Base temperature for development in Cape gooseberry (*Physalis peruviana* L.).

M.R. Salazar  
Facultad de Ingeniería  
Universidad de la Sabana

J.W. Jones  
Agricultural & Biological  
Engineering Department  
University of Florida

B. Chaves  
Facultad de Agronomía  
Universidad Nacional de Colombia

A. Cooman  
Centro de Investigaciones y  
Asesorías Agroindustriales.  
Universidad de Bogota Jorge TadeoLozano

Keywords: Nodes, simulation, thermal time, base temperature, Cape gooseberry.

Abstract

Very little research has been done to characterize the effects of temperature on development of Cape gooseberry (*Physalis peruviana* L.). We analyzed data on development of Cape gooseberry to evaluate how well a classical thermal time model could describe node appearance in different environments. The data used in the analysis were obtained from experiments conducted in Colombia in open fields and greenhouse conditions at two locations with different climate. An empirical, segmented linear model was used to estimate the base temperature and to parameterize the model for simulation of node appearance vs. time. The base temperature (Tb) used to calculate the thermal time (TT, °Cd) for node appearance was estimated to be 6.29 °C. The slope of the first linear segment was 0.023 nodes per TT and 0.008 for the second linear segment. The time at which the slope of node appearance changed was 1039.5 °Cd after transplanting, determined from a statistical analysis of model for the first segment. When these coefficients were used to predict node appearance at all locations, the model fit the observed data well, especially during the first segment where node appearance was more homogeneous than the second segment. More nodes were produced by plants grown under greenhouse conditions and minimum and maximum rates of node appearance rates were also higher. These results are consistent with the higher average temperatures in the greenhouses when compared with outside conditions at each location.

Introduction

The periodic study of biological phenomenons or natural events is dominated by phenology. Phenology is determined by phases that mark the appearance, transformation or disappearance of vegetative and reproductive organs, such as the emergence of plants, appearance of nodes, buds, flowers and fruits. Torres (1995) and Schwartz (1999) mentioned that the beginning and the end of the phases and the stages are good indicators of the rate of growth of the plants.
According to Angulo et al. (2003), the development rate can be determined by the measuring the time that lapses from one node appears until the next one appears which is normally done by counting nodes weekly and recording the temperature. In Cape gooseberry, each of the main stem units that consist of a leaf, a stem, and a fruit is a node.

The number of organs on a plant changes when new leaves, stems or fruits appear. The rate of emergence of new nodes, which is a phenological function that depends on temperature, is an important factor in the plant development. The number of nodes represents the development state or age of the plant. Sequentially, the organ development is regulated by the rate of node appearance and the rates of development of leaves and fruits (Cooman, 2002). The node appearance on the main stem is a central component of the leaf area index increment and thus radiation interception and growth (Robertson et al., 2002).

Reddy & Pachepsky (2002) indicated that the rate of node appearance defines the evolution of the cotton plant architecture and its height, properties that determine the appropriate management of cultivation. Scholberg et al. (2000) and Brown & Moot (2004) established that node appearance is influenced by temperature and is generally related to the accumulation of degree days or thermal time. Likewise, in other studies on cotton, Lucerne, melon, pea and soy among others, Ellis et al. (1995), Roche et al. (1998); Verghis et al. (1999), Baker & Reddy (2001); Moot et al. (2001), Reddy et al. (2002), Brown & Moot (2004) and Setiyono et al. (2005) found that phenological development, in addition to being influenced by temperature, may interact with solar radiation, age of the plant, source-sink relationships, and photoperiod duration.

The use of degree days or thermal time, instead of calendar days, to predict node appearance and plant development allows one to make appropriate decisions about crop management, especially when to establish support systems, managing planting to improve yield, and to plan the crop harvest (Miller et al., 2001). Functions of thermal time allow one to simulate phenological stages and node number. Likewise, they allow one to determine when crop management practices, like irrigation, fertilization and others, should be done in order to maximizing income (Viator et al., 2005).

Phenology models were formulated by Williams et al., (1985) and Ortega et al. (2002) for ‘Thompson’ grape and for vine cultivars, for Cabernet Sauvignon and Chardonnay wine,, as a decision support tool for the integrated management of pests and diseases.

The objective of this study was to build a simple simulation model for node appearance based on thermal time (TT) and the base temperatures required for the development.

**MATERIALS AND METHODS**

The data used to develop the thermal time development model were obtained from an experiment conducted in two different locations in Colombia (Chía, Cundinamarca and Miraflores, Boyacá,), under both greenhouse conditions and in the open field. Chía is located at 2560 m.a.s.l (4°53’N, 74°O) and Miraflores at 1850 m.a.s.l (5°11’N, 73°09’O).
During the experiment, the average daily temperatures in Chía were 13.5 °C and 15.8 °C and in Miraflores 16.5 °C and 18.3 °C, outside and inside the greenhouses, respectively. Maximum and minimum temperatures as well as photosynthetic active radiation (PAR) were measured for each trial. Average PAR values for Chía were 7.24 and 11.12 (MJ m\(^{-2}\)d\(^{-1}\)) and for Miraflores 8.79 and 11.17 (MJ m\(^{-2}\)d\(^{-1}\)) inside and outside the greenhouses, respectively.

The plant spacing used was 2 m by 2 m between plants in the rows and between rows for all locations. Dates of sowing and transplanting Cape gooseberry were 12/07/02 in the greenhouse and 15/07/02 outside at Chía, and in Miraflores 14/08/02 and 14/06/02, respectively. Plant management was done according to Angulo et al. (2005).

The greenhouses used in both locations were the traditional ones for the area (Angulo et al., 2005), built with a metallic structure on concrete foundations. The cover was transparent polyethylene. The opening of the span on top was 0.45 m, and the height was 2.5 m in the front and end facade, and 5.0 m in the center of the greenhouse. The ventilation system worked by means of lateral curtains in the front and end facades, the same as in the both sides. The curtains were managed manually. In addition, one had a tubular one in the opening of the span, which was filled automatically by means of an electric fan. Data were collected for a complete cycle of cultivation between 2002 and 2003.

The Cape gooseberry required “V” shape supports for its architecture in the production system used in Colombia. This support consists of the placement of two wooden beams that are buried in the same hole forming a “V” at the ends of the beds. From these beams, wire strings are tied to support the plant to keep it vertical while it grows and develops. A piece of line 30 cm in length was used to tie every three plants to the wire to prevent the plants from growing together and from competing for light, air, nutrients and water. This system was used both for plant management under greenhouse conditions and in the open field.

The plants were pruned to form an appropriate structure for managing the plants during production. The apical part was taken off of each plant to induce branching. After the pruning began, each plant was managed with six main stems, which generated lateral branches that were the productive part of the plant. As fruits from these stems were harvested, the leaves that were in the harvested nodes were eliminated since they were no longer productive sources for the reproductive sinks. The branches that appeared on the base of the plant were also eliminated since they reduce the quality of the fruits, the vigor and brightness of the plant, produce shade, and avoid appropriate conditions that are favorable for pests and diseases. Every 30 days, pruning was done in all locations, inside and outside the greenhouses to allow air entrance and light, especially to the calyx that wraps the fruits. The calyx can photosynthesize and help the fruit to grow quickly and with good coloration (Fischer et al. 2000).

For this experiment, 30 plants out of a total of 260 for the whole experiment were chosen randomly in the center of each block, maintaining uniformity of conditions (temperature
and humidity), and eliminating the border effect. Node appearance of 20 plants was monitored at every site, every other day.

**Node appearance model**

The appearance of nodes was modeled as a function of thermal time (Brown, 2004). In order to calculate thermal time (degree days), the lower temperature threshold, or base temperature (Tb, °C), for node appearance was estimated. A Segmented linear model with two segments was used in the analysis. Parameters of the first linear segment were estimated by a linear regression model and the second one by a nonlinear regression model. The beginning of the second segment was estimated by the accumulated thermal time (°C-d) corresponding to the change in slope of node number vs. cumulative thermal time. The following two models were used to estimate base temperature and intercept and slope of the linear relationship:

\[
\text{Node}_{1t} = a_1 \sum_{i=1}^{t_1} (T_i - T_{b0}) + b_1
\]

\[
\text{Node}_{2t} = a_2 \sum_{i=t_1}^{t} (T_i - T_{b0}) + b_2
\]

where: Node\(_{1t}\) and Node\(_{2t}\) are the numbers of nodes for segments 1 and 2, \(a_1\) and \(a_2\) are the slopes, \(b_1\) is the initial value of nodes at transplant, \(b_2\) is the intercept for segment 2, \(t_1\) is the time in days when the slope changes, \(T_{b0}\) is base temperature (estimated in the first segment and used for segment 2 as well), and \(T_i\) is the daily average temperature for day \(i\). Finally, the expression \(TT=\sum_{i=1}^{t} (T_i-T_{b0})\) is the thermal time accumulated from transplant (for the first linear segment, equation (1), and from the beginning of the second segment, \(t_1\), for the second linear segment, equation (2)).

The Euler integration method was used to simulate nodes vs. time as temperatures varied daily throughout the experiment (Thorney & Johnson, 1990; Keen & Spain, 1992; Jones & Luten, 1998) using equation (3) for the first segment and equation (4) for the second segment.

\[
\text{Node}_{1t} = \text{Node}_{1,t-1} + \{a_{10} (T_t - T_{b0})\} \Delta t
\]

\[
\text{Node}_{2t} = \text{Node}_{2,t-1} + \{a_{20} (T_t - T_{b0})\} \Delta t
\]

where \(\text{Node}_{1t}\) is the simulated number of nodes on day \(t\) during the first segment; \(\text{Node}_{1,t-1}\) is the simulated number of nodes on day \((t-1)\), the day before day \(t\); \(a_{10}\) is the estimated slope for the first segment; \(a_{20}\) is the estimated slope for the second segment, \(b_{10}\) is the initial value of nodes at transplant (estimated intercept for first segment) \(T_t\) is average temperature of the day \(t\), \(T_{b0}\) is the estimated base temperature (for both
segments, estimated in segment 1) and $\Delta t=1$ is the integration period of time of the model (one day). The initial value for $Node_{2t}$ is the value of $Node_{1t}$ at the $t_1$, the time when the first segment ends.

**Results and discussion**

**Tb estimation**

Figure 1 shows node numbers on the main stem of Cape gooseberry as a function of days after transplanting and Figure 2 shows node numbers vs. thermal time ($TT, ^{\circ}C\cdot d$). When thermal time was used as the independent coordinate, greater homogeneity was found in the number of nodes, especially in the initial segment. All data collapsed to fall on the same linear line up to a thermal time of just over 1000 $^{\circ}C\cdot d$. Clearly, there were two segments in the relationship of number of nodes vs. thermal time, each one with a different slope. The first slope ($a_1$) described the number of nodes vs. $^{\circ}C\cdot d$ until cumulative thermal time was estimated to be 1039.5 $^{\circ}C \cdot d$ (degrees days). The criterion used to determine the time at which the slope changed was minimum mean square error of (simulated – observed) node numbers. The slope $a_2$ of the second segment was less than the first one.

The estimated parameters, standard errors and confidence limits (95%) are shown in Table 2. The rates of node appearance from the first and second segments were significantly different. Over a time period of one thousand degree days, twenty three nodes were formed in the first segment; in contrast, only eight nodes were formed in the second segment. A Student t-test was used to verify that the average residuals were statistically equal to zero in both equations (Pr >|t|>1). The normality distribution test of Shapiro-Walks, (Pr < W 0.2617) confirmed that the residuals followed the normal distribution for the first segment. However, the distribution of residuals for the second segment was not normal. Furthermore, the variances were not heterogeneous in either case.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>Lower Limit 95%</th>
<th>Higher Limit 95%</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>0.023</td>
<td>0.00056</td>
<td>0.4513</td>
<td>0.96400</td>
<td>0.9046</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.702</td>
<td>0.12570</td>
<td>0.0212</td>
<td>0.02340</td>
<td></td>
</tr>
<tr>
<td>$Tb$</td>
<td>6.296</td>
<td>0.22070</td>
<td>5.8548</td>
<td>6.73770</td>
<td></td>
</tr>
<tr>
<td>$a_2$</td>
<td>0.008</td>
<td>0.00044</td>
<td>0.0074</td>
<td>0.00926</td>
<td>0.7100</td>
</tr>
<tr>
<td>$b_2$</td>
<td>15.27</td>
<td>1.10080</td>
<td>13.097</td>
<td>17.4500</td>
<td></td>
</tr>
</tbody>
</table>

During the first segment of the model, the average rate of node appearance was 0.02 nodes ($^{\circ}C\cdot d$)$^{-1}$; in the second phase average rate decreased to 0.008 nodes ($^{\circ}C\cdot d$)$^{-1}$. These results indicated that in the initial segment, until the accumulation of 1039.5 $^{\circ}C \cdot d$, the rate of node appearance was faster than in the second segment.
Plants of the Australian commercial sugarcane varieties Q117 and Q138 were grown to 6 months age in a controlled environment at temperatures of 14, 18, 22 and 26 °C. The rate of node appearance, which equates to the rate of leaf appearance, was significantly correlated with temperature across the temperature range examined. Analysis of the varietal rates of node deposition as a function of time allowed determination of both base temperature for node (hence leaf) appearance and phyllochron. The base temperatures for node appearance were 7.8 °C for Q117 and 7.6 °C for Q138, significantly lower than previously published base temperatures for leaf appearance in sugarcane, Campbell et al. (1998).

In tomato, Scholberg et al. (2000) found that the maximum rate of main-stem node development was near 0.5 nodes d\(^{-1}\) and by the time of transplant plants, the number of nodes was between 3.1 and 6.3. The initial flowering happened approximately 4 weeks after transplanting when there were a total of 8-10 nodes in the main stem. The initial rate of nodes was 0.027 nodes °C d\(^{-1}\) [while cumulative degrees days were less than 530 °C-d], assuming a base temperature of 10 °C and a maximum node development rate at 28 °C. In terms of days, the average node-development rate was 0.49 nodes d\(^{-1}\), similar to 0.5 nodes d\(^{-1}\) for greenhouse tomato found by Jones (1989). Main-stem node formation typically stopped increasing appreciably (tailed off) after the accumulation of 530 °C and the formation of 15.7 nodes. The total maximum number of main-stem nodes ranged from 19 to 21.

In Lucerne, Moot et al. (2001) and Brown & Moot (2004), found that node appearance was faster in spring and summer than in winter. They worked with a base temperature for thermal time accumulation of 1 °C when air temperatures were below 15 °C and with a base temperature of 5 °C for temperatures higher than 15 °C. The response for nodes appearance was linear with thermal time accumulation, but the node appearance rate (phyllochron) also varied in response to photo period.

The node development and internodes elongation are affected by temperature (Reddy and Pachepsky (2002)). These authors studied the effects of the temperature on the main stem node appearance in cotton, under controlled conditions and in the field. For temperatures below 25 °C, the rate of node appearance was 40% lower and the duration of the internode expansion was up to 23% more in the field than under controlled conditions. The parameter values for the rate of node appearance were significantly different for these two conditions. They concluded that these kinds of studies are valuable, contributing information for appropriate control and management of crop cultivation.

**Simulation of node appearance**

The empirical linear segmented model used to estimate the base temperature can also be used to simulate nodes vs. time in variable temperature conditions. Hesketh et al. (1973), Yan & Hunt (1999), Yin et al. (1995), Kim and Reddy (2004) and Setiyono et al. (2005) applied a non-linear model of development vs. temperature to describe and simulate the phenological behavior of diverse cultivations.
Minimum and maximum rates of node appearance were as greater in Miraflores than in Chía and the lowest rate was reached for higher temperatures. The duration, in terms of thermal time and in days after transplanting (DAT), and the number of nodes responded similarly to temperature (Table 3). It is interesting to observe how in Chía out (field-grown plants) and Miraflores in (greenhouse-grown plants), the lowest rate of node appearance was reached later than those grown in the other conditions. However, the highest rate was reached earlier in Chía out than in the others. As a result, Chía out showed a shorter duration between the minimum and maximum rate of node appearance, but the number of nodes was greater by the time the minimum rate was reached. However, plants in Chía out showed fewer numbers of nodes.

Table 2. Minimum$^1$ and maximum$^2$ rate of nodes appearance, duration and number of nodes.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Rate of nodes (nodes°C d$^{-1}$)</th>
<th>Temperature °C</th>
<th>Nodes</th>
<th>thermal time °C</th>
<th>DAT (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chía in</td>
<td>0.05$^1$</td>
<td>12.62</td>
<td>42.35</td>
<td>3524.13</td>
<td>351</td>
</tr>
<tr>
<td></td>
<td>0.30$^2$</td>
<td>19.36</td>
<td>2.90</td>
<td>509.42</td>
<td>44</td>
</tr>
<tr>
<td>Chía out</td>
<td>0.03$^1$</td>
<td>10.48</td>
<td>33.74</td>
<td>2537.88</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>0.21$^2$</td>
<td>15.53</td>
<td>19.18</td>
<td>1000.85</td>
<td>145</td>
</tr>
<tr>
<td>Miraflores in</td>
<td>0.08$^1$</td>
<td>15.85</td>
<td>46.59</td>
<td>3898.23</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>0.35$^2$</td>
<td>21.27</td>
<td>14.79</td>
<td>1064.10</td>
<td>84</td>
</tr>
<tr>
<td>Miraflores out</td>
<td>0.04$^1$</td>
<td>11.71</td>
<td>44.40</td>
<td>3518.07</td>
<td>336</td>
</tr>
<tr>
<td></td>
<td>0.32$^2$</td>
<td>19.92</td>
<td>12.73</td>
<td>740.41</td>
<td>71</td>
</tr>
</tbody>
</table>

Chía in, Chía out, Miraflores in and Miraflores out are the localities in (inside the greenhouse) out (open field).

The resulting equations for node appearance simulation applying Euler’s method were respectively for the first and second phase:

$$\text{Node}_{1t} = \text{Node}_{1,t-1} + \{0.023 \ (T_t - 6.29)\}$$

(5)

$$\text{Node}_{2t} = \text{Node}_{2,t-1} + \{0.008 \ (T_t - 6.29)\} \text{ when } TT > 1039.5 \ °C$$

(6)

Figures 1 and 2 show the number of observed and simulated nodes as functions of days after transplant and of thermal time for the locations under greenhouse and open field conditions, respectively. For the first segment, the simulated values were more accurately predicted than those of the second segment. The appearance of nodes was less variable during this segment, which corresponds to the vegetative phase of the plant. High variability of node appearance in the second segment, the reproductive phase, was found. During this phase, fruit are growing and being harvested, which may result in competition for new node formation due to source-sink relationships.

In soya, Setiyono et al. (2005) used two functions to estimate the rate of node appearance, one in terms of temperature, different from thermal time, and another with chronological time that relates to the decrease of the rate for nodes appearance. The simulation with both functions fit the data satisfactorily. On the other hand, Hesketh et al.
(1973) determined that vegetative development was sensitive to temperature and found a linear relationship between rate of node formation and temperature.

Yan and Hunt, (1999), simulated relative rates of growth as a function of the minimum, maximum and optimum temperatures in order to determine the phenology, adaptation and yield of corn, bean, sorghum, and wheat among other crops. The applied model described well the phenology of the cultures mentioned previously. Kim and Reddy (2004) developed a simple corn simulation model, in which they used the beta function, applied in other models by Yin et al., (1995). The rate of growth was expressed in terms of mean air temperature, optimum temperature at which the maximum rate of development was reached and base temperature at which the development ceases.
Conclusions

The relationship between node appearance and cumulative temperature was linear, demonstrating that thermal time is an appropriate model for node development of Cape gooseberry. It was possible to model the node appearance as segmented linear functions of thermal time. The empirical segmented model proposed for the first segment provided a basis for estimating the low threshold temperature for node appearance and also was useful for estimating the slope and intercept. The base temperature (Tb) for node appearance was estimated as 6.29 °C required for computing thermal time (TT). For the second segment, a second linear regression model was used to fit node appearance vs. thermal time and to estimate the slope using the base temperature computed for the first segment. The estimated parameters and thermal time allowed establishing the simulation model for node appearance. The simulation of first segment, vegetative stage, predicted more accurately than the second one due to multiple processes present in the reproductive stages.

References


Ortega, S.O., Lozano, P., Moreno, Y., y León, L. Desarrollo de modelos predictivos de fenología y evolución de madurez en vid para vino cv. cabernet sauvignon y chardonnay Agricultura Técnica (Chile), Vol. 62, No. 1, Jan-March, 2002, pp. 27 -37


Setiyono, T., Dobermann, A. Weiss, A., Specht, J., Bastidas., A. 2005. Soybean Phenology: Simulating Node-Appearance (V-Stages) Using Non-Linear Temperature and Chronological Function Related to Reproductive Stage. 1 Department of Agronomy and Horticulture, University of Nebraska-Lincoln The ASA-CSSA-SSSA International Annual Meetings November 6-10, 2005). Salt Lake City, UT School of Natural Resources, University of Nebraska-Lincoln This presentation is part of 135: Modeling Plant Growth and Yield


