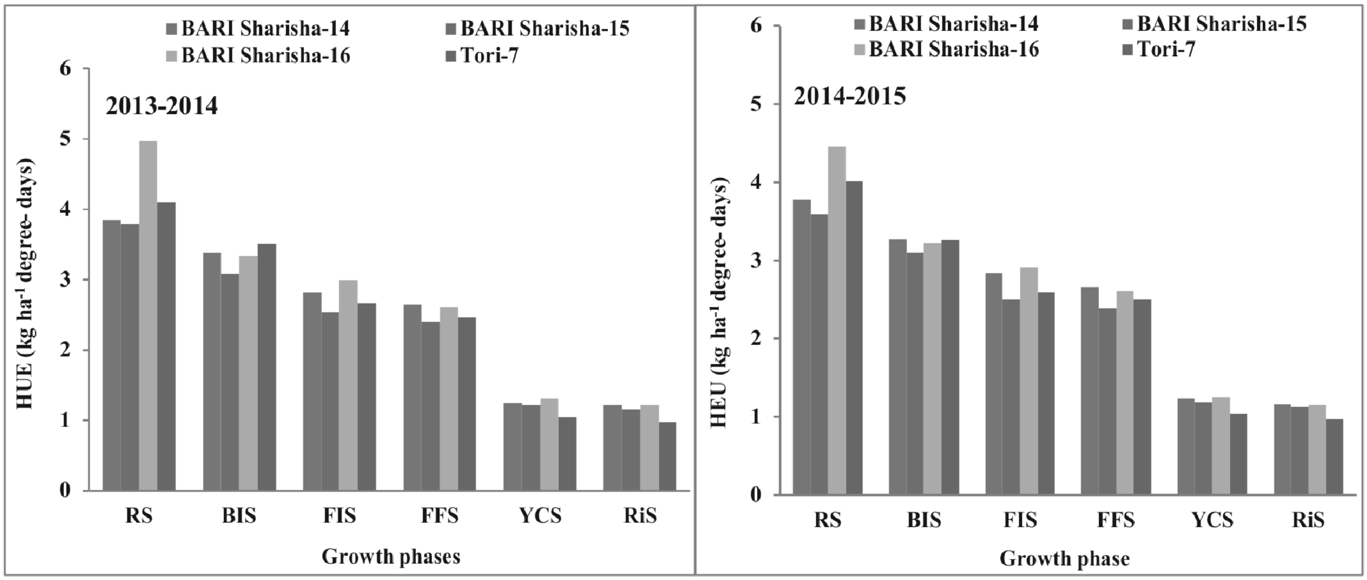

Fig. 5: Heat use efficiency (kg ha^{-1} degree-days^{-1}) requirement of mustard varieties at different phenophases in both years

sowing to maturity followed by 'BARI Sharisha-15', while the lowest GDD values were recorded in Tori-7 (Fig 2). Consequences of GDD at various phenological stages are in agreement with the findings reported by Renganayaki and Krishnasamy (2013).

Some other thermal indices estimated from GDD are also important indicators for prediction of growth stages as well as final harvest. HTU (degree-days hours) was increased gradually, whereas, PTI and HUE gradually decreased with the advancement of the plant ages during both the years (Fig 3, 4 & 5). The finding was in agreement with Singh *et al.* (2014), Neog and Chakravarty (2005). For different growth phases, the higher values of HTU and HUE and lower values of PTI were recorded in 'BARI Sharisha-16', while quite the opposite were obtained in Tori-7. Higher HUE in 'BARI Sharisha-16' was due to higher seed yield which increases the thermal efficiency. Furthermore, this indicated that the crop can utilize heat more efficiently, and can perform better under global warming scenarios (Kingra and Prabhjyot-kaur. 2013). Some earlier studies also indicated that thermal indices had an influence on phenological phases (Srivastava and Balkrishna, 2003; Khushu *et al*., 2008; Singh *et al*., 2014).

Leaf area index (LAI)

Growth indicators are the component that predict and reflect to crop yield. One of the growth indicators, leaf area index (LAI) is the ratio of leaf area and ground area that characterizes of canopy architecture. It regulates total light energy interception by the plants. Significant variation in LAI was observed at all growth phases for mustard varieties (Table 3). LAI increased with the advancement of the plant growth stages which caused variation in plant architecture of the varieties. LAI reached to a maximum level at 50% flowering stage then decreased at a later growth stage (YCS and RiS), because of leaves shading. Hence, dry matter produced decreases with decreasing of LAI (Islam *et al.,* 2017) and therefore has a large influence on crop yield (Dwyer and Stewart, 1986). Srivastava *et al.* (2005) also reported that LAI was positively correlated with accumulated GDD in mustard. However, 'BARI Sharisha-16' had highest LAI (0.39 to 3.30) followed by 'BARI Sharisha-14' (0.30 to 0.88) and 'BARI Sharisha-15' (0.23 to 0.87) and the lowest LAI were obtained at 'Tori-7'(0.19 to 0.35) in all the growth phases. It might be due to the canopy architecture was higher in 'BARI Sharisha-16' than those of other varieties.

Crop growth rate (CGR)

Crop growth rate (CGR) was estimated from the dry matter accumulation at different growth phases. Significant variation was observed in the crop growth rate (CGR) among the different mustard varieties at all growth stages (Table 3). The CGR was slow at early growth stages and thereafter it gradually increased up to 50% flowering and again declined until maturity. It might be due to leaf senescence and shading at the later growth stage which might have reduced the photosynthetic efficiency and ultimately reduced the dry matter accumulation rate. Toosi (2015) reported that after the rosette stage by increasing the temperature and increasing light by sunny days the plant growth increased significantly and reached the maximum at the flowering stage. However, the highest CGR was recorded in BARI Sharisha 16 (0.96 to 15.60 g m^{-2} day^{-1}) followed by BARI Sharisha 14 (0.66 to 11.01 g m^{-2} day^{-1}) and BARI Sharisha 15 (0.52 to 9.11 g m^{-2} day^{-1}), while the lowest growth rate was recorded in 'Tori-7'variety (0.67 to 5.18 g m^{-2} day^{-1}) in different growth phases.

Dry matter partitioning at different growth phases of mustard

Dry matter accumulation in terms of leaf, stem and capsule dry weight were significantly varied among the mustard varieties for different growth stages (Table 4). The dry weight of capsules was measured at YCS and RiS. Leaf dry weight at 50% flowering was highest among the growth stages irrespective of all varieties, due to shading of leaves. Significant increase in stem dry weight was obtained with all varieties along with the progression of different growth phases. However, 'BARI Sharisha-16' produced maximum leaf dry matter (16.19 g to 128.09 g/m^2), stem dry weight (4.62g to 664.79 g/m^2) and capsule dry weight (544.60g to 612.39 g/m^2) in various growth phases which was followed by 'BARI Sharisha-14' and 'BARI Sharisha-15'. Cultivar 'Tori-7'produced least dry matter in all cases may be due to its shorter life cycle as well as plant architecture. The dry weight per unit of area was higher with 'BARI Sharisha-16' indicating the favorable response of biomass production. Islam *et al.* (2017) reported that dry matter production by the plants depends on the amount of light energy interception by the leaves and its efficiency of conversion into chemical energy. Better dry matter production and its proper translocation into reproductive organ are the prime requisites of higher productivity of a crop (Ahmed *et.al*, 2010).

Yield contributing traits and seed yield

Plant height (PH), capsule $plant^{-1}$ (CPP), seeds/capsule (SPC), capsule length (CL), 1000-seed weight (TSW) and seed yield (SY) were significantly varied among the varieties (Table 5). Maximum SY (1.82 t ha^{-1}) was obtained with 'BARI Sharisha-16' which was followed by 'BARI Sharisha-14', 'BARI Sharisha-15' and Tori-7, it might be due to the fact that 'BARI Sharisha-16' got longer time period to utilize available resources (light, nutrients, moisture etc.). Statistically similar SY was produced from 'BARI Sharisha-14' (1.44 t ha^{-1}) and 'BARI Sharisha-15' (1.40 t ha^{-1}). The lowest SY (1.12 t ha^{-1}) were observed in Tori-7. Similar findings of lower resource utilization by short-duration varieties were also reported from earlier studies (Sultana *et al.,* 2009; Anjum *et al.,* 2005). The results also revealed that SY was less by 21%, 23% and 38% in 'BARI Sharisha-14', 'BARI Sharisha-15' and Tori-7, respectively, while compared to 'BARI Sharisha-16'. Highest PH (184.22cm) was recorded from 'BARI Sharisha-16' followed by 'BARI Sharisha-15' (105.18 cm) and the lowest (64.99 cm) was in Tori-7. Considerably highest CPP (207.74) was observed in 'BARI Sharisha-16' and the minimum (65.68) in 'BARI Sharisha-14'. The maximum CL (5.10cm) was obtained in 'BARI Sharisha-15' which was almost similar with 'BARI Sharisha-14' and the shortest capsule (3.98cm) was recorded in 'BARI Sharisha-16'. SPC was found higher in 'BARI Sharisha-14' (29.52) as compared to other varieties and the lowest SPC was found in 'Tori-7' (15.82) which was statistically similar with 'BARI Sharisha-16' (16.32). Lower values for all the yield attributing traits were also observed in varieties having a shorter growth cycle (Sultana *et al.,* 2009, Hossain and Khan, 2003). 'BARI Sharisha-16' produced the highest TSW (4.52g) followed by 'BARI Sharisha-14' (3.32g). The lowest TSW was obtained in 'Tori-7' (2.52g). The difference in TSW might be due to genetic variations among the mustard varieties.

Traits associations and dependence

Association analysis indicates the relationship and their direction among the studied traits. The analysis was performed using pooled data between GDD and growth indicating traits along with SY. For LAI and leaf dry matter FFS data were used as plants started to shed leaves after this stage; whereas, RiS data were used for other traits. The result from the analysis specifies that all the studied traits possessed a strong positive association with GDD (Table 6). From association analysis, it was clear that GDD had a significant contribution to growth indicators and seed yield. To assess the contribution of GDD, linear regression of GDD on some growth indicators and SY were done. To do so FFS data were used for LAI and leaf dry matter, whereas, RiS data were used for other traits. Results revealed that GDD accounted for 73%, 68%, 99%, 94%, 99% and 87% of the total LAI, leaf dry matter, stem dry matter, capsule dry matter, CGR and SY variation (Figure 6 & 7). LAI might have an influence on leaf dry matter and CGR. To reveal the influence linear regression of LAI on leaf dry matter and CGR done based on FFS data. The result indicated that LAI explained upto 99% and 83% variability of leaf dry matter and CGR (Figure 6).

Association of different studied traits among mustard varieties

The association analysis was also performed using two years mean data among yield and its attributing traits and the results revealed that SY showed a significant positive

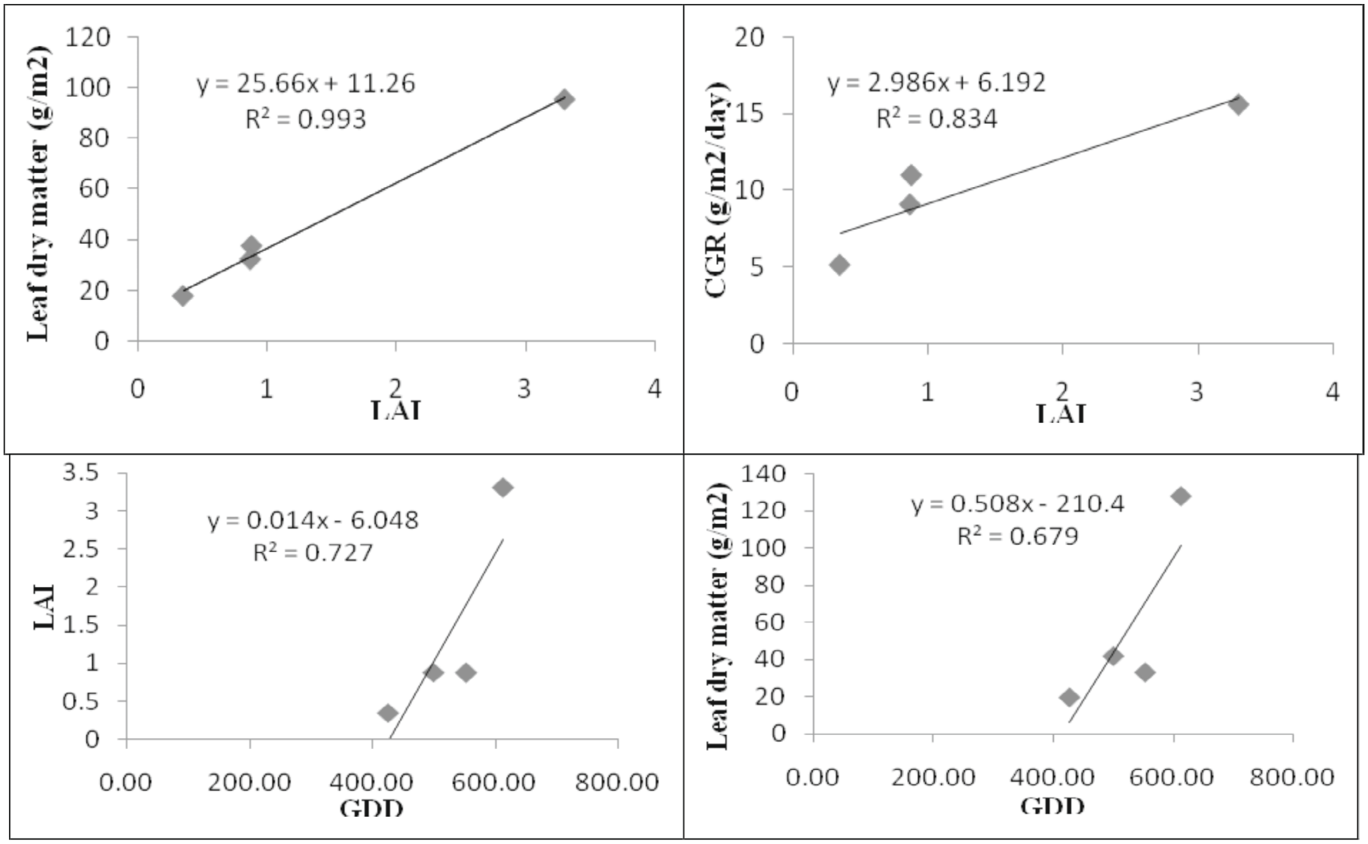

Fig. 6: Contribution of LAI (top) and GDD (bottom) on growth indicators

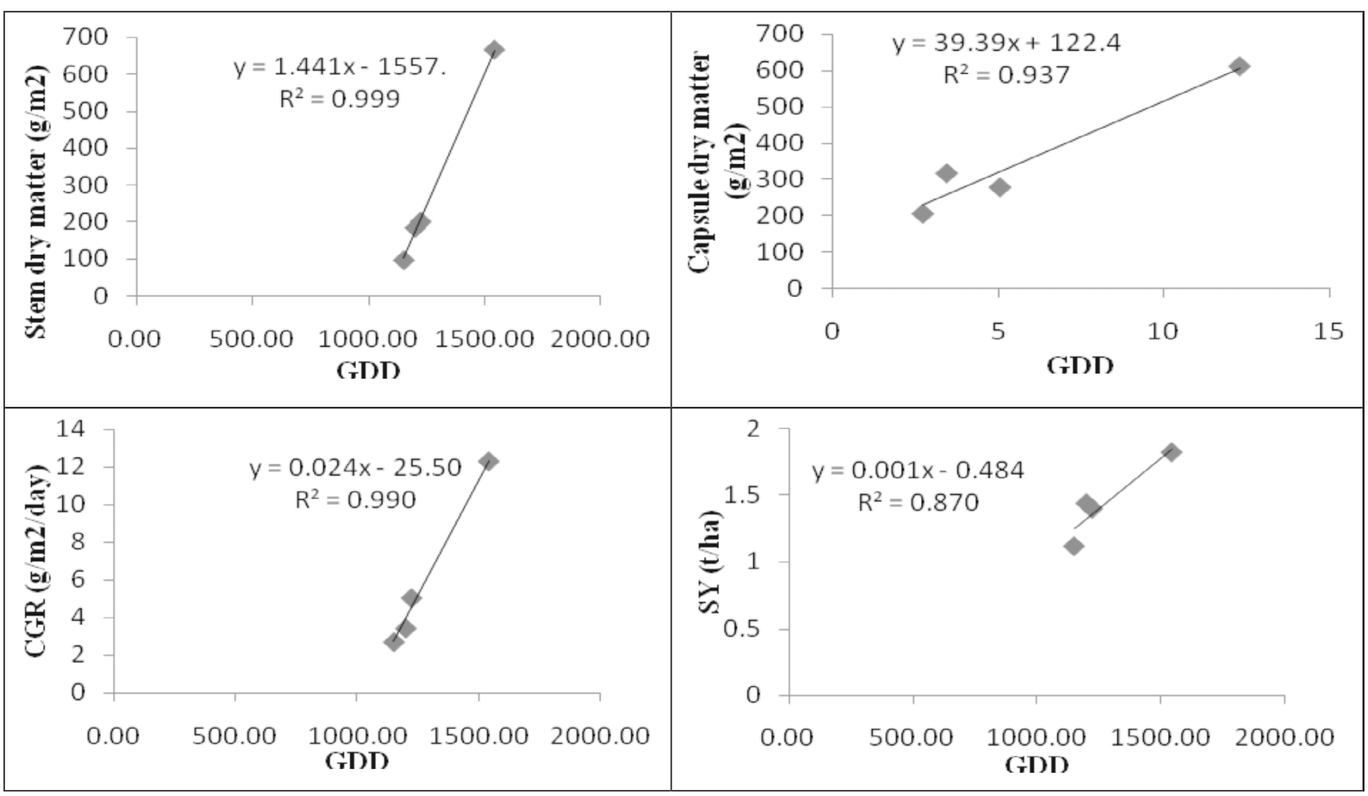

Fig. 7: Contribution of GDD on growth indicators

association with PH (r=0.94*) and TSW (r=0.99**) (Table 7). On the other hand, plant height showed a positive and significant relationship with CPP (0.95*) and TSW (0.95*); while it showed a negative correlation with SPC (-0.35) and CL (-0.75). Height of the mustard plant is associated with the total number of capsules in the plant. The number of capsules proportionally increases with the increase in height which consequently translates into the final seed yield. Similarly, seed yield increases with the increase in seed size (i.e., TSW). On the contrary with the decrease in height of the plant, length of the capsule and number of seeds per capsules increases; but the size of the seed decreases due to the translocation of the assimilates distributed into more seeds.

It was clear from the observations that 'BARI Sharisha-16' accumulated more thermal units in comparison with 'BARI Sharisha-14', 'BARI Sharisha-15' and Tori-7. Similarly, this variety possessed the highest LAI and accumulated most dry matter along with fastest growth rate per unit area. All these characters were ultimately translated as SY which is the reason for being ranked one among the studied varieties. It is pretty clear from these findings that the genotype with a longer life cycle normally gets the opportunity to accumulate higher thermal unit throughout the growing period. The longer life spans, the more the accumulations of thermal units. Kingra and Kaur (2012) and Tharranum *et al.* (2009) observed that earlier sown crop availed higher cumulated heat units at physiological maturity in groundnut and brassica species than delay sowing. Higher LAI ensures more light interception which increases the photosynthesis ability of the plant. Faster dry matter accumulation for a longer period of time helps in producing more yields. Association and regression analysis added a feather to these findings and strongly indicated that thermal unit accumulation had significant contribution to dry matter accumulation whereas LAI contributed via light interception and photosynthesis.

CONCLUSIONS

There was distinct variation in the duration of phenological stages mainly due to the thermal environment of the crop. The higher grain yield (1.82 t/ha) together with the thermal unit indices and growth indicators were recorded in 'BARI Sharisha-16'. GDD had a great contribution towards those traits expression/variations. Thermal unit indices enhance the plant growth and development resulting in higher yield potentiality of the crops. Growth stages of the plant could easily be predicted from thermal unit indices specifically from GDD. Different agronomic practices might also be applied based on GDD. Therefore, thermal unit indices can be used as an important tool along with growth indicators for selection of variety for any area.

AKNOWLEDGEMENT

We are most grateful to all staffs of Regional Agricultural Station, BARI, Ishordi, Pabna, Bangladesh

REFERENCES

Aggarwal, P.K. (2008). Impact of climate change on Indian agriculture: impacts, adaptation and mitigation. *Indian J. Agric. Sci.* 78: 911–919.

Ahmed, F., Islam, M.N., Rahman, M.T., Jahan, M.A. and Khan, M.S.A. (2010). Leaf area index, radiation interception, dry matter production and grain yield of hybrid maize as influenced by plant spacing. *Bangladesh Agron. J.* 13(1&2): 51-58.

Akhter, S., Singh, L., Saxena, A., Rasool, R., Ramzan, S. and Showqi, I. (2016). Agro meteorological indices for brown sarson (Brassica rapaL.) sown under different dates of sowing in temperate region of Kashmir. *The Bioscan*, 11(1): 279-283.

Anjum, R., Yousaf, M., Jahangir, M., Hussain, M., Nawaz, N. and Ahmed, A. (2005). Adaptation and yield potential of different genotypes of rapeseed and mustard under agro-climatic condition of Bahawalpur (Pakistan). *Int. J. Agric. Biol*. 7(4): 609-611.

Bal, S.K. and Minhas, P.S. (2017) Atmospheric Stressors: Challenges and Coping Strategies. In: P.S. Minhas et al. (eds) Abiotic Stress Management for Resilient Agriculture. Springer Nature Singapore Pte. Ltd., pp. 9-50.

BARC (Bangladesh Agricultural Research Council), (2005). Fertilizer Recommendation Guide. BARC, Farmgate, Dhaka 1215, Bangladesh.

Boomiraj, K., Wani, S.P., Garg, K.K., Aggarwal, P.K. and Palanisami, K. (2010). Climate change adaptation strategies for agro-ecosystem –a review. *J. Agrometeorol.,* 12(2): 145-160.

Dwyer, L.M. and Stewart, D.W. (1986). Leaf Area Development in Field-Grown Maize. *Agron. J.* 78: 334-343.

Freed, R., Einensmith, S.P., Gutez, S., Reicosky, D., Smail, V.W. and Wolberg, P. (1989). User's Guide to MSTAT-C Analysis of Agronomic Research Experiments. Michigan State University, East Lansing, U.S.A.

Gill, K.K., Kingra, P.K., Mukherjee, J. and Bal, S.K. (2007) Brassica yield forecasting in Central Punjab. *Indian J. Ecol.,* 34(1):36-39.

Hossain, M.A. and Khan, M.S.A. (2003). Genetic variation in root growth, dry matter accumulation, nutrient uptake and yield of Brassica Species. *Bangladesh J. Agric. Sci.* 30(1):143-150.

Islam, M.R., Zaman, R., Alam, M.A., Khan, M.A.A. and Hossain, J. (2017). Yield potentiality of maize as relay crop with T.Aman rice under different agronomic management. *Cercetări Agronomice în Moldova.* 50(2): 35-49.

Jackson, M.C. (1958). Soil chemical analysis. Prentice Hall incorporation Eaglewood Cliffs. New York.

Khushu, M.K., Naseer-Ur, R., Singh, M., Tiku, A.K. and Bali, A.S. (2008). Thermal time indices for some mustard genotypes in the Jammu region. *J. Agrometeorol.* 10(2): 224-227.

Kingra, P.K. and Prabhjyot-Kaur (2013). Agroclimatic Study for Prediction of Growth and Yield of Brassica sp. in Central Punjab. *J. Agric. Phys.*, 13(2): 148-152.

Li, Q.Y., Jun, Y.I.N., Liu, W.D., Zhou, S.M., Lei, L.I., Niu, J.S., Niu, H.B. and Ying, M.A. (2012). Determination of optimum growing degree days (GDD) range before winter for wheat cultivars with different growth characteristics in North China Plain. *J. Integrat. Agric.*, 11: 405–415.

Mall, R.K., Lal, M., Bhatia,V.S., Rathore, L.S. and Singh, R. (2004). Mitigating climate change impact on soybean productivity in India: a simulation study. *Agric. For. Meteorol.,* 121: 113–125.

McMaster, G.S. and Wilhelm, W.W. (1997). Growing degree-days: One equation, two interpretations. Agric. For. Meteorol., 87: 291–300.

Nanda, R., Bhargava, S.C. and Rawson, H.M. (1995). Effect of sowing date on rates of leaf appearance, final leaf numbers and areas in *Brassica campestris, B. jrtncea, B. napus* and *B. carinatu*. *Field Crops Res.*, 42: 125-34.

Neog, P. and Chakravarty, N.V.K. (2005). Thermal indices in Brassica grown under a semi-arid environment. *Ann. Agric. Res.*, 26: 291–296.

Renganayaki, P.R. and Krishnasamy, V. (2013). Correlation equation for synchronized flowering in sunflower (*Helianthus annuus* L.) hybrid KBSH-1 parental lines based on meteorological parameters., *Afr. J. Agric. Res.* 8(17): 1738–1742.

Singh M.P. and Lallu-Singh, N.B. (2014). Thermal requirement of Indian mustard (*Brassica juncea*) at different phonological stages under late sown condition. *Ind. J. Plant Physiol.,* 19(3): 238–243.

Singh, H., Prabhjyot-Kaur, Ratinderbir-Kaur, Mukherjee, J. and Bal, S.K. (2009). Influence of meteorological parameters on the incidence and development of white rust and alternaria blight in mustard (*Brassica juncea* L.) crop in the south-western region of Punjab. *J. Agrometeorol.*, 11(Special issue): 135-142.

Sippola, J. and Ervio, R. (1977). Determination of boron in the soils and plants by the Azomethine-H method. *Finnish Chem. Lett.*, 138–140.

Srivastava, A.K., Chakravarty, N.V.K., Sharma, P.K., Bhagavati, G., Prasad, R.N., Gupta, V.K., Sutradhar, A.K., Subba Rao, Y.V. and Chopra, U.K. (2005). Relation of growing degree-days with plant growth and yield in mustard cultivars grown under a semi-arid environment. *J. Agric. Phys.*, 5: 23-28.

Srivastava, J.P. (2003). Environmental parameters influencing phenological development of mustard in relation to yield. *Indian J. Plant Physiol.*, 8(4): 349-353.

Sultana, S., Amin, A.R. and Hasanuzzaman, M. (2009). Growth and yield of rapeseed (*Brassica campestris* L.) varieties as affected by levels of irrigation. *American-Eurasian J. Sci. Res.*, 4(1): 34-39.

Tharranum, M., Singh, R., Niwas, R. and Singh, D. (2009). Thermal time requirements and life span of Brassica species under different growing environments. Abstracts and Souvenier 4th National Seminar on Agrometeorology-Needs, Approaches and linkages for rural development, CCS HAU, Hisar., p. 34.

Toosi, A.F. (2015). Measuring of yield and yield components of winter rapeseed varieties on different planting dates. *Scientific Papers-Series A, Agron.*, 58: 195-197.

Walkley, A.C. and Black, T.A. (1935). Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.*, 47: 29–38.

Warthinhton, C.M. and Hatchinson, C.M. (2005). Accumulated degree days as a model to determine key development stages and evacuate yield and quality of potato in Northeast Florida. *Proc. State Hort. Soc.,* 118: 98–101.

Received : March 2019 : Accepted : August 2019