



Heat unit and photoperiod on growth and development of banana

Kumar, P.S.*, M.S. Saraswathi, I. Ravi, R. Renganathan, K.N. Shiva, K. Kamaraju and S. Uma

ICAR- National Research Centre for Banana, Thayanur Post, Tiruchirappalli- 620 102, Tamil Nadu, India

ABSTRACT

Field experiment was conducted to identify the growing degree days (GDD), helio-thermal unit (HTU), Photo-thermal unit (PTU) and heat use efficiency (HUE) of eleven banana varieties namely cooking (Monthan, Saba), dessert (Grand Naine, Pachanadan, Ney Poovan, Poovan, Rasthali, Karpuravalli, Udhayam) and dual purpose (Popoulu and Nendran) varieties. Crop duration was maximum in Udhayam (470 days) followed by Karpuravalli (415 days). The yield recorded in Udhayam (95 t/ha) was significantly higher than other varieties. Highest GDD of 8011°C day was recorded for Udhayam during the entire growth period. Similarly, Karpuravalli (7114°C days) and Rasthali (6975°C days) required more GDD than other varieties. Whereas Nendran (5338°C days) needed the least GDD. However, estimation of degree days requirement from flowering to fruiting indicated that var. Ney Poovan required more GDD (2031.50°C days) whereas var. Popoulu required lesser GDD (1125.50°C days). HTU requirement of different varieties ranged from 22219.07 to 41519°C days for days taken for flowering. Accumulated PTU was also maximum in Udhayam and minimum in Nendran and Popoulu. The HUE was significantly higher for Grand Naine (16.92) followed by Udhayam (11.80) whereas, the least HUE was observed in Rasthali (4.03) and Poovan (4.90).

Key words: *Musa* sp, degree days, photo-thermal unit, heat use efficiency, flowering, maturity, quality.

INTRODUCTION

Banana is grown in about 135 countries with the production of 119.83 million tons in an area of 5.20 million hectares, led by India and China with a combined total of 29% of global production (FAO, 5). India produces 32.45 million tons of banana from an area of 0.88 million hectares with the productivity of 34.75 t/ha (NHB, 6). India houses more than 100 different varieties of banana in different climatic zones. Andhra Pradesh (16.27%), Gujarat (14.54%), Maharashtra (13.69%), Tamil Nadu (10.41%) and Uttar Pradesh (10.31%), leads in production. The other major banana producing states are Karnataka, Kerala, West Bengal and Assam (NHB, 6). Banana grows well in the temperature range of 15°C to 40°C whereas the growth is retarded at temperatures of lesser than 13°C and more than 35°C. Optimum mesoclimatic characters like relative humidity, precipitation and solar radiation are essential for better growth and yields. Environment, location and topography greatly influences the pheno-physiological characters like bunch growth, size, duration for maturity for different banana varieties.

Generally, fully matured, green banana bunches are harvested and being a climacteric, later, ripened artificially without compromising on yield and quality. Harvest indices is the optimal stage for harvesting the bunch, termed as horticulture maturity, at which fruit growth and yield are maximum, nearer to

physiological maturity with optimum green life (Ganry and Chillet, 4). The variation in traditional maturity indices like days to maturity, fullness of bunches necessitate alternative maturity indices which could be used without biasness about the area where it is grown. Heat units are therefore developed for different crops with the assumption that temperature influences the plant growth and development and it ceases beyond threshold temperature. The heat unit approach or remainder index method is also known by other expressions like growing degree days (GDD), growth units, thermal time or degree days (Feng and Hu, 2). Changes in banana production cycle is expected with the temperature variability across banana growing regions in the coming years. Therefore, temperature based indices using the sum of daily temperature like helio-thermal units (HTU), photothermal units (PTU) and growing degree days (GDD) could be computed and successfully employed to elucidate the phenological behaviour and yield (Neog and Chakravarty, 8; Singh and Bhatia, 10; Singh *et al.*, 11). Temperature and photoperiod plays pivotal role in the carbohydrate partitioning (Fischer *et al.*, 3).

Normally, banana is harvested with its percentage of physical maturity and denoted as 70, 80, 90 and 100 % maturity for different markets. Since it is arbitrary, identifying alternative methods like caliper, heat units are essential for obtaining better quality fruits and enhancing the export value for the produce

*Corresponding author: psureshars@gmail.com

(Fischer *et al.*, 3). Considering the importance of heat unit and photoperiod on growth and development of banana, an experiment was carried out to illustrate and identify the heat unit requirement for different banana varieties grown in central region of Tamil Nadu.

MATERIALS AND METHODS

A field experiment was conducted in the experimental research farm of ICAR- National Research Centre for Banana (10°47'N 78°34'E, 98 m MSL) with eleven varieties namely, Monthan (ABB), Saba (ABB), Grand Naine (AAA), Pachanadan (AAB), Ney Poovan (AB), Poovan (AAB), Rasthali (AAB), Karpuravalli (ABB), Udhayam (ABB) dual purpose Popoulu (AAB) and Nendran (AAB) during the period of 2017-2019. The average temperature in Tiruchirappalli is 28.8 °C with the rainfall of around 860 mm per year. The soil is silty clay loam, neutral to slightly alkaline (pH 7.00 and 8.50) and low in organic carbon content (0.2%), low in available nitrogen (150 kg/ha), available phosphorus (5 kg/ha) and available potassium (230 kg/ha). Similarly, soil bulk density was 1.33 g/cc, particle density was 2.60 g/cc and porosity was 25 -30%.

Disease free, tissue culture plants (var. Grand Naine) and sword suckers (1-1.5 kg) of uniform size from high yielding plants (other varieties) were selected for planting. A spacing of 2.1 × 2.1 m was followed for all the varieties. Date of planting for different varieties is presented in the table 1. Recommended cultural practices were followed for the varieties which includes scientific intercultural operations like mat management, side sucker removal, fertigation, micro nutrient spray and bunch covering and need based application of pesticides for insect pests and disease management. Data were

recorded on plant height (cm), days to flowering and fruiting, number of fingers, hands per bunch, bunch weight (kg), finger length (cm), circumference (cm) and weight (g). Pulp to peel ratio (PPR) of unripe fruit was also measured. The days to flowering was noted when the inflorescence was pendulous and the bracts were not yet opened from the randomly selected ten plants. Days to maturity was also recorded on the same set of selected plants.

Daily maximum and minimum temperature (°C), bright sunshine (BSS) hours were taken from the automatic weather station at the Research farm of ICAR- NRC Banana. The GDD was calculated by considering the base temperature of 13°C for the banana as defined by Ganry and Chillet (4). For each pheno-phase, growing degree days were calculated for different varieties using the following formula.

$$\text{Growing degree days (GDD)} = \sum (T_{\text{Max}} + T_{\text{Min}}) / 2 - T_{\text{Base}}$$

Similarly, helio -thermal unit was calculated as the product of GDD and the BSS for a given day and summed up for each growth pheno-phases. Photo-thermal unit was calculated by multiplying GDD and the day length of Tiruchirappalli, India (10°47'N), obtained from ICAR-CRIDA, Hyderabad. Heat use efficiency (HUE) was calculated by dividing the total dry matter production against growing degree days so as to decipher the production efficiency of different banana varieties.

Helio -thermal units (HTU) = GDD × actual bright sunshine hours (n)
Photo thermal units (PTU) = GDD × day length (N)

$$\text{Heat use efficiency (HUE)} = \frac{\text{Yield (kg)}}{\text{GDD}}$$

Fruit firmness (N) and TSS (°Brix) were measured with varying maturity (80, 90 and 100%) of varieties and the same was corroborated with thermal units to identify the correlation among the variables.

Table 1. Numbers of days required for commencement of different phenological events in banana varieties.

| Variety | Date of planting | Days taken for flowering | Days taken for fruiting | Crop duration (Maturity) |
|--------------|------------------|--------------------------|-------------------------|--------------------------|
| Monthan | 5th April | 260 ± 2 ^{cd} | 85 ± 3 ^g | 345 ± 8 ^d |
| Saba | 5th April | 255 ± 10 ^{cd} | 80 ± 2 ^h | 335 ± 14 ^{de} |
| Grand Naine | 5th April | 210 ± 3 ^f | 100 ± 3 ^e | 310 ± 12 ^g |
| Pachanadan | 3rd June | 235 ± 4 ^e | 90 ± 3 ^f | 325 ± 10 ^{efg} |
| Ney Poovan | 5th May | 265 ± 9 ^c | 110 ± 2 ^d | 375 ± 14 ^c |
| Poovan | 10th Dec | 280 ± 6 ^b | 100 ± 5 ^e | 380 ± 8 ^c |
| Rasthali | 10th Dec | 285 ± 10 ^b | 120 ± 5 ^c | 405 ± 12 ^b |
| Karpuravalli | 10th Dec | 290 ± 6 ^b | 125 ± 5 ^b | 415 ± 10 ^b |
| Udhayam | 10th Dec | 340 ± 5 ^a | 130 ± 2 ^a | 470 ± 10 ^a |
| Popoulu | 28th March | 250 ± 3 ^d | 80 ± 5 ^{gh} | 330 ± 7 ^{def} |
| Nendran | 5th April | 225 ± 6 ^e | 90 ± 3 ^f | 315 ± 12 ^{fg} |

One-way analysis of variance (ANOVA) was used to statistically analyse the data using SPSS version 21 (IBM SPSS Inc., Chicago, IL), expressed as mean \pm Standard deviation using the Duncan Multiple Range Test ($p < 0.05$). Origin 8.5 version (Origin Lab) software was used for graphical representation.

RESULTS AND DISCUSSION

The mean monthly meteorological parameters pertaining to temperature as observed during the banana growth and development is presented in Fig.1 a and b. The monthly Tmax and Tmin varied significantly. Maximum temperature (37.93 – 40.45°C) was observed during the month of April and May in both the years, whereas the minimum temperature (21.39 – 22.23°C) was observed in the month of December and January. Temporal variation in total amount of Relative Humidity (RH) received is depicted in the Fig. 2. Maximum RH was observed during the month of December and January (74.65 - 81.52%). Whereas the minimum was recorded during the month of June (34.60 - 40.20%) in both the years.

Among the varieties, days required for flowering and fruit maturation varied significantly (Table 1). Days required for flowering in different varieties varied between 210 - 340 days whereas flowering to fruiting took 80 - 130 days. Days taken for flowering was earliest in Grand Naine (210 days) followed by Nendran (225 days), and Pachanadan (235 days) whereas the Pisang Awak type varieties like Udhayam and Karpuravalli took 290 and 240 days respectively. Udhayam, a high yielding banana took approximately 50 more days to flower than karpuravalli. Similarly, the cooking varieties like Monthan and Saba took 255-260 days for flowering. Poovan and Rasthali behaved similar with respect to flowering however, Rasthali took comparatively more time to fruiting (120 days) than the Poovan (100 days). In spite of a greater number of days for flowering (250 days), var. Popoulu took lesser days to fruiting than Nendran (90 days). In general cooking bananas like Monthan and Saba required lesser number of days to fruiting (80-85 days) than the dessert bananas like Grand Naine, Rasthali, and Poovan (100-120 days). Similar to flowering, among the varieties studied, Udhayam needed maximum number of days (130 days) to fruiting. The genetic makeup of the varieties determines the early, mid and late flowering and fruiting characteristics of different varieties (Uma *et al.*, 12).

Morphological variation among the varieties is given in Table 2. The height of the plant differed significantly ($p < 0.05$). Higher plant height was

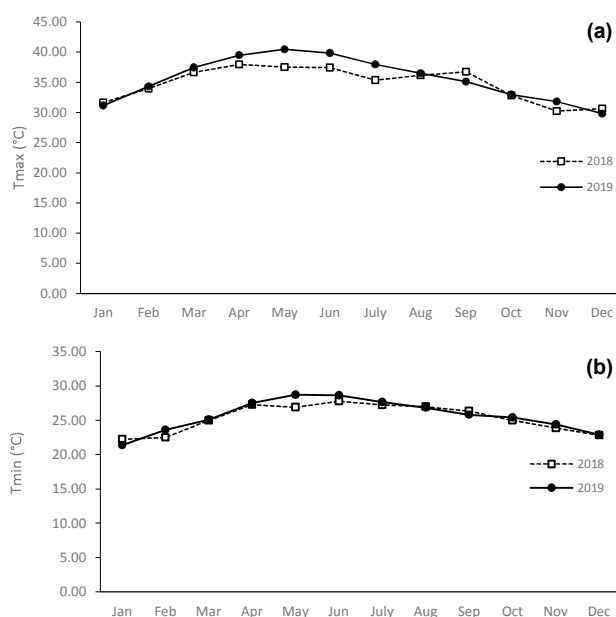


Fig. 1. Monthly maximum (a) and minimum (b) temperature during banana growing season.

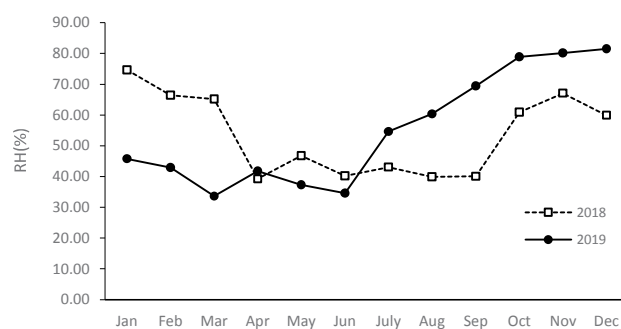


Fig. 2. Monthly average Relative Humidity during banana growing season.

noted for Karpuravalli (416 cm), Udhayam (420 cm) and Ney Poovan (380 cm) than other banana varieties. Lesser plant height was recorded for varieties Nendran (240 cm), Grand Naine (244 cm) and Popoulu (260 cm). Stem girth varied from 52 ± 3 cm (Poovan, Rasthali) to 95 ± 5 cm (Udhayam, Karpuravalli). During the growth period, Ney Poovan has recorded higher leaf production followed by var. Poovan. Huge difference in the bunch yield (28 – 94 t/ha) was recorded among the eleven banana varieties. With higher duration of more than 450 days, var. Udhayam registered the highest yield of 94.5 t/ha followed by Grand Naine (89 t/ha, 310 days) and Karpuravalli (55 t/ha, 415 days). In spite of more number of days for fruiting (405 days), var. Rasthali recorded the lesser yield (28.12 t/ha). Nonetheless of lesser days var. Popoulu recorded

higher yield (38 t/ ha) than var. Nendran (28 t/ha). Corresponding to the yield, hands per bunch was also differing in the varieties with the following descending order; Udhayam (17)> Karpuravalli (17)> and Grand Naine (13) whereas the lesser number of hands were observed with Monthan, Nendran, and Popoulu (6-7 hands). Highest number of fingers / bunch was recorded in Udhayam (350) whereas the least was observed in Nendran (88) and Monthan (72). Finger weight varied between 50-250 g among the varieties. Ney Poovan, Rasthali, Karpuravalli and Udhayam were at par for finger weight (50-55 g) whereas Popoulu, Monthan and Nendran did not vary significantly (225-250 g). Fruit diameter, an important parameter to determine the quality of the fruit varied among the varieties. Higher fruit diameter was recorded in Popoulu (5.68 cm) followed by Saba (5.22 cm). However, var. Ney Poovan was the least in diameter (3.07 cm) other varieties like Poovan, Karpuravalli and Udhayam (3.52-3.65 cm) were at par for fruit diameter. Pulp to peel ratio was higher in Popoulu (3.22) and Ney Poovan (2.86) due its thin peel whereas it was lesser in Saba (1.15) and Pachanadan (1.16).

In the study of crop-weather relationship, development of pheno-phases are the essential components. The accumulated thermal unit requirement of banana varieties for phenophases differed significantly (Table 3). Growing degree day requirement from planting to flowering varied significantly among the varieties. Udhayam recorded the highest GDD (6080 °day). Karpuravalli (5279.5°day) and Rasthali (5196.5°day) were on par with their degree day requirement. Cvs. Pachanadan and Grand Naine needed the least GDD units (3880.5 °day, 3884 °day) followed by Nendran (4104.5 °day). Similar to the results of Ganry and Chillet, (3), the GDD requirement from flowering to fruiting among the varieties varied from 1125 (Popoulu) to 2031 (Ney Poovan) degree days. It is essential to calculate the heat units to identify the right time for specific growth and development phase for the maximization of crop yield and to harvest the banana at right time to enhance the Green life (GL) during transit and handling in the domestic transport and export line (Saniya *et al.*, 10).

Being grown in tropical place where the mean maximum and minimum temperature did not vary much, resulted into higher degree days for each day and thus the variation of 2-3 days resulted in attainment of maximum degree days as observed with Ney Poovan and Udhayam. The overall GDD requirement of varieties varied significantly among the varieties. Udhayam was stand alone

Table 2. Growth and yield characteristics of eleven banana varieties at full maturity.

| Variety | Monthan | Saba | Grand Naine | Pachanadan | Ney Poovan | Poovan | Rasthali | Karpuravalli | Udhayam | Popoulu | Nendran |
|----------------------|----------------------------|-----------------------------|----------------------------|---------------------------|---------------------------|---------------------------|----------------------------|---------------------------|---------------------------|----------------------------|----------------------------|
| Plant height (cm) | 385 ± 8.0 ^b | 336.70 ± 12.14 ^c | 244 ± 5.23 ^c | 290 ± 4.26 ^{ef} | 380 ± 8.66 ^b | 295 ± 9.33 ^d | 260 ± 6.88 ^e | 416 ± 8.87 ^b | 420 ± 15.14 ^a | 260 ± 10.12 ^b | 240 ± 4.67 ^f |
| Stem Girth (cm) | 69.30 ± 1.86 ^d | 75.60 ± 2.44 ^c | 73.60 ± 2.27 ^c | 70 ± 1.90 ^f | 63 ± 0.98 ^e | 52 ± 1.41 ^f | 53.20 ± 1.17 ^f | 85 ± 0.96 ^b | 97 ± 1.43 ^a | 70 ± 2.14 ^d | 65 ± 0.87 ^e |
| Leaf/ plant | 14 ± 1.00 ^e | 15 ± 1.00 ^d | 13 ± 0.50 ^f | 14 ± 1.00 ^e | 23 ± 0.50 ^a | 22 ± 1.00 ^b | 14 ± 0.80 ^e | 13 ± 1.00 ^f | 16 ± 1.00 ^c | 13 ± 1.00 ^f | 13 ± 1.00 ^f |
| Hands/ bunch | 6 ± 2.00 ^f | 8 ± 1.00 ^e | 13 ± 1.50 ^b | 8 ± 1.00 ^e | 11 ± 1.00 ^c | 11 ± 1.00 ^c | 9 ± 1.00 ^d | 14 ± 1.00 ^b | 17 ± 2.00 ^a | 7 ± 2.00 ^e | 6 ± 1.00 ^f |
| Finger/ bunch | 72.20 ± 4.00 ^h | 98.50 ± 5.00 ^f | 155 ± 4.00 ^d | 130 ± 3.00 ^e | 164 ± 4.00 ^c | 154 ± 5.00 ^d | 168 ± 2.00 ^c | 230 ± 3.00 ^b | 350 ± 5.00 ^a | 95 ± 6.00 ^f | 88 ± 4.00 ^g |
| Finger weight (g) | 235.10 ± 6.70 ^b | 219.57 ± 8.00 ^c | 132.23 ± 6.55 ^d | 55.50 ± 7.00 ^f | 50.46 ± 5.44 ^g | 54.67 ± 3.85 ^f | 65 ± 5.76 ^e | 52.05 ± 3.98 ^f | 50.15 ± 2.78 ^f | 224.67 ± 8.11 ^c | 247.67 ± 6.09 ^a |
| Finger length (cm) | 23.20 ± 0.50 ^b | 17.7 ± 0.80 ^d | 20.79 ± 0.75 ^c | 10.2 ± 0.46 ^f | 11.44 ± 0.43 ^f | 12.5 ± 0.66 ^e | 10.50 ± 0.50 ^g | 10.6 ± 0.41 ^g | 11.5 ± 0.54 ^{ef} | 18.73 ± 0.39 ^d | 25.13 ± 0.55 ^a |
| Finger girth (cm) | 19.3 ± 0.33 ^a | 16.2 ± 0.44 ^c | 11.79 ± 0.29 ^e | 9 ± 0.23 ^g | 8.07 ± 0.51 ^f | 9.50 ± 0.48 ^f | 11.21 ± 0.44 ^{ef} | 10.56±0.52 ^{ef} | 10.42 ± 0.22 ^f | 17.83 ± 0.62 ^b | 14.03 ± 0.43 ^d |
| Finger diameter (cm) | 4.87 ± 0.21 ^c | 5.22 ± 0.18 ^b | 3.75 ± 0.17 ^f | 4.22 ± 0.21 ^d | 3.07 ± 0.20 ^h | 3.52 ± 0.32 ^d | 4.02 ± 0.27 ^e | 3.62 ± 0.31 ^g | 3.58 ± 0.29 ^g | 5.68 ± 0.58 ^a | 4.79 ± 0.25 ^c |
| Bunch weight (kg) | 18.2 ± 0.38 ^f | 21.6 ± 0.50 ^c | 35.06 ± 0.55 ^b | 14 ± 0.81 ^e | 18.2 ± 0.55 ^f | 13 ± 0.50 ^{ef} | 11.25 ± 0.47 ^g | 22 ± 0.35 ^e | 37.80 ± 0.58 ^a | 18.5 ± 0.37 ^d | 11.5 ± 0.45 ^g |
| Yield(kg) / ha | 45500 ± 340 ^d | 54000 ± 529 ^c | 89000 ± 192 ^b | 35000 ± 261 ^e | 45500 ± 210 ^d | 32500 ± 200 ^f | 28125 ± 454 ^g | 55000 ± 102 ^c | 94500 ± 890 ^a | 35000 ± 390 ^f | 28750 ± 486 ^g |
| Pulp to peel ratio | 1.25 ± 0.12 ^h | 1.15 ± 0.14 ^h | 1.87 ± 0.17 ^f | 1.16 ± 0.19 ^h | 2.86 ± 0.18 ^b | 1.7 ± 0.29 ^g | 2.12 ± 0.25 ^d | 2.36 ± 0.31 ^c | 2.3 ± 0.20 ^e | 3.22 ± 0.22 ^a | 2.01 ± 0.19 ^e |

Table 3. Influence of varying maturity stages on growing degree days (GDD) on TSS, starch and firmness of banana varieties.

| | 80% maturity | | | | 90% maturity | | | | 100% maturity | | | |
|--------------|---------------------|-------------------------|--------------------------|-------------------------|----------------------|------------------------|-------------------------|-------------------------|----------------------|------------------------|-------------------------|--------------------------|
| | GDD (°C day) | TSS (° Brix) | Firmness (N) | Starch (%) | GDD (°C day) | TSS (° Brix) | Firmness (N) | Starch (%) | GDD (°C day) | TSS (° Brix) | Firmness (N) | Starch (%) |
| Monthan | 970.5 ^f | 1.06±0.21 ^f | 26.12±0.34 ^d | 39.45±0.45 ^a | 1131.0 ^{ef} | 1.89±0.25 ^f | 24.1±0.55 ^c | 38.94±0.23 ^b | 1277.1 ^f | 3.06±0.11 ^e | 23.65±0.26 ^c | 37.23±0.23 ^b |
| Saba | 906.4 ^e | 1.72±0.53 ^e | 29.61±0.16 ^b | 40.04±0.43 ^a | 1020.0 ^f | 2.98±0.36 ^d | 27.87±0.24 ^a | 39.14±0.46 ^a | 1159.5 ^g | 3.46±0.13 ^d | 26.4±0.32 ^a | 38.26±0.54 ^a |
| Grand Naine | 1092.5 ^d | 0.89±0.42 ^g | 26.15±0.18 ^c | 34.24±0.57 ^c | 1229.5 ^d | 1.43±0.21 ^g | 24.22±0.26 ^c | 33.56±0.34 ^e | 1375.5 ^e | 2.21±0.21 ^f | 22.43±0.45 ^c | 32.19±0.36 ^f |
| Pachanadan | 1226.5 ^c | 2.01±0.36 ^d | 24.61±0.34 ^e | 28.23±0.59 ^e | 1413.8 ^c | 3.79±0.19 ^c | 21.17±0.34 ^e | 27.11±0.16 ^g | 1596.5 ^d | 5.12±0.32 ^b | 20.36±0.52 ^e | 26.45±0.48 ^h |
| Ney Poovan | 1603.6 ^a | 2.23±0.45 ^c | 22.56±0.26 ^f | 30.57±0.76 ^d | 1840.5 ^a | 3.84±0.15 ^c | 20.87±0.87 ^e | 29.04±0.52 ^f | 2031.5 ^a | 4.36±0.13 ^c | 19.54±0.42 ^f | 28.59±0.75 ^g |
| Poovan | 1251.4 ^c | 3.47±0.42 ^a | 25.36±0.24 ^e | 34.12±0.49 ^c | 1385.5 ^d | 5.95±0.20 ^a | 22.05±0.45 ^d | 33.82±0.23 ^e | 1519.5 ^d | 7.03±0.35 ^a | 20.8±0.62 ^e | 32.64±0.64 ^e |
| Rasthali | 1450.5 ^b | 2.34±0.52 ^{bc} | 26.48±0.46 ^f | 23.55±0.71 ^g | 1620.5 ^b | 4.77±0.23 ^b | 22.98±0.69 ^d | 36.18±0.46 ^c | 1778.5 ^{cd} | 5.36±0.36 ^b | 21.5±0.38 ^d | 35.03±0.26 ^c |
| Karpuravalli | 1492.5 ^b | 1.08±0.43 ^f | 25.19±0.19 ^e | 27.36±0.94 ^f | 1668.5 ^b | 2.14±0.25 ^e | 24.11±0.54 ^c | 26.58±0.16 ^g | 1834.5 ^{bc} | 3.22±0.42 ^d | 22.54±0.54 ^c | 25.36±0.35 ^f |
| Udhayam | 1472.5 ^b | 0.78±0.498 ^g | 20.44±0.55 ^g | 30.22±0.54 ^d | 1697.8 ^b | 1.4±0.27 ^a | 18.23±0.61 ^f | 28.54±0.25 ^f | 1931.7 ^b | 2.81±0.20 ^f | 17.54±0.38 ^g | 27.36±0.46 ^{gh} |
| Popolu | 866.3 ^f | 1.14±0.51 ^f | 28.33±0.78 ^{bc} | 36.73±0.36 ^b | 991.5 ^g | 2.37±0.31 ^e | 26.98±0.49 ^b | 35.88±0.46 ^d | 1125.5 ^g | 3.39±0.39 ^d | 25.45±0.49 ^b | 34.23±0.42 ^d |
| Nendran | 964.7 ^d | 2.56±0.54 ^b | 30.21±0.25 ^e | 36.41±0.34 ^b | 1093.5 ^f | 3.78±0.35 ^c | 27.02±0.57 ^a | 34.09±0.65 ^e | 1233.5 ^f | 4.35±0.16 ^c | 25.78±0.89 ^b | 33.17±0.55 ^e |

on its GDD requirement (8011 °day) whereas the varieties like Grand Naine, Pachanadan and Nendran required 5200-5400 °days. Commercial banana varieties like Ney Poovan, Rasthali and Poovan required 6400-6900 °days. Cooking and dual purpose varieties like Monthan, Saba and Popolu required >5600 and <5800 °days for completion of one crop cycle. Accumulated sum of mean daily temperature has the correlation with the fruit growth and physiological age of banana fruits (Jullien *et al.*, 7). The results revealed that the annual variation in growth of the plant as well as its yield could also be possibly influenced by weather parameters too. We opine that phenology of banana could be greatly influenced by the increase or decrease of temperature as temperature and other parameters like photoperiod influences plant growth and bunch development.

Time period of bright sun shine hours is also notably accounted as one among the salient factors for growth and development of banana. In our study, significant differences were observed among the varieties for their response to sun shine hours. It ranged from 22219.07 (Pachanadan) to 41519 (Udhayam) units for days taken for flowering whereas it has the index of 6592.8 (Poovan) to 17041.8 (Ney Poovan) during the phenology of flowering to fruiting. During the crop growth period varieties like Karpuravalli, Rasthali, Poovan and Ney Poovan required HTU of 43000-45000 whereas var. Udhayam required HTU of 53000. Other varieties required HTU of 32000-36000 which essentially portrayed the sunshine requirement of banana varieties. With varying maturity stages the GDD, TSS, firmness and starch content of different varieties differed significantly (Table 3). Irrespective of maturity stages, var. Ney Poovan required higher number for GDD followed by Rasthali which reflected the poor photosynthate utility of these varieties. Whereas varieties like Popolu and Nendran with lesser GDD reflected the better source-sink relationship and maximum utilization of photosynthates for the accumulation of carbohydrate i.e. starch in the banana hands. Though the change in not significant, firmness get reduces with the progression of maturity whereas slight increase in TSS was observed. Better source-sink relationship could be maintained with optimum temperature and photo-period as discussed earlier (Bal *et al.*, 1; Fischer *et al.*, 3).

Determining the optimum harvesting time to ensure right yield and a higher postharvest life during shipping is essential for efficient supply chain and export of banana, which requires 3-4 weeks of green life. Among the banana varieties, data

revealed that accumulated PTU varied between 46308.25 – 73057.64 °C (days taken for flowering), 12703 - 24260.61°C (Flowering to fruiting) (Table 4). It was substantiated that GDD for early varieties like Grand Naine (63114.5 °C) required lesser PTU than long duration varieties like Udhayam (95102.21 °C). The accumulated PTU requirement of different banana followed the order: Udhayam (95102.21) > Karpuravalli (84686.83) > Rasthali (83116.86) > Poovan (79292.51) > Ney Poovan (77611) > Monthan (70050.35) > Saba (67878.27) > Popoulu (67204.06) > Pachanadan (65172.76) > Nendran (64008.94) > Grand Naine (63114.05). Results of present study also described that within group variation of accumulated PTU was maximum in Udhayam and successively lower for Nendran and Grand Naine.

Fruit yield and GDD showed linear relationship and which in turn positively influenced the HUE (Fig. 3). Least HUE was observed in traditional varieties like Rasthali (4.03), Poovan (4.90) and Nendran (5.39). Interestingly, nevertheless of higher duration, with its yield, Udhayam recorded the significantly higher HUE than its counterpart Karpuravalli (6.34). Similarly, Saba recorded higher HUE than its predecessor Monthan. The HUE of other varieties were in the range of 5-7 which were far less than the most popular variety Grand Naine (17.2). This has proven that varieties tend to display more thermal heat accumulation and good utilization of energy with higher HUE. Photoperiod and temperature has a greater role to play on the photosynthate production and translocating it into the sink i.e. bunches in banana.

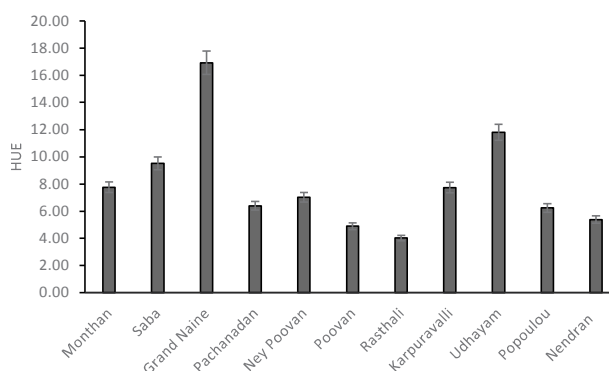


Fig. 3. Heat Unit efficiency of different banana varieties.

The study confirmed the importance of various thermal units on growth, development and fruit yield of banana varieties. 210-340 days of flowering was required for the banana varieties and fruit maturation in a time period of 80-130 days. The long duration cultivars such as Udhayam, Karpuravalli as well as Ney Poovan reported more days of phenology with higher values of PTU, HTU and GDD. In accordance, varieties such as Popoulu, Rasthali and Saba owing to their shorter duration reported lower values of GDD, PTU and HTU values. Accumulated GDD, PTU and HTU were linearly related with vegetative as well as reproductive stages of banana. In order to enhance the effective utilisation of energy besides biomass production, it is concluded that in lieu of the changing climatic scenario, it is the need of the hour to bred higher HUE varieties of banana with acceptable quality (Table 4).

Table 4. Growth Degree Days (GDD), Helio Thermal Unit (HTU), Photo Thermal Unit (PTU) and Heat Use Efficiency (HUE) requirement of eleven banana varieties at different phenological stages.

| Variety | Days taken for flowering | | | Flowering to fruiting | | | Crop duration | | |
|--------------|--------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|------------------------|------------------------|
| | GDD (°C day) | HTU (°C hour) | PTU (°C hour) | GDD (°C day) | HTU (°C hour) | PTU (°C hour) | GDD (°C day) | HTU (°C hour) | PTU (°C hour) |
| Monthan | 4583.00 ^c | 27087.62 ^c | 55489.09 ^c | 1277.00 ^c | 10491.60 ^d | 14561.26 ^g | 5860.00 ^d | 37579.22 ^d | 70050.35 ^e |
| Saba | 4515.50 ^c | 26815.37 ^c | 54732.42 ^c | 1159.50 ^c | 9068.05 ^e | 13146.86 ^h | 5675.00 ^{de} | 35883.42 ^{de} | 67879.27 ^{ef} |
| Grand Naine | 3884.00 ^e | 23037.47 ^f | 47605.95 ^e | 1375.50 ^e | 9044.40 ^{ef} | 15508.11 ^f | 5259.50 ^g | 32081.87 ^f | 63114.05 ^g |
| Pachanadan | 3880.50 ^e | 22219.07 ^f | 46308.26 ^e | 1596.50 ^e | 14471.10 ^b | 18864.50 ^d | 5477.00 ^{efg} | 36690.17 ^{de} | 65172.76 ^{fg} |
| Ney Poovan | 4447.50 ^c | 25956.62 ^d | 53350.95 ^c | 2031.50 ^c | 17041.80 ^a | 24260.61 ^a | 6479.00 ^c | 42998.42 ^c | 77611.56 ^d |
| Poovan | 5115.00 ^b | 36420.55 ^b | 61837.10 ^b | 1519.50 ^b | 6592.85 ⁱ | 17455.41 ^e | 6634.50 ^c | 43013.4 ^c | 79292.51 ^{cd} |
| Rasthali | 5196.50 ^b | 36824.20 ^b | 62823.40 ^b | 1778.50 ^b | 7994.35 ^h | 20293.47 ^c | 6975.00 ^b | 44818.55 ^{bc} | 83116.86 ^{bc} |
| Karpuravalli | 5279.50 ^b | 37383.45 ^b | 63824.71 ^b | 1834.50 ^b | 8611.95 ^{fg} | 20862.11 ^c | 7114.00 ^b | 45995.40 ^b | 84686.83 ^b |
| Udhayam | 6080.00 ^a | 41519.00 ^a | 73057.64 ^a | 1931.00 ^a | 12113.70 ^c | 22044.57 ^b | 8011.00 ^a | 53632.70 ^a | 95102.21 ^a |
| Popoulou | 4482.50 ^c | 27230.72 ^c | 54501.05 ^c | 1125.50 ^c | 7903.45 ^h | 12703.01 ^h | 5608.00 ^{def} | 35134.17 ^e | 67204.06 ^{ef} |
| Nendran | 4104.50 ^d | 24184.02 ^e | 50108.79 ^d | 1233.50 ^d | 8508.80 ^g | 13900.16 ^g | 5338.00 ^{fg} | 32692.82 ^f | 64008.94 ^{fg} |

AUTHORS' CONTRIBUTION

Conceptualization of research (PSK, IR and SU); Designing of experiment (PSK, MSS and KNS); Contribution of experimental materials (IR, MSS and KNS); Field/lab experiments and data collection (RR and KK); data interpretation (PSK, IR, RR and KK); Preparation of the manuscript (PSK, SU, RR and MSS).

DECLARATION

Authors declare that we do not have any conflict of interest.

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