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Research Article

Effect of Weather Variability on Yield and Thermal Utilization for Attaining Different Phenological Stages in Mustard

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ABSTRACT

An experiment was conducted on the sandy loam soil of research farm of IARI, New Delhi during *Rabi* 2010-11 and 2011-12 with mustard cultivar (Pusa Gold, Pusa Jaikisan and Pusa Bold) sown on three different dates with the aim for generating different weather conditions during various phenological stages. Different crop growth parameters and accumulated thermal indices were calculated during different phenological stages. Results showed that the early sown crop had longer crop span than the late sown. Delay in sowing reduced the value of thermal indices as well as biomass and seed yield in both the year resulted that the weather during crop growing period influence the crop production. The heat use efficiency as well as the photo thermal index decreased from germination to the maturity. The biomass and yield had positive correlation with different accumulated thermal index. Therefore, thermal index could be used for studying biomass accumulation at different phenological stages and for assessing crop yield forecast.

Key words: Mustard, Biomass, Thermal indices, Heat use efficiency

Introduction

Oil seed crop plays an important role in India's economy. Among different oil seed crops, mustard (*Brassica* spp.) is the second most important and contributing nearly 30% of total oil seed production in the country. Micro-environment influences the growth and yield of the crop. Depending upon the crop condition, the micro environment varies during the crop growing period. Various environmental factors affecting the crop growth are light intensity, photo synthetically active radiation, temperature, relative humidity, wind speed, soil temperature and soil moisture. Radiation and temperature has key role in influencing crop production. Gouri *et al*. (2005) reported that growing degree days can be used for estimating the occurrence of different phenological events during crop growing period in relation to temperature. Accumulated GDD can estimate the harvest date as well as crop development stage (Roy *et al*., 2005).

The duration of a particular stage of growth was directly related to the temperature and this duration could be predicted using the sum of daily air temperature (Wang, 1960). Dwyer and Stewart (1986) reported that the thermal time is an independent variable to describe the plant development. Effect of temperature on phenology and yield of wheat crop can be studied under field conditions through accumulated heat unit system (Haider *et al.*, 2003 and Pandey *et al.*, 2010). Rao *et al.* (1999) reported that heat use efficiency is the efficiency of utilization of heat in terms of

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dry matter accumulation, depends on crop type, genetic factors and sowing time and has great practical application.

In the present study of accumulated thermal indices were calculated under variable weather conditions. Weather variability causes substantial fluctuations in crop productivity of crops. In order to optimize growth and seed yield in the crop, optimum weather condition is required during different phenological stages of the crop. Therefore, crop weather relationship could helps in determining proper time for sowing and crop yield forecast.

Materials and Methods

Field experiments with three varieties of mustard (Pusa Gold, Pusa Jaikisan and Pusa Bold) sown on different dates (Oct., 22nd & 30th and Nov., 15th during *rabi* 2010-11, Oct., 14th & 31st and Nov., 16th during *rabi* 2011-12) were conducted at research farm of IARI, New Delhi (latitude: 28°38′23″ N, longitude: 77°09′27″ E) for estimating the influence of accumulated heat unit on yield of mustard under variable weather conditions. The seeds (5 kg/ha) were sown in random block design followed by the standard agronomic practices. Numbers of days taken to reach different phenological stage during the crop growth period were noted day to day observations. Crop growth parameters such as biomass, leaf area index at different phenological stages as well as seed yield were measured.

The climate of Delhi is semi-arid with hot summer and mild winter season. The normal and actual weekly maximum temperature during the crop growing period in both the year is sown in Fig 1. The mean maximum temperature during the entire growing period of the crop was 24 and 25°C during r*abi* 2010-11 and 2011-12, respectively as compared to the normal value (25°C). The corresponding value of mean minimum temperature during the crop growing period was 10 and 9°C, respectively as compared to the normal value 10°C (Fig. 2). The mean maximum and minimum temperature was 1°C lower than normal during 2010-11 and 2011-12

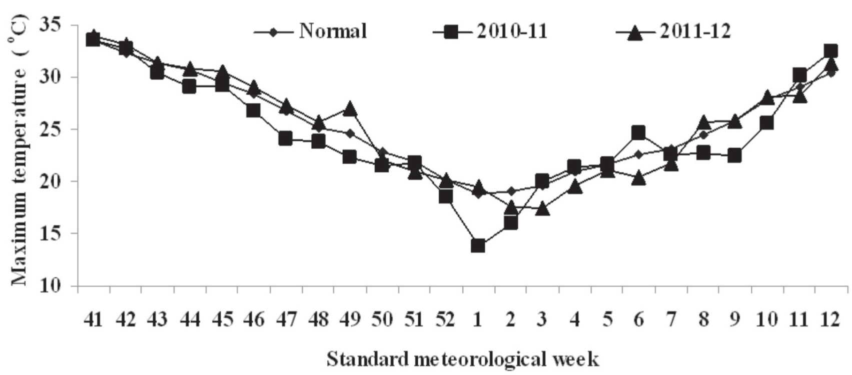

Fig. 1. Normal and actual maximum temperature during *rabi* 2010-11 and 2011-12

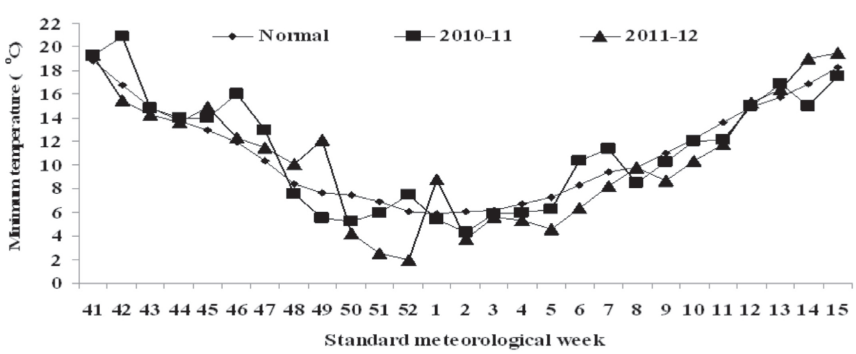

Fig. 2. Normal and actual minimum temperature during *rabi* 2010-11 and 2011-12

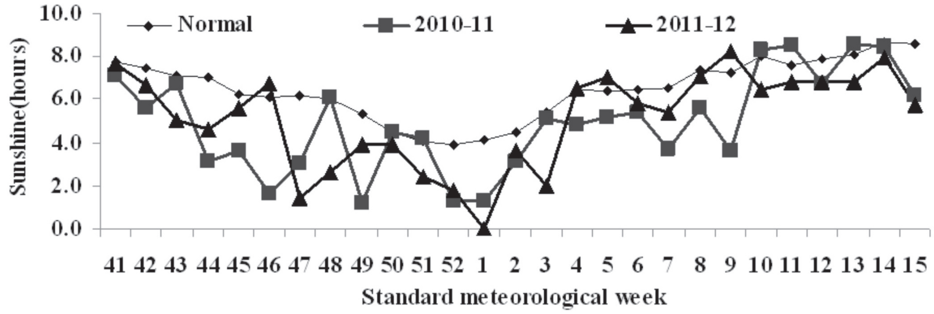

Fig. 3. Normal and actual maximum sunshine hours during *rabi* 2010-11 and 2011-12

respectively. The mean value of bright sunshine hours during crop growing period of *rabi* 2010-11 and 2011-12 was found to be 4.9 and 5.1 hours, respectively as compared to the normal value 6.5 hours (Fig. 3).

The plant samples were collected at different phenological stages for measuring the leaf area index and biomass. Different accumulated thermal indices were calculated at different phenological stages using the following formula:

Growing degree days, GDD = $\Sigma\{ ((T_{max} + T_{min})/2) - T_{base}\}$

Where T_{max} = daily maximum temperature (^oC), T_{min} = daily minimum temperature (^oC) and T_{base} = base temperature (5^oC)

Heilo thermal units (HTU) = $\Sigma \{(((T_{max} + T_{min})/2) - T_{base})$X bright sunshine hours}

Photo thermal unit (PTU) = $\Sigma \{(((T_{max} + T_{min})/2) - T_{base})X\ N\}$

where N is the maximum possible sunshine hours

Relative temperature disparity (RTD) = $\Sigma ((T_{max} - T_{min})/ T_{max}) X\ 100$

Photo thermal index (PTI) = GDD/growing days

Heat use efficiency (HUE) = Yield/GDD

GDD, HTU, PTU and RTD were accumulated from the date of sowing to each phenological stage. The analysis was done using MS Excel and SPSS10.0.

Results and Discussion

The number of days required for germination to harvest was found to be more in cultivars Pusa Jaikisan and Pusa Bold as compared to the corresponding value in the Pusa Gold during both the years. During year 2011-12, the total growing period was found to be more for all the three varieties as compared to the year 2010-11 for first and third sown crop except for Pusa Gold during the 2010-11, the crop duration was more for third sown crop as compared to the corresponding value during 2010-11. For second sown crop the crop duration was found to be more during 2010-11 as compared to the corresponding value during 2011-12 for the all three varieties (Table 1).

Thermal indices

The accumulated value of growing degree days for different phenological stage under variable weather conditions for both the years are sown in Table 1. Result showed that earlier sown crop had higher value of growing degree days as compared to late sown crop during 2011-12. But during *rabi* 2010-11, the second sown crop had higher value of growing degree days followed by first and third sown crop. The cultivar Pusa Gold required less value of accumulated growing degree days as compared to cultivars Pusa Jaikisan and Pusa Bold in both the years. The cultivar Pusa Gold required 1772, 1568, 1294°C accumulated growing degree days during 2011-12 and 1635, 1588, 1357°C during 2010-11 for first, second and third sown crop, respectively. The cultivar Pusa Jaikisan and Pusa Bold required 2013, 1735, 1728°C accumulated growing degree days during 2011-12 and 1784, 1896, 1632°C during 2011-12 for first, second and third sown crop respectively. Pandey *et al.* (2010) also reported lower consumption of heat unit under

Table 1. Number of days and accumulated growing degree days (°C day) for different phenological stages of mustard sown under

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
***Rabi* (2010-11)**									
100% Germination	9 (176.1)	10 (192.6)	10 (192.6)	5 (99.3)	6 (115.4)	6 (115.4)	6 (107.7)	7 (121.1)	7 (121.1)
Flower initiation	60 (812.0)	62 (829.3)	64 (848.2)	56 (705.7)	58 (717.1)	60 (730.2)	62 (574.7)	63 (581.8)	65 (596.1)
50% Flowering	66 (859.6)	68 (872.7)	69 (882.8)	60 (730.2)	62 (750.1)	64 (763.5)	66 (603.0)	67 (609.9)	70 (638.5)
50% Pod formation	93 (1035.9)	95 (1051.6)	97 (1071.2)	94 (967.3)	96 (986.2)	99 (1025.0)	90 (846.5)	92 (875.9)	95 (903.9)
Physiological maturity	138 (1533.6)	144 (1617.5)	144 (1617.5)	132 (1417.3)	149 (1719.6)	149 (1719.6)	121 (1228.7)	133 (1455.8)	133 (1455.8)
Harvest maturity	145 (1634.9)	153 (1784.4)	153 (1784.4)	142 (1588.4)	158 (1895.9)	158 (1895.9)	128 (1356.9)	142 (1632.2)	142 (1632.2)
***Rabi* (2011-12)**									
100% Germination	11 (233.7)	15 (300.6)	15 (300.6)	4 (86.6)	4 (86.6)	4 (86.6)	8 (135.8)	8 (135.8)	8 (135.8)
Flower initiation	50 (844.7)	57 (944.3)	59 (963.3)	51 (709.9)	53 (724.4)	54 (728.6)	46 (508.1)	51 (552.3)	52 (561.6)
50% Flowering	55 (915.3)	62 (987.1)	63 (993.9)	56 (737.8)	57 (743.3)	59 (757.7)	51 (552.3)	56 (586.2)	58 (595.0)
50% Pod formation	93 (1201.7)	100 (1244.2)	102 (1257.7)	75 (874.8)	78 (906.1)	80 (913.5)	94 (881.6)	97 (915.3)	100 (958.7)
Physiological maturity	141 (1645.7)	154 (1830.7)	154 (1830.7)	131 (1432.4)	141 (1591.5)	141 (1591.5)	118 (1196.7)	137 (1542.9)	137 (1542.9)
Harvest maturity	150 (1772.1)	164 (2012.5)	164 (2012.5)	140 (1568.0)	149 (1735.4)	149 (1735.4)	124 (1294.0)	145 (1728.2)	145 (1728.2)

*Value in the bracket are showing the value of accumulated growing degree days (°C day) delayed sowing. The requirement of GDD was lower for late growing than the normal growing conditions. This was due to un-favourable weather conditions for late sown crop, the duration of crop growing period decreased as compared to normal sown crop. Similar findings were observed in wheat by Masoni *et. al.* (1990), Bishnoi *et al.* (1995) and Tripathi *et. al.* (2004)

The requirement of helio thermal unit for different phenolological stage under different weather conditions are shown in Table 2. It was observed from the results that Pusa Gold had lesser requirement for the heilo thermal unit as compared to cultivars Pusa Jaikisan and Pusa bold in both the years. The total value of heilo thermal unit from germination to harvest for cultivars Pusa Gold was 7158, 6886 and 6283°C days hour during *rabi* 2010-11 and 8772, 7574 and 6106°C days hour during *rabi* 2011-12, for first, second and third sown crop, respectively. For Pusa Bold and Pusa Jaikisan the total value of heilo thermal unit from germination to harvest was 8148, 9554, 8695°C days hour during *rabi*. 2010-11 and 10384, 8594, 9327°C days hour during *rabi* 2011-12 for first, second and third sown crop. Masoni *et. al.* (1990) reported that HTU for different phenological stage in wheat was decreased with delay in the sowing.

The variation in photo-thermal units (PTU) under different weather condition for both the year for different phenological stages are shown in Table 2. Results showed that Pusa Gold had lower value of photo thermal units as compared to the cultivar Pusa Jaikisan and Pusa Bold. It was observed that sowing dates influence the accumulation of photo thermal units. The total value of photo thermal unit from germination to harvest for cultivars Pusa Gold was 17590, 17159 and 14713°C days hour during *rabi* 2010-11 and 19075, 16883 and 13946°C days hour during *rabi* 2011-12, for first, second and third sown crop, respectively. For Pusa Bold and Pusa Jaikisan the total value of heilo thermal unit from germination to harvest was19374, 20912, 18079°C days hour during *rabi*. 2010-11 and 21946, 18904 and 19261°C days hour during *rabi* 2011-12 for first, second and third sown crop respectively.

The photo thermal index for consecutive phenological stage was also calculated and shown in Table 3. It was observed that the photo thermal index gradually decreased from germination to maturity in all dates of sowing in both the years this indicating that daily heat consumption was decreased towards the maturity being highest during germination and lowest during pod formation.

The relative temperature disparity for different phenological stages under variable weather condition is shown in the Table 3. Cultivar Pusa Gold had lower value of relative temperature disparity as compared to the corresponding value of Pusa Jaikisan and Pusa Bold in both the year under variable weather condition. The total value of RTD was found to be decreased with delay in sowing period in both the year except during 2010-11 Pusa Jaikisan and Pusa Bold had higher value for second sown followed by first and third sown crop.

Heat use efficiency was calculated for different phenological stages for mustard crop under different weather condition for both the year (Table 4). It was observed that heat use efficiency gradually decreased from germination to maturity in both the year under different weather conditions, indicates that the heat consumption decreased towards the maturity. HUE decreased with delay in sowing after 31st October. Kingra and Kaur (2012) reported that the thermal unit required to attain a particular phenological stages decreased as sowing was delayed in groundnut. Kingra and Kaur (2012) also reported that the photo thermal index gradually decreased from emergence to maturity in all the three dates of sowing during all the years being highest at emergence and lowest during maturity of the crop.

Correlation between heat indices with biomass and yield

As the ambient daily temperatures are highly variable therefore the response of the plants to the thermal environment for their growth and development can better be expressed through the accumulated thermal indices instead of

Table 2. Accumulated helio thermal unit and photo thermal unit (°C day hour) for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
				***Rabi* (2010-11)**					
100% Germination	963.8	986.9	986.9	357.8	357.8	357.8	261.6	368.8	368.8
	(1938.5)	(2117.7)	(2117.7)	(1077.7)	(1250.5)	(1250.5)	(1130.6)	(1270.3)	(1270.3)
Flower initiation	3013.1	3085.2	3161.5	2343.7	2343.7	2381.9	1805.1	1851.2	1910.6
	(8597.6)	(8773.6)	(8966.4)	(7394.2)	(7510.3)	(7643.7)	(5923.2)	(5996.9)	(6146.3)
50% Flowering	3161.5	3199.7	3199.7	2381.9	2381.9	2412.7	1959.6	1992.0	2131.0
	(9082.5)	(9215.9)	(9318.4)	(7643.7)	(7846.2)	(7983.0)	(6218.3)	(6290.4)	(6589.7)
50% Pod formation	3760.2	3848.7	3960.5	3269.1	3409.2	3615.1	3191.3	3284.2	3378.5
	(10901.3)	(11066.8)	(11273.1)	(10111.0)	(10313.2)	(10731.0)	(8824.8)	(9148.2)	(9457.0)
Physiological maturity	6271.0	7022.0	7022.0	5669.5	8065.7	8065.7	5481.1	7206.6	7206.6
	(16401.9)	(17383.5)	(1783.5)	(15134.8)	(18742.7)	(18742.7)	(13185.0)	(15910.3)	(15910.3)
Harvest maturity	7158.1	8147.8	8147.8	6885.6	9553.8	9553.8	6283.4	8694.7	8694.7
	(17589.5)	(19374.2)	(19374.2)	(17159.2)	(20911.6)	(20911.6)	(14713.1)	(18079.2)	(18079.2)
***Rabi* (2011-12)**									
100% Germination	1510.7	1834.7	1834.7	421.6	421.6	421.6	477.3	477.3	477.3
	(2615.0)	(3349.4)	(3349.4)	(938.8)	(938.8)	(938.8)	(1421.1)	(1421.1)	(1421.1)
Flower initiation	4188.0	4585.2	4653.7	2924.3	2965.7	2979.3	1572.0	1572.7	1572.7
	(9104.1)	(10124.1	(10318.0)	(7435.6)	(7583.1)	(7626.4)	(5234.4)	(5687.1)	(5782.0)
50% Flowering	4512.0	4755.5	4785.4	3016.7	3037.4	3040.7	1572.7	1611.5	1656.9
	(9827.3)	(10560.0)	(10629.2)	(7720.0)	(7775.5)	(7922.7)	(5687.1)	(6034.9)	(6126.2)
50% Pod formation	5144.0	5275.1	5345.9	3160.4	3278.6	3291.8	3232.8	3485.6	3814.5
	(12754.2)	(13197.0)	(13338.6)	(9122.9)	(9447.0)	(9524.0)	(9192.5)	(9567.5)	(10053.9)
Physiological maturity	7969.0	9187.9	9187.9	6661.9	7762.3	7762.3	5485.0	7834.4	7834.4
	(17609.7)	(19766.0)	(19766.0)	(15280.4)	(17163.9)	(17163.9)	(12793.2)	(16962.1)	(16962.1)
Harvest maturity	8772.2	10384.2	10384.2	7574.3	8593.8	8593.8	6105.6	9326.8	9326.8
	(19075.1)	(21946.2)	(21946.2)	(16883.0)	(18903.8)	(18903.8)	(13946.3)	(19261.6)	(19261.6)

*value in the bracket are showing the value of photo thermal unit (°C day hour)

Table 3. Photo thermal index (^{o}C day day^{-1}) and relative temperature disparity for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
				***Rabi* (2010-11)**					
100% Germination	19.6 (492.6)	19.3 (544.3)	19.3 (544.3)	19.9 (310.8)	19.2 (362.6)	19.2 (362.6)	17.9 (305.3)	17.3 (361.6)	17.3 (361.6)
Flower initiation	13.5 (3520.9)	13.4 (3669.4)	13.3 (3813.3)	12.6 (3420.1)	12.4 (3565.3)	12.2 (3671.1)	9.3 (3999.8)	9.2 (4057.5)	9.2 (4217.8)
50% Flowering	13.0 (3958.6)	12.8 (4064.3)	12.8 (4104.2)	12.2 (3671.1)	12.1 (3753.5)	11.9 (3855.5)	9.1 (4295.7)	9.1 (4376.7)	9.1 (4590.9)
50% Pod formation	11.1 (5713.0)	11.1 (5876.6)	11.0 (5999.6)	10.3 5975.2)	10.3 (6111.1)	10.4 (6303.4)	9.4 (5895.2)	9.5 (5974.2)	9.5 (6133.5)
Physiological maturity	11.1 (8395.8)	11.2 (8770.0)	11.2 (8770.0)	10.7 (8122.5)	11.5 (9088.0)	11.5 (9088.0)	10.2 (7632.8)	10.9 (8282.2)	10.9 (8282.2)
Harvest maturity	11.3 (8831.8)	11.7 (9263.2)	11.7 (9263.2)	11.2 (8697.7)	12.0 (9537.7)	12.0 (9537.7)	10.6 (8016.6)	11.5 (8732.0)	11.5 (8732.0)
				***Rabi* (2011-12)**					
100% Germination	21.2 (614.4)	20.0 (838.1)	20.0 (838.1)	21.7 (289.0)	21.7 (289.0)	21.7 (289.0)	17.0 (502.1)	17.0 (502.1)	17.0 (502.1)
Flower initiation	16.9 (2814.7)	16.6 (3191.5)	16.3 (3335.6)	13.9 (3215.4)	13.7 (3387.5)	13.5 (3487.5)	11.0 (3306.7)	10.8 (3595.5)	10.8 (3627.8)
50% Flowering	16.6 (3104.3)	15.9 (3581.2)	15.8 (3669.9)	13.2 (3686.5)	13.0 (3782.0)	12.8 (3954.8)	10.8 (3595.5)	10.5 (3909.2)	10.3 (4095.7)
50% Pod formation	12.9 (6008.2)	12.4 (6503.5)	12.3 (6660.3)	11.7 (5055.7)	11.6 (5227.3)	11.4 (5383.7)	9.4 (6659.2)	9.4 (6844.6)	9.6 (7030.2)
Physiological maturity	11.7 (9324.5)	11.9 (10123.9)	11.9 (10123.9)	10.9 (8865.4)	11.3 (9454.5)	11.3 (9454.5)	10.1 (8199.2)	11.3 (9201.4)	11.3 (9201.4)
Harvest maturity	11.8 (9910.3)	12.3 (10658.4)	12.3 (10658.4)	11.2 (9408.5)	11.6 (9876.2)	11.6 (9876.2)	10.4 (8534.3)	11.9 (9577.2)	11.9 (9577.2)

*value in the bracket are showing the value of relative temperature disparity

Table 4. Heat use efficiency (g m^2 C^{-1} day^{-1}) for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing			CV
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	%
				***Rabi* (2010-11)**						
100% Germination	6.5	10.9	10.1	11.6	23.0	20.4	5.6	8.8	8.9	50.96
Flower initiation	1.4	2.5	2.3	1.6	3.7	3.2	1.0	1.8	1.8	40.66
50% Flowering	1.3	2.4	2.2	1.6	3.5	3.1	1.0	1.7	1.7	40.20
50% Pod formation	1.1	2.0	1.8	1.2	2.7	2.3	0.7	1.2	1.2	41.53
Physiological maturity	0.7	1.3	1.2	0.8	1.5	1.4	0.5	0.7	0.7	37.85
Harvest maturity	0.7	1.2	1.1	0.7	1.4	1.2	0.4	0.7	0.7	36.85
				***Rabi* (2011-12)**						
100% Germination	5.2	8.0	8.2	12.5	27.4	26.6	3.2	10.1	12.5	68.83
Flower initiation	1.5	2.5	2.6	1.5	3.3	3.2	0.9	2.5	3.0	36.18
50% Flowering	1.3	2.4	2.5	1.5	3.2	3.0	0.8	2.3	2.9	37.60
50% Pod formation	1.0	1.9	2.0	1.2	2.6	2.5	0.5	1.5	1.8	41.35
Physiological maturity	0.7	1.3	1.4	0.8	1.5	1.4	0.4	0.9	1.1	35.80
Harvest maturity	0.7	1.2	1.2	0.7	1.4	1.3	0.3	0.8	1.0	37.41

temperatures. Growing Degree Days (GDD) are the most common and simple ways of quantifying the thermal environment. Degree-day based approach is based on the premise that plants need a certain definite amount of accumulated heat to fulfill their requirement for phenological development. Differentiation in phenological events does not take place until this requirement is met. The basic concept of heat unit assumes a linear or logarithmic relationship between growth and temperature, which is predicted by Vant Hoff's Law. Heat unit is a measure of departure of mean daily temperature from a base temperature below which the internal biochemical activity ceases. The response of plant growth parameters (LAI, biomass and seed yield) to the prevailing thermal environment (represented by thermal units GDD) can be depicted by curves, termed as thermal response curves. Thermal response curves may serve as ready reference for expressing the relationship of growing degree-days with biomass production and yield and these curves can be used for predicting biological or economical yield of a crop well in advance, besides in crop simulation studies. The correlation between plant growth parameters and different heat indices are shown in Table 5. Positive correlations were observed between growth parameters biomass and yield with accumulated thermal indices (GDD, HTU, PTU, RTD). From the results, it was observed that heat unit can be used for prediction of the yield. The correlation coefficient was found to be higher value for yield than biomass.

It was observed that third order polynomial equations in yield that is 60 to 98 per cent variation in production could be explained through the accumulated thermal indices, when crop was sown in variable weather conditions (Fig. 4). Biomass production in *Brassica* species were reported to be positively correlated with

Table 5. Correlation coefficient between thermal indices, biomass and yield

Thermal indices	GDD	HTU	PTU	RTD
		***Rabi* (2010-11)**		
Yield	0.95	0.74	0.94	0.96
Biomass	0.81	0.65	0.81	0.82
		***Rabi* (2011-12)**		
Yield	0.84	0.78	0.83	0.86
Biomass	0.54	0.60	0.58	0.50

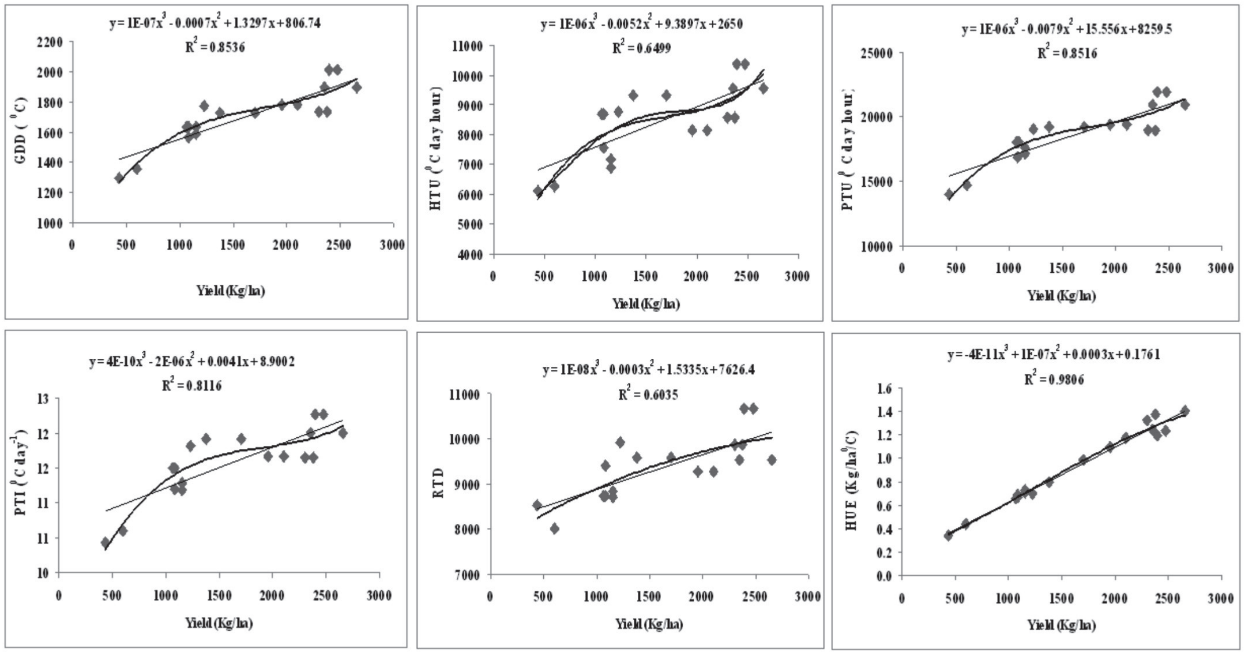

Fig. 4. Relationship between thermal indices and seed yield

GDD accumulation during the crop growth period (Chakravarty and Sastry, 1983 and Patel and Mehta, 1987).

Leaf area index (LAI)

Leaf area index is an important parameter for the crop growth studies since it is useful in interpreting the capacity of a crop for producing dry matter in terms of the intercepted utilization of radiation and amount of photosynthesis synthesized. During the crop season (*rabi* 2011-12), the maximum leaf area index under different weather condition was found to be 2.6,3.59 and 3.04 for first sown crop, 3.63, 4.10 and 5.76 for second sown crop, 2.04, 2.56 and 2.14 for Third sown crop in Pusa Gold, Pusa Jaikisan and Pusa Bold respectively at 50% flowering. During *rabi* 2010-11 crop season, the maximum leaf area index under different weather condition was found to be 3.35, 4.49 and 3.81 for first sown crop, 4.87, 5.41 and 5.49 for second sown crop, 2.06, 2.54 and 2.51 for third sown crop in Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively at 50% flowering (Fig. 5). Sowing of crop after 31st October reduced the leaf area index in both the year in all the three varieties. Cultivar Pusa Gold had lower value of leaf area index as compared to Pusa Jaikisan and Pusa Bold in both the year under variable weather conditions.

Among the plant growth parameters, leaf area index is the most important parameters exhibiting overall performance of the growth and development under varying weather conditions.

Rao and Agarwal (1986) reported that, the maximum LAI was found at 90 DAS and thereafter declined towards maturity. Working on *Brassica napus* cv. B.O. 54, *B. juncea* cv. Pusa bold and *B. campestris,* Kar and Chakravarty (1999) reported that LAI was lower in a season with higher temperatures (2 to 3°C) during vegetative and grain filling stages as compared to the season with relatively lower temperatures in the same period. Working on three varieties Pusa Jaikisan, Varuna and Agrani under Delhi condition, Roy *et al.* (2005) reported that delay of a fortnight sowing from 1st October to 1st November reduced LAI significantly in all three cultivars.

Biomass production

Biomass production of the plant is the process of organic substance formation of carbohydrates, the products of photosynthesis and from small

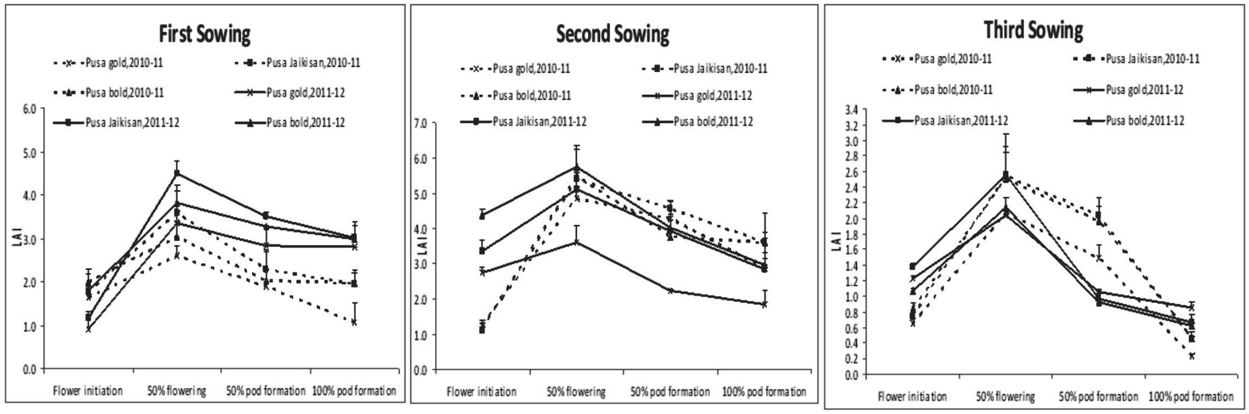

Fig. 5. Leaf area index in different varieties of mustard sown under different weather conditions

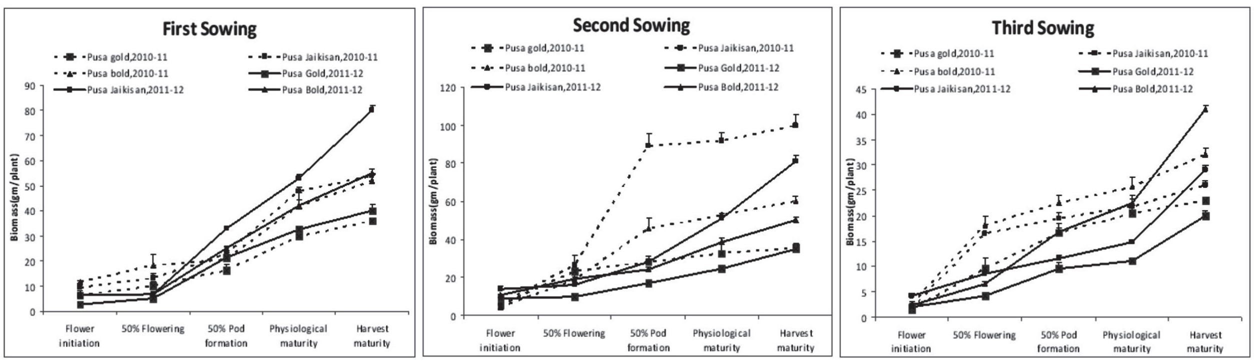

Fig. 6. Biomass (g/plant) in different varieties of mustard sown under different weather conditions

quantity of inorganic substance absorbed by roots from the soil. The timely accumulation of dry matter by the crop is important as it is followed by adequate translocation of assimilates to the sink resulting in higher yield. The higher biomass in the first sown crop may be due to favourable weather during crop growth period.

The maximum above ground biomass in the first, second and third sown crop was 40, 80, 55 g/plant, 35, 81, 50 g/plant and 20, 29, 41 g/ plant for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively during r*abi* 2010-11. During r*ab*i 2011-12, the maximum above ground biomass in the first, second and third sown crop was 36, 54, 52 g/plant, 36, 100 60 g/plant and 23, 26, 32 g/ plant for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively. Pusa Jaikisan and Pusa Bold had higher value of biomass production as compared to Pusa Gold in both the year under variable weather conditions (Fig. 6). Pusa Jaikisan had highest value of biomass followed by Pusa Bold and Pusa Gold in first and second sown crop however Pusa Bold had higher value of biomass followed by Pusa Jaikisan in third sown crop. The biomass production levels obtained in the present study and the reduction of biomass production due to late sowing are in conformity with the earlier findings in mustard and soybean (Kar and Chakravarty, 2001; Vashisth *et al.*, 2011; 2012).

Radiation use efficiency (RUE)

During the crop growing period the peak value of RUE (g/MJ) during 2010-11 was 1.35, 1.75, 1.42 g/MJ for Pusa Gold, Pusa Jaikisan, Pusa Bold in first sown crop at 134 days after sowing while the peak value of RUE for second sown crop was 1.57 g/MJ for Pusa gold at 126 days after sowing and 4.44 g/MJ for Pusa Jaikisan at 86 days after sowing and 2.27g/MJ for Pusa Bold at 97 days after sowing. During 2011-12, the peak value of RUE was 1.53, 2.46, 1.99 g/MJ

Table 6. Radiation use efficiency (RUE) of different varieties of mustard grown under different weather conditions

DAS	First sowing			Second sowing			Third sowing			CV
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	%
					***Rabi* (2010-11)**					
38	0.34	0.38	0.43	0.28	0.36	0.41	0.12	0.19	0.30	32.85
62	0.59	0.82	1.02	0.70	0.83	0.60	0.79	1.34	1.47	34.48
86	0.83	1.15	1.02	1.55	4.44	1.83	1.01	1.30	1.33	68.76
105	1.11	1.70	1.39	1.37	4.39	2.27	1.09	1.10	2.81	57.41
126	1.35	1.75	1.42	1.57	3.73	2.11	1.01	1.03	1.99	45.04
					***Rabi* (2011-12)**					
50	0.22	0.58	0.55	0.96	1.50	1.13	0.34	0.71	0.42	58.03
62	0.37	0.49	0.50	1.02	1.68	1.99	0.37	0.75	0.56	69.17
78	1.28	1.89	1.46	1.16	1.91	1.63	0.61	0.76	1.05	35.36
96	1.53	2.46	1.99	1.18	2.49	1.89	0.58	0.72	1.08	45.77
124	1.05	2.19	1.46	0.99	2.22	1.39	0.84	1.09	1.46	35.49

Table 7. Seed yield (kg/ha) of different varieties of mustard grown under different weather conditions

First sowing			Second sowing			Third sowing		
Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
				***Rabi* (2010-11)**				
1150±57^{a}	2100±58^{bd}	1950±175^{bf}	1150±104^{a}	2650±132^{c}	2350±75^{bcd}	600±76^{e}	1067±116^{a}	1083±17^{a}
				***Rabi* (2011-12)**				
1225±137^{a}	2391±58^{bcd}	2475±224^{cd}	1080±117^{a}	2375±55^{bcd}	2300±63^{d}	434±57^{e}	1375±180^{a}	1700±80^{f}

Numbers followed by same letter in column are not significantly different at P£ 0.05 as per DMRT test.

and 1.18, 2.49, 1.99 g/MJ for first and second sown crop for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively at 96 days after sowing. For the third sown crop the value of RUE was 0.84, 1.09, 1.48 at 124 days after sowing for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively (Table 6). The third sown crop had lower value of RUE as compared to first and second sown crop in both the years. Cultivar Pusa Gold had lower value of RUE as compared to Pusa Jaikisan and Pusa Bold in both the years under variable weather conditions. The results are in conformity with the earlier findings of researchers (Kar and Chakravarty, 1999, Dhaliwal and Hundal, 2004) who reported RUE in the range of 1.0 to 5.0 g/MJ in different mustard varieties grown under varied thermal regimes.

Seed yield

During r*abi* 2011-12, seed yields of Pusa Gold, Pusa Jaikisan and Pusa Bold were 1225, 2391 and 2475 kg/ha, 1080, 2375 and 2300 kg/ha, 434, 1375 and 1700 kg/ha in first, second and third sown crop. During r*abi* 2010-11, seed yields in first, second and third sown crop for Pusa Gold, Pusa Jaikisan and Pusa Bold were 1150, 2100 and 1950 kg/ha, 1150, 2650 and 2350 kg/ha, 600, 1067 and 1083 kg/ha. During 2011-12, the seed yield was decreased with delay in sowing. Delay in 15 days from 14th October onward decreased seed yield to the 12% in Pusa Gold, 0.4% in Pusa Jaikisan and 7% in Pusa Bold. Further delay in sowing by 15 days reduced the yield to 65% in Pusa Gold, 42% in Pusa Jaikisan and 31% in Pusa

Bold. During 2010-11, the seed yield was found to be highest for Pusa Jaikisan and Pusa Bold for second sown crop followed by first and third sown crop. However, for Pusa Gold the seed yield decreased with delay in sowing. The seed yield was found to be higher in Pusa Jaikisan and Pusa Bold in both the years under different weather conditions (Table 7). The results are in conformity with the earlier findings (Kar and Chakravarty, 1999, Roy et al, 2005, Neog, 2005 and Vashisth et al, 2011), reported a reduction in seed yield due to delay of week /fortnight from the normal sowing.

Conclusions

It was concluded that the change in the crop micro environment due to different sowing dates was reflected during the different phenological stages. Seed yield could be optimized by favorable weather condition under different phenological stages. Yield is positively correlated with the growing degree days and different accumulated thermal indices, therefore, difference in the value of thermal indices could be used for studying biomass accumulation at different phenological stages and crop yield forecast. Also, Pusa Jaikisan and Pusa bold showed greater ability to use solar energy (heat) and accumulated thermal indices than the Pusa gold, which indicates that the Pusa Jaikisan and Pusa bold had lower heat susceptibility than the cultivars Pusa Gold.

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