Thermal utilization and heat use efficiency of sorghum cultivars in middle Indo-Gangetic Plains

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ABSTRACT

A field experiment was carried out during the summer seasons of 2015 and 2016 in clay loamy soil of ICAR Research Complex for Eastern Region, Patna to study the phenology, accumulation of growing degree days (GDD), heliothermal units (HTU), heat use efficiency (HUE), heliothermal use efficiency (HTUE) and performance of five sorghum cultivars including 3 hybrids (CSH 13 ,CSH16 and CSH 30) and 2 varieties (CSV 23 and SPV 462) were grown under two sowing dates *viz.*16th February and 3rd March in split-plot design. For our study purpose and as per package of practices, February 16 is considered as early sowing and March 3 as timely sowing condition. It was observed that GDDs and HTU reduced significantly by 45.9 ºC days and 663.6 ºC days hr respectively, in early sowing. The sorghum cultivars SPV 462 and CSH 13 accumulated markedly higher GDDs and HTUs. On mean basis, cv. CSH 16 produced significantly higher grain yield (5.51 tha^{-1}) followed by CSH 13 (4.93 t ha^{-1}). The significant reduction in grain yield was recorded in earlier sowing date than the timely sown crop. The phenothermal index gradually increases from emergence to maturity in all the tested cultivars irrespective of sowing date. Sorghum hybrid CSH 16 showed better performance in terms of HUE and HTUE followed by CSH 13 and SPV 462. Varieties giving higher yield, HUE and HTUE are identified under the varying growing environments, so as to suggest the appropriate sowing time of sorghum cultivars in middle the middle Indo-Gangetic Plains.

Key words: Sorghum, cultivars, growing degree days, heat use efficiency, helio-thermal units and sowing dates.

Sorghum (*Sorghum bicolor* L. Moench) ranks third in the major food grain crops in India, whereas it is the fourth important food grain of the world. Millions of the people in Africa and Asia depend on sorghum as the staple food. The crop has potential to compete with maize under good environmental and management condition. Basically sorghum is a tropical crop. It is drought tolerant and is recommended for dry regions. Grain sorghum follows a predictable pattern of growth from planting through the physiological maturity. Temperature is one of the primary micro-climatic factors driving rates of growth. Rate of plant growth and development is dependent upon temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum, and optimum. These values were summarized by Hatfield *et al.* (2011) for a number of different species typical of grain and fruit production. The number of days required for cultivars to reach maturity depends primarily on location, date of planting and tempera-ture. Due to variations in daily minimum and maximum temperatures from year to year and between location, number of days from planting to physiological maturity varies and, is not a good predictor of crop develop-ment. Meteorological indices *viz.* growing degree days (GDD), heliothermal unit (HTU), and photothermal unit (PTU) based on air temperature are used to describe changes in phenological behavior and growth parameters (Paul *et al.,* 2000; Girijesh *et al.,* 2011; Prakash *et al.,* 2015). The temperature based agrometeorological indices provide a reliable prediction for crop development and yield.

Influence of temperature on phenology and yield of crops can be studied under the field condition through accumulated heat unit system (Pandey *et al.,* 2010). Duration of crop/cultivars is a genetic attributes, and is influenced by environmental condition, which varies with location and years in which it is grown because the rate of development is largely influenced by the temperature and photoperiod.

Plants have a definite heat requirement before they attain certain phenophases. A change in temperature during phenolophases of a crop adversely affects the initiation and duration of different phenophases and finally the economic yield. It is therefore, indispensable to have knowledge of the

Table 1: Yield and yield attributes of sorghum cultivars under different thermal environments (Pooled analysis over two seasons)

Treatment	Days to 50 % flowering	Days to maturity	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})
Sowing date					
16 Feb.	63.2	103.2	3.61	18.1	21.7
3 March	75.9	102.5	4.59	20.8	25.4
SEm±	0.4	0.5	0.12	0.4	0.4
CD (P=0.05)	1.1	NS	0.37	1.1	1.3
Cultivars					
CSH 13	74.3	102.5	4.93	22.7	27.6
CSH 16	71.0	102.5	5.51	15.8	21.4
CSH 30	70.5	100.3	2.91	12.6	15.5
CSV 23	62.8	102.3	3.25	27.1	30.3
SPV 462	69.0	106.5	3.89	18.9	22.8
SEm±	0.6	0.7	0.19	0.6	0.7
CD (P=0.05)	1.8	2.2	0.58	1.1	2.0

exact duration of phenophases in a particular environment and their association with yield attributes for achieving the higher yield, hence keeping above in view the present investigation was carried out.

MATERIALS AND METHODS

Field experiment was conducted during the summer seasons of 2015 and 2016 in the experimental farm of ICAR Research Complex for Eastern Region, Patna (25^0 30'N latitude, 85^0 15'E longitude and 52 m above mean sea level). The treatments comprised of two dates of sowing *viz.* 16th February and 3rd March, in main plot and five grain sorghum cultivars including three hybrids and two inbred as sub-plot were replicated thrice in a split plot design. Soil of experimental site (0-15 cm) was clay loam in texture (23.36% sand, 39.64% silt and 37% clay), low in organic carbon (0.47%), available nitrogen (213 kg N ha^{-1}) and medium in phosphorus (19.7 kg P ha^{-1}) and high in potassium (436 kg K ha^{-1}) and neutral in soil reaction (pH 7.43). The bulk density of experimental field was 1.46 g cm^{-3}. The recommended dose of fertilizers i.e. 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} were applied for grain sorghum for the region. Phosphorus as di-ammonium phosphate (DAP) and potassium as muriate of potash (MOP) were applied as basal on the day of planting. Nitrogen as urea were applied in 2 splits, 50 per cent at sowing as basal application and remaining at 35 days after sowing (DAS). Three irrigations were given during the cropping period as per critical stages of crop. Other cultural operations and plant protection measures were followed as per the recommendations contained in package of practices. Meteorological data were recorded from Agrometeorological Observatory, ICAR RCER, Patna.. The grain, stover and biological yields were recorded as per treatments and expressed in t ha^{-1}.

Growing degree days (GDD), heliothermal units (HTU), phenothermal index (PTI), heat use efficiency (HUE), and heliothermal use efficiency were computed using the daily meteorological data. The base temperature of 10 °C was used for computation of GDD on daily basis (Leong and Ong, 1983). Agro-meteorological indices were computed for different phenophases of crop (emergence, three leaf visible stage, tillering, panicle initiation stage and physiological maturity) by adopting the procedure laid out by Rajput (1980).

Data were analyzed with analysis of variance (ANOVA) as suggested by Gomez and Gomez (1984).Treatments was compared by computing the F-test. The significant differences between treatments were compared pare wise by critical difference at the 5 per cent level of probability.

RESULT AND DISCUSSION

Phenology

In general attributes of sorghum cultivars were markedly influenced with sowing date (Table 1). The 16th February sown crop significantly reduced the number of

Table 2: Accumulated GDD (°C days), HTU (°C days hr) and PTI (°C days day^{-1}) during different phenophases of sorghum cultivars as affected by various treatment (Pooled analysis over two seasons)

Treatment	Emergence			Three leaf visible stage			Max. tillering Stage			Panicle initiation stage			Maturity		
	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI
Sowing dates															
16 Feb.	73.2	473.6	12.4	132.4	858.4	11.4	868.0	5821.0	17.0	1147.8	7853.4	17.4	1934.6	11997.2	22.2
3 March	74.4	386.4	14.0	205.2	1303.2	16.3	1031.8	7611.5	17.6	1275.8	8839.2	18.4	1980.5	12660.8	23.2
SEm±	0.9	4.4	0.2	2.0	11.9	0.1	11.4	72.2	0.2	14.5	87.9	0.2	12.4	130.3	0.2
CD (P=0.05)	NS	13.2	0.5	6.1	35.7	0.4	34.0	216.1	0.5	43.4	263.1	0.5	37.1	390.1	0.7
Varieties															
CSH 13	70.0	378.0	12.5	153.0	977.5	14.0	953.0	7206.0	16.5	1238.5	8891.9	19.5	1962.5	12478.5	23.0
CSH 16	74.5	485.5	11.5	170.0	1083.5	13.0	970.5	6723.0	17.5	1215.5	8446.0	18.5	1911.1	12274.4	22.0
CSH 30	70.4	358.5	14.4	159.5	995.5	12.9	840.0	5822.4	16.0	1166.5	7828.5	20.5	1857.1	12069.5	21.5
CSV 23	67.0	405.0	11.5	160.0	1041.5	15.5	932.0	6302.5	18.5	1105.5	7634.5	10.5	1881.8	11862.0	24.5
SPV 462	87.0	523.0	16.0	201.5	1306.0	14.0	1054.0	7527.5	18.0	1333.0	8930.4	20.5	2175.1	12969.5	22.5
SEm±	1.4	7.0	0.3	3.2	18.8	0.2	18.0	114.11	0.3	22.9	138.9	0.3	19.6	206.	0.4
CD (P=0.05)	4.3	20.8	0.5	9.6	56.4	0.7	53.8	341.6	0.8	68.7	415.9	0.9	58.7	616.7	1.1

days required for 50 per cent flowering (63.2) compared to 3rd March sown crop (75.9) but reverse trend was recorded in case of days to maturity. This might be due to the fact that sowing time determines time available for vegetative phase before onset of flowering, which is mainly influenced by the photoperiod.

Days to 50 per cent flowering and days to maturity differed significantly among the sorghum cultivars. In general, varieties flowered earlier (65.9 days) than hybrids (71days). But the reverse trend was followed in maturity, whereas the hybrids took lesser duration (102 days) compared to varieties (105 days). The variation in phenology of sorghum cultivars was also reported by Rao *et al*. (2013).

Yield attributes

The yield parameters of sorghum cultivars markedly influenced with sowing time (Table 3). Grain and stover yields of sorghum cultivars were significantly higher with 3rd March sown crop (4.59 t ha^{-1}) and respective increase was 27.2 per cent over 16th February sowing. Higher seed yield was realized in case of 3rd March sown crop because of higher growth and yield attributed which lead to higher yield of the respective treatments. Under early sown conditions of 16th February, however plants could not accumulate the sufficient photosynthates due to poor vegetative growth (Mishra *et al*. 2017). Azrag and Dagash (2015) reported that sowing date had greater effect on yield than the cultivar.

Grain and stover yield differed significantly among the sorghum cultivars. The sorghum hybrid 'CSH 16' recorded significantly higher grain yield (5.51 t ha^{-1}) followed by 'CSH 13' (4.93 t ha^{-1}) and the lowest with 'CSH 30' (2.91 t ha^{-1}). Among varieties, 'SPV 462' (3.89 t ha^{-1}) recorded significantly higher yield followed by 'CSV 23' (3.25 t ha^{-1}). On mean basis, hybrids produced 24.65 per cent higher grain yield over the varieties. This might be due to more growth attributes like more plant population, no of green leaves, dry matter and leaf area was recorded more with the respective treatments (Kumar *et al*., 2015a, b; Kumar and Bohra, 2014; Kumar *et al*., 2016 and Mishra *et al*., 2017).

Agrometeorological indices

The agrometeorological indices (GDD, HTU and PTI) during different phenophases of sorghum are presented in Table 2. The February 16 sown crop took longer duration for maturity than the timely sown (March 3) crop in all the cultivars due to lower temperature in month of February, crop took more days to fulfill the thermal requirement. The total accumulated GDD and HTU during the maximum

Table 3: Heat use efficiency (HUE) and heliothermal use efficiency (HTUE) of sorghum cultivars as affected by various treatments (Pooled analysis over two seasons)

Treatment	HUE (kg ha^{-1}°C day)			HTUE (kg ha^{-1} °C day hr)		
	Grain yield	Stover yield	Biological yield	Grain yield	Stover yield	Biological yield
Sowing date						
16 Feb	1.93	9.67	11.60	0.31	1.53	1.84
3 March	2.29	10.72	12.67	0.36	1.68	1.99
SEm±	0.03	0.14	0.17	0.004	0.02	0.03
CD (P=0.05)	0.08	0.43	0.50	0.01	0.06	0.08
Cultivars						
CSH-13	2.55	11.73	14.27	0.39	1.84	2.25
CSH-16	2.86	8.24	11.11	0.45	1.30	1.75
CSH-30	1.54	6.67	8.21	0.24	1.05	1.29
CSV-23	1.68	14.13	15.82	0.27	2.23	2.49
SPV-462	1.94	10.20	12.16	0.31	1.63	1.80
SEm±	0.04	0.23	0.26	0.007	0.03	0.04
CD (P=0.05)	0.13	0.68	0.78	0.02	0.11	0.12

vegetative stage of the crop decreased from 868 °C days and 5821 °C days' hr under Feb. 16 sowing to 1031 and 7611 under timely sowing on March 3, respectively. March 3 sown crop accumulated more heat unit (1980.5 °C days) to reach maturity followed by February 16 (1934.6 °C days). Fifteen days delay in sowing from February 16 (early sown) to March 3 (timely sown) increased the accumulated heat units and helio-thermal units by 45.9 °C days and 663.6 °C days' hr, respectively. Among the cultivars, SPV 462 had higher heat units (2175.1 °C days) and helio-thermal units (12969.5 °C days hr), which might be due to significantly higher number of days taken to maturity followed by CSH 13 (1962.5 °C days and 12478.5 °C days hr). Phenothermal index was highest at maturity (Table 1), the value of which was significantly higher (23.2 °C) in timely sown crop. Among different cultivars, PTI values in 'CSV 23' and 'CSH 16' were significantly higher than 'CSH 13' and 'CSH 16'. This might be due to better growing conditions such as temperature, light, humidity and rainfall to fully exploit genetic potentiality of crop (Bahar *et al*., 2015).

Heat use efficiency and heliothermal use efficiency

At maturity, HUE for grain and straw production was significantly higher (2.29 and 10.7) for March 3 sown crop as compared to February 16 (1.93 and 9.67) sown crop (Table 2).

Among cultivars, CSH 16 had significantly higher heat use efficiency (2.86) followed by CSH 13 (2.55), SPV 462 (1.94), CSV 23 (1.68) and CSH 30 (1.54) for grain production, whereas, CSV 23 had significantly better HUE (14.13) for straw production followed by CSH 13 (11.73), SPV 462 (10.20), CSH 16 (8.24) and CSH 30 (6.67). Helio-thermal use efficiency for grain and straw was found maximum 0.31 and 1.53, respectively for 3rd March sown crops. In case of cultivars, CSH 16 and CSV 23 had highest helio-thermal use efficiency 0.45 and 2.23, respectively for grain and straw production. The minimum heliothermal use efficiency was found in CSH 30 for grain as well as straw production. Higher HUE and HTUE in timely sown could be attributed to the highest grain and straw yield. As the temperature was optimum throughout growing period crop utilized heat more efficiently and increased biological activity that confirm higher yield. Similar relationship was expressed by Thavaprakash *et al*. (2007).

CONCLUSIONS

Based on the above findings, it may be concluded that sorghum cultivar CSH 16 produced higher grain yield (5.51 tha^{-1}) followed by CSH 13(4.93 t ha^{-1}), SPV 462 (3.89 t ha^{-1}), CSV 23 (3.25 t ha^{-1}) and CSH (2.91 t ha^{-1}). On an average, timely sown cultivars produced the maximum grain. The cultivar CSH 16 showed stable yield in almost both the sowing dates and performing overall best in terms of utilization of HUE and HTUE. The growing degree day, helio-thermal units and phenothermal index for entire crop growing period decreased with early sowing. This study also indicated that change in microclimate due to different sowing time is reflected in individual phenological stage. Differences in agro-meteorological indices for various phenological stages indicated that accumulated temperature can be utilized for dry biomass and crop yield forecast.

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