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Thermal requirement for phenophases of mango varieties in the sub-humid tropics of east-central India

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ABSTRACT

Mango flowering and fruiting phenophases are influenced by both genetics and environmental factors. An experiment was conducted with nine mango varieties at Jagdalpur during 2018-2020 to study the influence of heat units, photothermal units and heliothermal units on phenology of mango varieties. The growing degree days, heliothermal unit and photothermal unit were recorded lower for many phenophases of early maturing varieties like Dasheheri, Alphonso and MahmoodBahar. Majority of phenophases showed higher heat use efficiency for Sundreja and lowest for MahmoodBahar. Days taken to panicle emergence toappearance of 50% flowering, days to 50 % flowering to full bloom and days to full bloom to first fruit set, all have a significant negative correlation with heat use efficiency. All the phenophases were positively correlated to growing degree days.

Key words: *Mangifera indica* L., growing degree days, heliothermal unit, heat use efficiency, phenophases.

INTRODUCTION

The king of fruits, mango, is an important fruit crop in India, extensively cultivated in tropical and subtropical areas around the world (Patel *et al*., 8). Its potential yield is much higher than observed under Indian climatic conditions. Even so, fruit productivity, which is determined by crop-climate-soil interactions, is slightly lower in Indian states than in the global average (Rajan, 10). Plants require a specific temperature so that they can reach specific phenological phases. A change in optimum temperature throughout various phenophases of a crop seems to have a detrimental effect on the commencement and length of various phenophases, as well as the crop's economic yield (Kumari*et al*., 4). A change in this energy demand often accelerates or delays phenological events, which can have an effect on fruit production and heat use efficiency of crops.

Temperature is a significant aspect of the climate that directly influences potential productivity, especially for winter crops and temperate fruits (Singh and Bhatia, 14). Temperature dependent agro-meteorological indices such as growing degree days (GDD), photothermal unit (PTU), heliothermal unit (HTU) and heat use efficiency (HUE), are based on the notion that real-time phenological stage attainment is linearly related to temperature in the range between base and optimum temperatures(Monteith, 7). Fruit development includes physiological, biochemical and physical processes, which are influenced by the temperature that prevails during the developmental stage (Shinde *et al.,* 12).However, the calculation of heat unit accumulation during development has been used as a simple and practical method for evaluating fruit maturity(Rai *et al*., 9). Air temperature based agro-meteorological *viz*., GDD, PTU, and HTUare used to describe the changes in phonological behaviour of fruit crops (Rai *et al.,*9; Gupta *et al.,*1; Singh and Bhatia, 14). However, in mango the information pertaining to heat unit accumulation for different phenophases is not available in Chhattisgarh. Hence, an effort was made to determine the heat unit and related indices of various mango varieties in the sub-humid tropics of south Chhattisgarh.

MATERIALS AND METHODS

The investigation was carried out during 2018-2020 on nine mango varieties in the Horticulture Nursery cum Instructional Farm of ShaheedGundadhoor College of Agriculture and Research Station (Indira Gandhi KrishiVishwavidyalaya), Kumhrawand, Jagdalpur, Bastar, Chhattisgarh (19°05'43'' N latitude, 81°57'60'' E longitude and an altitude of 552 m above mean sea level). The region has a sub-humid climate, and is located in the agro-meteorological zone of the eastern plateau and hills.The average annual rainfall in the area is 1544 mm. A major amount of precipitation occurs between June and September (about 3-4 months). Daily temperature (maximum and minimum), open pan evaporation and rainfall were recorded from the meteorological observatory

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of Gramin Krishi Mausam Sewa Kendra situated in the station (Fig. 1). Rainfall received during 2018, 2019 and 2020 were 1359.20 mm, 2313.00 mm and 1376.50 mm, respectively. The bearing mango trees of Dasheheri, Langra, Bombay Green, Sundeja, Amrapali, Mallika, Alphonso, Mahmood Bahar and LalSinduri varieties of uniform age (21 years old) planted at a spacing of 10 x 10 mwere selected for the study.We observed nine important phenophases using the extended BBCH scale (Rajan*et al.,* 11) *viz*., days for panicle emergence (511), days for flower emergence (514), days for the appearance of 50% flowers (613), days for full bloom (617), days for first fruit set (619), days to attain pea stage (701), days to attain marble stage (705), days to attain egg stage (709) and days to attain maturity stage (801).

Growing degree days were calculated by simple arithmetic accumulation of daily mean temperature above the base temperature value of 10°C considered for mango. Agro-meteorological indices and heat use efficiencies were calculated on a daily basis and accumulated from panicle initiation to harvesting stage. GDD, PTU, HTU and HUE were calculated for each phenophase (Singh *et al*., 15). A correlation analysis (Pearson) between agro-meteorological indices and days required to attain different phenophases was estimated. To determine the significance of correlation coefficients, the student's t-test technique was used.

RESULTS AND DISCUSSION

All nine varieties showed significant variation for the period of different phenological phases (Table 1). The results of a three-year pooled analysis showed that the number of days required by different varieties varied from 21.76-28.45 days for panicle initiation to flower initiation, 4.56-9.05 days for flower emergence to appearance of 50% flowering, 4.89-9.56 days for the days required for the appearance of 50% flowering to full bloom. The phenophases days from egg stage to maturity stage (31.47-45.35 days) had the highest days for attaining the next phenophase, whereas the days to first fruit set to the days to attain pea stage (5.23-6.37 days) had the lowest days required to attend a phenophase. The earlier days to flower imitation (21.76 days), appearance of 50 % flowering to full bloom (4.89 days) and days required to attain pea stage to marble stage (22.45 days) were recorded in Sundreja. Dasheheri had the longest time required from panicle initiation to flower initiation, at 28.45 days. Mallika had the longest duration from first fruit set to pea stage (6.37 days), pea stage to marble stage (29.23 days) and from egg stage to maturity stage (45.35 days).The varieties Sundreja, Dasheheri and Alphonso showed fewer days to attain maturity from the panicle initiation stage, whereas these were highest in Lal Sinduri. Singh and Pathak

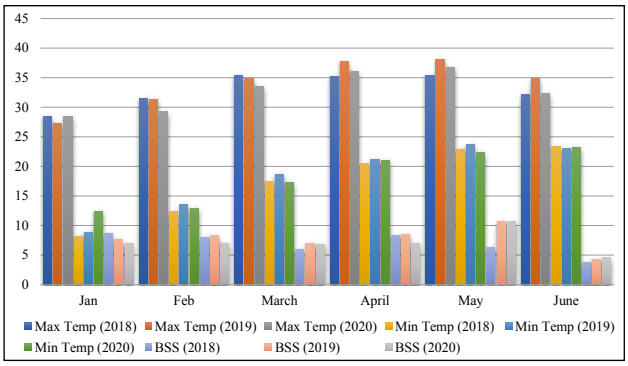

Fig. 1. Temperature and sunshine hours during study period of 2018, 2019 and 2020

Table 1. Days required attaining phenological phases in mango varieties (pooled over 3 years)

Varieties	DPI to DFI	DFI to DAFF	DAFF to DFB	DFB to DFF	DFF to DPS	DPS to DMS	DMS to DES	DES to DMTS	DPI to DMTS	Yield (kg/ tree)
Dasheheri	28.45	5.45	6.23	8.56	5.56	26.23	24.23	31.47	133.23	38.45
Langra	24.67	5.56	6.78	9.47	5.23	25.12	24.36	37.05	135.05	31.47
Bombay Green	28.23	6.45	8.34	7.35	5.89	25.98	27.56	35.37	141.17	34.72
Sundreja	21.76	6.28	4.89	9.46	5.34	22.45	25.73	38.23	130.68	42.36
Amrapali	26.32	4.56	5.46	14.12	5.78	27.45	24.58	41.16	146.03	48.63
Mallika	23.89	6.67	5.12	12.35	6.37	29.23	22.34	45.35	148.74	40.61
Alphonso	26.34	8.35	7.78	7.87	5.31	24.65	23.58	33.89	133.27	28.63
MahmoodBahar	25.56	8.32	8.34	6.48	5.56	26.87	24.16	36.49	138.37	23.18
LalSinduri	26.67	9.05	9.56	6.48	5.98	28.67	30.06	35.03	148.74	40.19

DPI: Days for panicle emergence, DFI: Days taken to flower emergence, DAFF: Days for appearance of 50 per cent flowers, DFB: Days for full bloom, DFF: days for first fruit set, DPS:Days to attain pea stage, DMS: Days to attain marble stage, DES: Days to attainegg stage, DMTS: Days to attain maturity stage

(13) also reported significant deviation in panicle emergence to 50 % flowering (12.67 to 21.33 days). The cultivars Amrapali, Langra, Dashehari, Mallika and Alphonso took 112.67, 98.33, 111.00, 107.83 and 95.17 days respectively, to attain fruit maturity under Varanasi conditions (Hada and Singh, 2). The difference in maturity of fruits from various cultivars may be due to differences in panicle emergence date and changing environmental factors, in addition to their genetic makeup (Kundu *et al*., 5).

The accumulated thermal unit requirement of mango to achieve their phenological phases varied with cultivars,varying from 3095 ºC days to 3811 ºC days between flower emergence to fruit maturity (Table 2). Meanwhile, the highest GDD was observed at maturity stage among all phenological phases. Sundreja had the lowest GDD for days to panicle emergence (429.70), 50% flowering to full bloom (73.10) and days to attain pea stage to marble stage (594.05).Dasheheri had the lowest GDD in terms of days for flower initiation to appearance of 50% flowering (93.60) and days to first fruit set to pea stage (94.20). The lowest GDD for days to attain egg stage to maturity stage was observed in Mahmood Bahar (680.65). The maximum GDD for days to flower emergence to the appearance of 50 % flowering (164.85), days taken for the appearance of 50 % flowering to full bloom (172.75) and days to attain marble stage to egg stage (853.80) were recorded in Lal Sinduri. Mallika achieved the highest GDD for days from first fruit set to pea stage (151.20), pea stage to marble stage (800.55) and egg stage to maturity (1283.95). The lower values of GDD were recorded for early maturing varieties like Dasheheri, Mahmood Bahar and Alphonso compared to late maturing varieties like Amrapali and Mallika. Shinde *et al.* (12) recorded a total heat unit of 803.48 in the Alphonso from fruit set to maturity stage. Rai *et al.* (9) observed the GDD requirements of Amrapali (2261.05), Mahmood Bahar (2224.65), Mallika (2238.63), Langra (1910.15), Alphonso (1719.97), Dasheheri (1872.08) and Bombay Green (1681.95) in the Plateau region of Eastern India.

The highest accumulated heliothermal unit (7389.75) is required to reach maturity stage, while the lowest (629.90) is required to reach pea stage (Table 2).Days to panicle emergence to flower emergence (1335.28), days taken to flower emergence to appearance of 50% flowering (1485.65) and days to attain pea stage to marble

Table 2. Days required for attaining phenological phases in mango varieties (pooled over 3 years)

Varieties	DPI to DFI	DFI to DAFF	DAFF to DFB	DFB to DFF	DFF to DPS	DPS to DMS	DMS to DES	DES to DMTS
				GDD (° day)				
Dasheheri	570.85	93.60	116.65	172.85	94.20	647.65	673.20	887.90
Langra	493.05	108.00	117.80	201.45	119.60	680.20	683.30	1084.15
Bombay Green	578.35	123.75	164.90	153.55	115.95	675.65	768.50	1026.40
Sundreja	429.70	131.60	73.10	198.50	117.70	594.05	708.50	1112.35
Amrapali	536.90	84.40	103.85	312.10	121.70	738.40	690.25	1186.15
Mallika	473.30	131.60	94.20	246.50	151.20	800.55	630.15	1283.95
Alphonso	541.55	152.00	149.25	117.80	108.05	618.35	647.90	950.00
MahmoodBahar	517.35	152.30	168.65	120.30	105.40	670.05	680.65	680.65
LalSinduri	525.35	164.85	172.75	128.50	96.95	697.70	853.80	853.80
				HTU (°C days hour)				
Dasheheri	645.84	1096.51	1434.65	518.10	4209.73	4308.48	7103.20	4395.54
Langra	950.40	753.92	1369.86	657.80	4625.36	5329.74	8131.13	3648.57
Bombay Green	1027.12	1137.81	1044.14	637.72	4594.42	5533.20	7800.64	4511.13
Sundreja	1171.24	438.60	1310.10	647.35	3980.14	5172.05	8676.33	3566.51
Amrapali	793.36	799.64	2059.86	669.35	5168.80	5591.02	7472.74	4026.75
Mallika	1171.24	536.94	1676.20	831.60	5603.85	5167.23	7190.12	3597.08
Alphonso	1368.00	1253.70	753.92	594.27	4390.29	4146.56	7790.00	4007.47
MahmoodBahar	1233.63	1416.66	854.13	579.70	4757.36	4424.23	5513.27	3983.59
LalSinduri	1335.28	1485.65	1143.65	533.22	4674.59	5720.46	6830.40	3887.59

stage (5720.46) were found to have the highest HTU in the variety Lal Sinduri. Mallika also had the highest HTU for the phenophases *viz.*, days to full bloom to first fruit set (831.60) and days to first fruit set to pea stage (5603.85). The highest HTU for days to attain marble stage to egg stage (8676.33) and days to attain egg stage to maturity stage (4511.13) was recorded in the varieties Sundreja and Bombay Green, respectively. The number of days required to reach various phenophases varies depending on the variety under study. The varieties that require lower GDD are reported to have lower heliothermal units. Singh and Bhatia (14) also reported high heliothermal unit for phenophases with late maturing apple varieties.

The maximum PTU for days to panicle emergence to flower emergence (80.67) and days to attain egg stage to maturity stage (515.36) were observed in Alphonso, whereas the maximum PTU for days to flower emergence to days to 50 % flowering (24.56) and days to 50 % flowering to full bloom (27.20) were recorded in Mahmood Bahar (Table 3). The minimum PTU for days to full bloom to first fruit set (16.13), days to attain pea stage to marble stage (82.61) and days to attain marble stage to egg stage (86.42) were recorded in Alphonso. PTU gradually increased from flower emergence to later phenological stages, being highest at the maturity stage and lowest at flower emergence. However, the values of PTU at later stages of fruit set indicated an increase in daily heat consumption towards maturity, which might be due to a gradual increase in day and night temperature, resulting in an increase in PTU for various phenophase. Similar results were also reported by Singh and Bhatia (14) in apple and Gupta *et al.* (1) in grape.

HUE was estimated for mango varieties for various phenophases (Table 3). The variety Amrapali had the highest HUE (1.86), whereas the variety Mahmood Bahar had the lowest HUE (0.85). Sundreja had the highest HUE for days from panicle emergence to flower emergence (0.098), days for appearance of 50% flowering to full bloom (0.579) and days from pea stage to marble stage (0.070). Whereas, the minimum HUE for the majority of phenophases like day to panicle emergence to flower emergence (0.044), days to flower emergence to days for appearance of 50 % flowering (0.152), days for appearance of 50 % flowering to full bloom (0.137), days to first fruit set to pea stage (0.219),

Table 3. Days required for attaining phenological phases in mango varieties(pooled over 3 years)

Varieties	DPI to DFI	DFI to DAFF	DAFF to DFB	DFB to DFF	DFF to DPS	DPS to DMS	DMS to DES	DES to DMTS
				PTU (°C days hour)				
Dasheheri	76.39	20.17	15.57	27.88	20.30	96.47	89.94	282.40
Langra	65.87	23.28	15.72	28.19	25.78	92.83	91.29	146.54
Bombay Green	77.40	16.51	26.60	21.02	24.99	92.21	104.47	165.87
Sundreja	58.08	17.56	9.91	27.78	25.37	106.24	96.70	148.91
Amrapali	79.98	11.44	22.38	45.66	26.23	100.38	92.22	160.70
Mallika	63.13	17.56	20.30	36.31	20.18	103.24	112.70	171.76
Alphonso	80.67	24.51	20.43	16.13	23.29	82.61	86.42	515.36
MahmoodBahar	70.61	24.56	27.20	16.05	22.72	99.81	90.93	134.74
LalSinduri	78.26	23.07	24.18	17.15	20.90	93.37	116.07	137.98
				HEU (kg $^{o}C^{-1}$ day)				
Dasheheri	0.067	0.410	0.329	0.222	0.408	0.059	0.057	0.043
Langra	0.063	0.291	0.267	0.156	0.263	0.046	0.046	0.029
Bombay Green	0.060	0.280	0.210	0.226	0.299	0.051	0.045	0.033
Sundreja	0.098	0.321	0.579	0.213	0.359	0.071	0.059	0.038
Amrapali	0.090	0.576	0.468	0.155	0.399	0.065	0.070	0.040
Mallika	0.085	0.308	0.431	0.164	0.268	0.050	0.064	0.031
Alphonso	0.052	0.188	0.191	0.243	0.264	0.046	0.044	0.030
MahmoodBahar	0.044	0.152	0.137	0.192	0.219	0.034	0.034	0.034
LalSinduri	0.076	0.243	0.232	0.312	0.414	0.057	0.047	0.047

days to attain pea stage to marble stage (0.034) and days to attain marble stage to egg stage (0.034) were recorded in Mahmood Bahar. HUE increases as crop phenology moves from flowering to fruiting phases; however, it decreased slightly at physiological maturity (Lal *et al*., 6). Irrespective of variety, the increase in HUE was maximum during the reproductive phase. Varietal differences for HUE were also found at all growth stages of mango.

The correlation was computed for different phenophases with agro-meteorological indices (Table 4). Phenophases days to panicle emergence to flower emergence (0.995**), flower emergence to 50 % flowering (0.966**), 50 % flowering to full bloom (0.985**), full bloom to first fruit set (0.981**) and days to attain marble stage to egg stage (0.997**) were significantly positively correlated with GDD at 1 % level of significance. HTU was reported to be significantly positively correlated with days to flower emergence to 50 % flowering (0.676*), days to full bloom to first fruit set (0.693*) and days to first fruit set to pea stage (0.720*). A highly significant positive correlation(0.976**) was observed between the photothermal unit and the days to full bloom to first fruit set. In contrast, heat use efficiency recorded a significant negative correlation with days to flower emergence to 50 % flowering (-0.820*), days to 50 % flowering to full bloom (-0.885*) and days to full bloom to first fruit set (-0.705*) respectively at 5 % level of significance. A positive correlation between phenophase days to full bloom to first fruit set (0.686*) was also observed. Kumar *et al*. (3) also reported positive correlations of phenophases with GDD, HTU, PTU and HEU in white clover.

Late maturing varieties like Amrapali, Mallika and Lal Sinduri had higher days for phenological phases with higher values of GDD, PTU and HTU, while early maturing varieties like Dasheheri, Sundreja and Mahmood Bahar had the lowest days of phenophases with the lower values of GDD, PTU and HTU. The accumulation of GDD, PTU and HTU was found to be linearly related to the reproductive stages of the mango varieties. Long duration varieties were more efficient in utilizing heat units to produce a higher fruit yield than short duration varieties.

Table 4. Correlation coefficients between agro-meterological indices, yield and phenological phases of mango varieties

Phenophase	GDD	HTU	PTU	HEU	Yield
DPI to DFI	0.995**	-0.363	0.878*	-0.508	-0.126
DFI to DAFF	0.966**	0.676*	0.702*	-0.820*	-0.535
DAFF to DFB	0.985**	-0.654	0.754*	-0.885*	-0.547
DFB to DFF	0.981**	0.693*	0.976**	-0.705*	0.686*
DFF to DPS	0.814*	0.720*	-0.485	-0.270	0.404
DPS to DMS	0.889*	0.276	0.120	-0.200	0.184
DMS to DES	0.997**	-0.049	0.538	-0.269	0.183
DES to DMTS	0.735*	-0.608	-0.460	-0.256	0.421

* Significant at p=0.05, **Significant at p =0.01

AUTHORS' CONTRIBUTION

Conceptualization of research (VR); Designing of the experiments (VR, AS, NK); Execution of field/lab experiments and data collection (AS, NK, AKK); Analysis of data and interpretation (VR, AS); Preparation of the manuscript (VR, AKK).

DECLARATION

The authors declare that there is no conflict of interest regarding this article.

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