Annals of Arid Zone 38(2): 161-166, 1999

Thermal Time Requirement for Fruit Development and Maturity of Jujube (*Zizyphus mauritiana*) Grown Under Rainfed Conditions in Indian Hot Desert

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Abstract: Relationships between phenological stages in three promising cultivars of jujube (viz., Tikadi, Seb and Gola) and ambient temperature were worked out for an established orchard in arid sub-tropical climate of NW India under rainfed conditions. It was observed that Gola fruits mature early because they need relatively lesser thermal time (heat units), around 168919 degree Celsius days (°Cd) than others, after fruit setting. Tikadi and Gola cultivars required 335°Cd and 88°Cd for a mm increase in their fruit size, respectively. This could be one of the reasons for the faster development rate of Gola fruits. Thermal time calculated for the fruit maturity of different cultivars during three consecutive years 1990-93, were used for predicting the fruit maturity time during the next two seasons, 1993-94 and 1994-95. Heat use efficiency of Gola fruits was the highest (4.57 kg fruit ha^{-1} $°Cd^{-1}$); followed by Tikadi and Seb cultivars.

Key words: Thermal time, jujube, phenology, fruit maturity, rainfed.

The *Zizyphus* species are distributed throughout the tropical, sub-tropical and temperate regions of both the hemispheres (Rendle,1959). In north India, the growth of jujube starts from late June to early July, with the advancement of SW monsoon, followed by flower emergence, fruit setting in October and fruit maturity during February to April. In arid Rajasthan, owing to dry conditions (low humidity), a shorter winter and early start of summer, the jujube fruits mature during January to March (earlier than in other regions of northern India).

This spatial variation in the maturity time of the jujube fruit is mainly due to change in thermal regime from one place to the other. Therefore, this study was undertaken to quantify the heat units (thermal time) requirement by three promising cultivars. Among these, Tikadi is a local cultivar and it keeps larger canopy with more or less stable fruit yield during different rainfall situations. Gola cultivar is high yielding with a closer canopy. Its fruit quality is good and it also matures early (Vashistha and Pareek, 1989). Seb is a mid-season cultivar, having short canopy as well as good shelf life of fruits. Thermal time approach could offer better means for prediction of harvesting time of fruits than the number of calendar days.

Materials and Methods

The study was conducted in a 15-year-old jujube (*Zizyphus mauritiana* Lamk) orchard located at Central Arid Zone Research Institute, Jodhpur (26.3°N, 73.02°E, 224 m above MSL). The region receives an average annual rainfall of 368 mm, out

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of which about 90% occurs during the main growing season (June-September) of jujube. The soil is loamy sand (Typic Camborthid) and moderately deep (50-75 cm), below which hard kankar (Murram) prevails. The experiment was laid out in Randomised Block Design with three cultivars and treatments replicated 15 times at random and spaced at 6 x 6 metres.

The heat units (thermal time) were computed using mean daily air temperature minus the base (threshold) temperature (Singh *et al.*, 1996, 1998). In this study, the base temperature of 5°C was used, as tissue activity gets greatly retarded below 5°C. Daily values of the heat units have been summed up for each development stage from pruning date till fruit maturity as well as upto pruning in succeeding year. Thermal time was accumulated for each of the development event, viz., bud formation, fruit setting and fruit maturity. The accumulated thermal time for each of the three phenophases, i.e., pruning to (a) bud formation, (b) fruit setting and (c) first harvest of fruits, were then divided by the cumulative thermal time from pruning to last harvest, to obtain fraction of thermal time (FTT) for these developmental intervals. The time for first harvest of fruits was when 30% of the fruits in a tree had matured to edible stage.

Fruit samples from each cultivar were harvested and collected randomly from all directions at different development stages at periodical interval of 15 days. Fruit sizes (length and width) were measured with the help of vernier callipers. Total soluble solids (TSS) was measured in °Brix using Hand Refractometer. For this purpose, fruits were harvested randomly from different cultivars at maturity (edible stage) and immediately brought to laboratory for the TSS measurements.

Dry biomass (kg ha^{-1}) of each cultivar of jujube was measured. The pruning of new shoots was done in the middle of May. Sums of daily radiation received over the orchard during a complete life cycle were worked out to estimate the energy use efficiency, EUE (%) assuming 16.7 KJ are required for producing one gram of dry matter (Lemon, 1969). The daily values of radiation and temperatures were obtained from agrometeorological observatory located near the orchard.

Heat use efficiency (HUE) of crop production (kg ha^{-1}) per unit degree day (°Cd), with respect to fruit yield and pruned dry biomass production, was computed following Sastry *et al.* (1985).

Results and Discussion

Phenological development in jujube in relation to thermal time

The data on thermal time requirement indicate that Seb cultivar requires the lowest accumulation of thermal time (259510°Cd) during pruning to the stage of bud formation. This variety is followed by Gola and Tikadi, with the latter requiring the highest heat summation units (3044°Cd). It was observed that fruit setting in the Seb cultivar occurred about two weeks earlier than that in Tikadi and Gola cultivars in this region (Table 1). However, Gola cultivar matured earlier than all other cultivars (Vashistha and Pareek, 1989; Singh *et al.*, 1998). It needs only 1689°Cd accumulation from fruit setting to first harvest of fruit whereas Seb

Table 1. Heat unit accumulation for the completion of different growth stages of jujube cultivars in hot arid climate at Jodhpur

Growth stages	Cultivars			SEm (±)	CD at 5%
	Tikadi	Seb	Gola		
Pruning to bud formation	3044	2595	2874	10	29
Budding to fruit setting	763	938	928	9	27
Fruit setting to maturity	1954	2191	1689	19	54

Note: CD: Critical difference SEm: Standard Error (mean).

cultivar require much accumulation of thermal time (2191°Cd), followed by Tikadi cultivar (1954°Cd).

FTT and development stages

The thermal time required for the completion of different phenological stages, as a fraction of the total growing period thermal time from pruning (May 15) to fruit maturity (final harvest), showed (Table 2) that the total thermal time (pruning to complete maturity) was less for Gola and varied in different years from 5820 to 6050 and higher for Seb (6079-6436) and Tikadi (6007-6415). The fraction of thermal time, for any of the three development intervals for a particular cultivar, varied within very narrow limits. From pruning to bud formation, the thermal time used were about 47, 40 and 46% of the total thermal time needed for fruit maturity for Tikadi, Seb and Gola cultivars, respectively. FTT from pruning to fruit setting was minimum (55%) for the Seb, followed by Tikadi (60%) and Gola (61%). The total FTT, up to first picking of fruits, was 91% in all cultivars. By and large, maximum thermal time, i.e., about 45%, was utilized by fruits of Seb cultivar, whereas Tikadi and Gola required less, 40 and 39%, respectively, between fruit setting and its maturity (Vashistha and Pareek, 1989). This study clearly brings out that Seb fruits need more degree days for maturity, despite early fruit setting in comparison to Tikadi and Gola cultivars in the region.

Table 2. Heat units in different growth stages as fraction of total growing period heat units

Cultivar	Year	Pruning to bud formation	Pruning to fruit setting	Pruning to fruit maturity (first harvest)	Total heat units (°Cd) from pruning to last fruit harvest
Tikadi	1990-91	0.45	0.59	0.91	6135
	1991-92	0.50	0.62	0.93	6007
	1992-93	0.47	0.59	0.90	6415
Seb	1990-91	0.39	0.53	0.91	6135
	1991-92	0.41	0.58	0.93	6079
	1992-93	0.41	0.55	0.90	6436
Gola	1990-91	0.44	0.58	0.88	5975
	1991-92	0.47	0.62	0.93	5821
	1992-93	0.47	0.63	0.90	6051

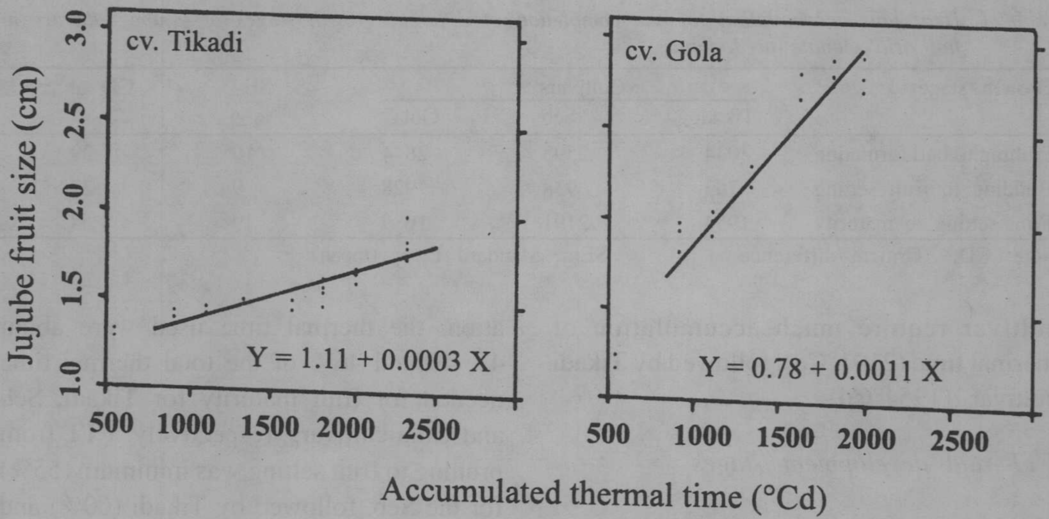

Fig. 1. Relationship between jujube fruit growth size and accumulated thermal time under arid conditions.

Fruit development-thermal time relationship

Relationship between jujube fruit growth size (cm) and accumulated heat units after fruit setting for two contrasting cultivars (Tikadi and Gola) were worked out (Fig. 1). In both cases linear regression was the best fit with high correlation coefficients, significant at 1% level.

The regression equation fitted between fruit size (Y) and thermal time (X) in case of Tikadi and Gola cultivars maintained under rainfed conditions, respectively, were

$$Y = 1.11 + 0.0003\ X \text{ with c.c. of } 0.90, \quad d.f. = 24 \qquad ...(1)$$

$$Y = 0.78 + 0.0011\ X \text{ with c.c. of } 0.97, \quad d.f. = 19 \qquad ...(2)$$

This reveals that inspite of taking almost similar time for fruit setting by both the cultivars, the fruits of local Tikadi cultivar, thereafter, grow slowly and need more heat units (around 335°Cd) per mm of growth, in comparison to the fruits of Gola cultivar, which grows rapidly and requires less heat units (88°Cd) per mm growth.

TSS at fruit maturity

TSS (°Brix) measured in fruits of different jujube cultivars at maturity during five consecutive seasons revealed that TSS values for Gola cultivars varied between 20.4 and 22.4, whereas it was between 20.9 and 23.2 for Seb cultivar and between 27.5 and 30.0 for Tikadi cultivar. TSS content in Tikadi fruits was significantly more in comparison to Gola and Seb cultivars. Considerable changes in TSS values from one season to another season in the fruits of same cultivar was also observed. These changes in TSS are attributed to variation in rainfall and weather conditions during the growing season.

Table 3. Rainfall and mean air temperatures during different growing seasons of jujube

Year	Annual rainfall (mm) June-May	Mean air temperature (°C)				Fruit yield (kg tree^{-1})		
		June-Sep	Oct-Jan	Feb-May	Annual	Tikadi	Seb	Gola
1990-91	788.9	30.6	21.6	27.6	26.6	20.0	24.2	27.0
1991-92	241.0	31.5	22.1	26.8	26.8	17.4	18.1	21.6
1992-93	419.8	31.3	21.9	27.6	26.9	19.0	20.6	28.5
1993-94	345.1	31.7	23.2	28.1	27.7	5.5	5.4	8.6
1994-95	547.0	29.1	20.8	27.7	25.9	15.0	30.8	35.1

Prediction of fruit maturity time

Thermal time worked out for the maturity time of fruits of different cultivars was tested to predict the maturity of the fruits in subsequent years, 1993-94 and 1994-95. It was calculated that the actual thermal time required by the fruits of Gola cultivar for maturity were 1656 and 1729°Cd during the year 1993-94 and 1994-95, respectively. These thermal time values are almost close to the predicted time (1689°Cd) for the fruit maturity of Gola cultivars. Similarly, the predicted time for fruit maturity of Seb and Tikadi cultivars were also comparable to the actual thermal time taken during the year 1993-94 and 1994-95 in the region. In general, different jujube trees took more (104 to 137) days for their fruit maturity during the season 1994-95 in comparison to days (85 to 116) taken in 1993-94 season. The likely reason for this could be the considerably lower ambient temperature (20.8°C) regime during the fruit development period (October-January) in 1994-95, in comparison to the same period in 1993-94 (23.2°C). The rainfall was much higher in 1994-95, which had favoured the growth of the jujube tree canopy and ultimately high fruit yield was recorded (Table 3). But, in the same year, cropping season was prolonged due to low temperature regime and finally, fruit maturity was delayed by 12 to 21 days during the season.

Fruit yield and HUE

Fruit yield (kg ha^{-1}) and the heat units (°Cd) utilised by three different cultivars of jujube from fruit setting to their maturity were worked out for the three consecutive years, with rainfall above normal (788.9 mm) during first year (1990-91), below normal (241.0 mm) during second year (1991-92), and normal (419.8 mm) in third year (1992-93). HUE in terms of kg ha^{-1} °Cd^{-1} were calculated for all the cultivars for the three years under different rainfall situations (Table 4). HUE of Tikadi cultivar varied between 2.53 kg ha^{-1} °Cd^{-1} during below normal rainfall year and 2.75 kg ha^{-1} °Cd^{-1} during normal and above normal rainfall years. However, the HUE of Seb cultivar was lowest and varied between 2.31 and 2.82 kg ha^{-1} °Cd^{-1}. The HUE of Gola cultivar was the highest among all and it varied between 3.55 and 6.07 kg ha^{-1} °Cd^{-1}. This analysis also clearly indicates that the HUE increases with the increased quantum of rainfall during the monsoon season. Thus, it is concluded that jujube crop utilized available temperature

Table 4. Heat use efficiency (HUE) of jujube fruits of different cultivars during three consecutive years

Cultivar	1990-91			1991-92			1992-93		
	Fruit yield (kg ha^{-1})	Heat unit consumed (°Cd)	HUE (kg ha^{-1} $°Cd^{-1}$)	Fruit yield kg ha^{-1}	Heat unit consumed (°Cd)	HUE (kg ha^{-1} $°Cd^{-1}$)	Fruit yield (kg ha^{-1})	Heat unit consumed (°Cd)	HUE (kg ha^{-1} $°Cd^{-1}$)
Tikadi	5504	1998	2.75	4773	1885	2.53	5371	1956	2.75
Seb	6644	2353	2.82	4960	2151	2.31	5402	2190	2.47
Gola	7423	1807	4.11	5941	1673	3.55	10169	1675	6.07

regime more efficiently during high and normal rainfall years when the soil moisture in the root zone was adequate to meet the crop water requirement.

Dry biomass, energy and heat use efficiencies

The analysis indicated that values of EUE (0.08%) and HUE (0.38 kg ha^{-1} $°Cd^{-1}$) of Tikadi cultivar were higher because they could produce more biomass and had larger canopy compared to other cultivars under study. The mean daily radiation (MJ m^{-2}) varied from 23.7 in April to 11.1 in December, whereas sun shine hours (hrs day^{-1}) ranged from 10.2 in April to 6.4 in August over the orchard. Interestingly, during jujube fruit development period (November-January), the mean daily photoperiod was high, being about 9.1 hours day^{-1} while mean daily radiation recorded was comparatively low, around 12.6 MJ m^{-2}

The results of this study indicated that thermal time could be used as a better tool for prediction of fruit maturity time of jujube in comparison to conventional calendar day in the region. Fruit yield of Gola was significantly higher during good rainfall years. However, EUE of Tikadi cultivar, with respect to its dry matter production, was always higher due to its faster growth of canopy in comparison to all others.

Acknowledgements

Authors are thankful to Director, CAZRI, Jodhpur, for providing necessary facilities to conduct this study.

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