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Appropriate Six Equations to Estimate Reliable Growing Degree-Days for Eggplant

[1]*Ihab I. Sadek,* [2]*Doaa M. Mostafa and* [3]*Mona M. Yousry*

[1]Central Laboratory for Agricultural Climate (CLAC),
Agriculture Research Center, Giza, Egypt
[2]Horticulture Research Institute, Agriculture Research Center, Giza, Egypt
[3]Department of Vegetable Plant Production, Faculty of Agriculture, Saba Basha,
Alexandria University, Alexandria, Egypt

Abstract: Procedures for estimating Growing Degree-Day (GDD) accumulation are frequently instead of the more accurate method of calculating degree-days. Field experiment was carried out on summer seasons at farm the Faculty of Agriculture, Alexandria University, with four eggplant cultivars (*Solanum melongena* L.) sown at three times starting April 22th, May 2nd and May 12th during two seasons 2011 and 2012, to determine the most reliable method to calculate GDD of eggplant based on daily maximum and minimum air temperature. Six methods of heat units were tested. Results were observed that [Eq3] and [Eq5] methods gave very low identical values of tested characteristics (accumulative GDD all over sowing dates months and growing seasons) and high correlation and regression with stander equation [Eq1]. Moreover, reduced ceiling methods were very good by [Eq3] and [Eq5]. In addition, two equations had minimum values of stander deviation (SD), coefficient of variation (CV) and root mean square error (RMSE).

Key words: Growing Degree-Days (GDD) · Heat Unite · Eggplant · Air Temperature

INTERODUCTION

Eggplant *(Solanum melongena* L.) which belong to Solanaceae family is an important crop, eggplant has a growing reputation and is now cultivated globally. Eggplant is a valuable for the human diet; eggplant is grown commercially as a fresh vegetable crop, with the fruit being the edible portion. Botanically, eggplant may live for more than a year. It requires a long and warm growing season to produce optimum yields of eggplant is highly susceptible to injury due to frosts and long periods of cold temperatures.

On other hand, the response of eggplants to environmental stresses depends on the plant development stage and the length of severity stress. Temperature is one of the most important factors governing plant growth. Each plant has its own temperature range, i.e. it's minimum, optimum and maximum for growth, for any plant, a minimum or base temperature must be reached before any growth stage. Above the base temperature is more rapid the growth rate of the plant. Once the optimum temperature is exceeded the growth rate will begin to slow until a maximum temperature is reached at which growth ceases [1-9].

Moreover, the heat unit theory postulates is important for eggplants measure heat requirements that can be quantified and linked to maturity time of fruits. The eggplant will not grow if the mean temperature falls below its base temperature, the only portion of the mean daily temperature that contributes to the plant's development if the amount of the temperature exceeded than the base temperature, to measure the total heat requirements of a plant, the accumulation of daily mean air temperatures above the plant's base temperature is recorded over the period of the plant's growth and expressed in terms of heat units. Degree-days provide a simple estimate of the accumulated heat energy available over the growing season or life cycle of an organism and represent an important factor for all biological development. The rate of growth and phenological development of individual plant has been found to increase almost linearly from a base to a limiting temperature threshold [10,11].

Corresponding Author: Ihab Ibrahim Sadek, Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center, Giza, Egypt.

Since 1730 when Reaumur introduced the concept of heat units, or thermal time, many methods of heat units have been used successfully in the agricultural application. Particularly in the areas of crop phenology and development, the concept of heat units, to measured growing degree-days (GDD, °C-day), has vastly improved description and prediction of phenological events compared to other approaches such as time of year or number of days [12-17].

Knowledge concerning the timing of crop phenological events is important for management decisions such as the timing of pesticide application, scheduling harvest crops, select genotypes for optimum yield in varying climates and irrigation scheduling. Since it was developed, the heat unit concept has been widely used to determine the length of the growing season for vegetables and field crops [18,19]. Most of the research on field crops have been conducted for Maize [20,21], Wheat [22,23] and Sunflower [24,25]. Studies for vegetables include: Potatoes [26,27], Tomatoes [28], Cucumber [29], [30,31] and others [32-34]. The concept of heat units (HUs) is expressed in Growing degree Days (GDDs), which is calculated [19,23].

MATERIALS AND METHODS

Growing Degree Days (GDD) was calculated for different four eggplant cultivars (*Solanum melogena* L. *cvs*. Romy, Long white balady, Long purple F1 and Long black balady). The four cultivars were sowed in three different sowing dates during summer seasons 2011 and 2012 (April 22[th], 2[nd] and 12[th] May) respectively under field conditions at the experimental farm of Faculty of Agriculture, Alexandria University. Experimental were carried out in a randomized complete blocks design with 3 replications. The size of each plot was 6m × 0.5m. Plant row spacing was 1.00 m and the distance between plants within row was 0.35m. Recommended amount of N P K fertilizers were add in all plots. Total amount of P and 40% of the N and K fertilizers were applied prior to planting and thoroughly mixed to the soil during plowing. The remaining 60% of N and K were added equally at weekly intervals through the drip irrigation system starting from fourth leave until the second harvest. Irrigation was scheduled three times weekly and applied by drip-irrigation system. Weeds were controlled by hand hawing when is needed also, there were no infections related to diseases and insects. The daily minimum and maximum air temperature were recorded by the weather station at the experimental site.

The daily of GDD was calculated using the standard formula of degree day:

- Equation 1 [Eq1]GDD= $[(T_{max} + T_{min})/2 - T_{bas}]$

Where

T_{max} is the daily maximum air temperature, T_{min} the daily minimum air temperature and T_{bas} the base temperature of 11°C according to [35].

Five additional constraints are used in the GDD calculations.

- Equation 2 [Eq2]: If the T_{min} is less than T_{bas}, then it is set to T_{bas},
- Equation 3 [Eq3]: If the T_{max} exceed to 30°C (ceiling temperature), it is set to T_{max}= 30.
- Equation 4 [Eq4]: If the T_{max} exceed to 32°C (ceiling temperature), it is set to $[32-(2 \times (T_{max}-32))]$.
- Equation 5 [Eq5]: Appling constraints (2) + (3).
- Equation 6 [Eq6]: Appling constraints (2) + (4).

The stander deviation (SD), coefficient of variation (CV) and root mean square error (RMSE) were used to identify the best method for calculating growing degree-days.

The objectives of this paper are to describe the six implementations of calculating GDD, to determine whether if among several degree-day estimation methods that utilize min/max daily temperature data; there is one method that consistently provides more accurate estimates. Recorded climatic data were analyzed using the GLM procedure [36] and Duncan multiple range tests [37] was used to measure the significant differences according to the following model:

$$Y_{ijk} = \mu + Ses_i + Time_j + (Ses*Time)_{ij} + e_{ijk}$$

Where:

Y_{ijk}	:	is the GDDs Equations on the k^{th} replicates of the i^{th} season, j^{th} times;
μ	:	is the overall mean;
Ses_i	:	is the fixed effect of the season (i =1, 2; 1 =Summer season 2011 and 2 =Summer season 2012);
$Time_j$	:	is the fixed effect of the Times (j = 1, 2, 3; 1 = 22[th] April, 2 =2[nd] May and 3 =12[th] May);
$(Ses*Time)_{ij}$	:	is the effect of the interactions between seasons and times;

E_{ijk} : and independently distributed with zero mean and σ^2_e variance.

Partial correlation coefficient within GDDs equations was estimated.

RESULTS AND DISCUSSION

The average maximum temperature during crop growing season during 2011 varied from 21.03 to 31.61°C, while, temperature varied from 24.07 to 32.32°C during 2012. The average minimum temperature varied from 13.22 to 23.71°C during 2011 and 13.77 to 24.90°C during 2012 crop seasons. The average maximum and minimum temperature conditions are almost similar in both crop growing seasons (Fig. 1). Also, from (Fig. 2) it's observed that the highest maximum temperatures were recorded36.00°C in May and September in first season, but it recorded 36.00°C, 36.00°C and 35.00°C in August, May and July, respectively, during second season. While the lowest minimum temperatures were obtained during November and April which were recorded (9.00, 10.00, 10.00 and 10.00°C) in the two seasons, respectively.

The growing data, (Table 1) show that the lowest values of growing degree-days were found in April and followed by November (68.50, 186.00, 74.50 and 299.00) in 2011 and 2012, respectively. On other hand, the highest values were observed in July (516.00) in 2011 and 544.00 in August and followed by June (541.50) and July (541.00) in 2012.

The growing degree-days between six equations were arranged from in April 68.50 to 70.00, in May 321.00 to 327, in June 414.00 to 421.50, in July 490.00 to 516.00, in August 489.00 to 504.00, in September 455.00 to 466.50, in October 345.00 to 350.00 and in November 186.00 to 190.50 at all first season. Also, varied in second season as follow in April 75.50 to 74.50, in May 350.00 to 354.50, in June 436.00 to 541.50, in July 505.50 to 507.00, in August 510.00 to 544.00, in September 446.50 to 451.50, in October 401 and in November 266.00 to 268.00 (Fig. 3).

Moreover, (Fig. 4) indicated that great differences between the equation of total growing degree-days values are observed in both seasons Eq1= 2840.00, 3084.50, Eq2= 2846.00, 3087.50, Eq3= 2771.50, 2991.00, Eq4= 2807.00, 3018.50, Eq5= 2777.50, 2994.00 and Eq6= 2813.00, 3021.50, respectively.

Furthermore, data in (Fig. 3 and 4) clear that the equations Eq3 and Eq5 recorded the lowest values of growing degree-days during two growing season as month's values except months May and October in season 2011 and May in season 2012. The total growing degree-days values were 2771.50, 2777.50, 2991.0 and 2994.00 in both growing seasons 2011 and 2012.

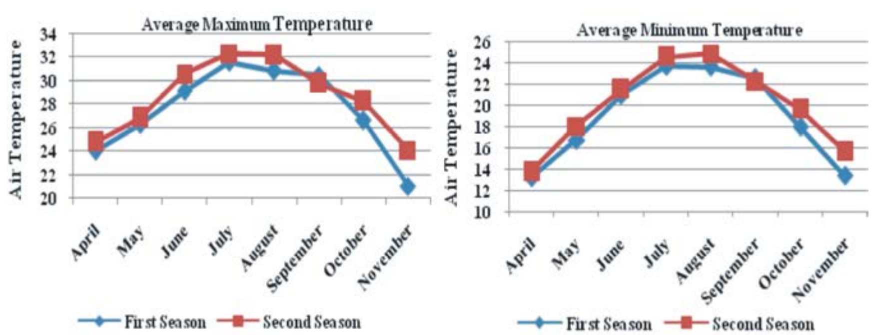

Fig. 1: Average maximum and minimum air temperature during 2011 and 2012 seasons.

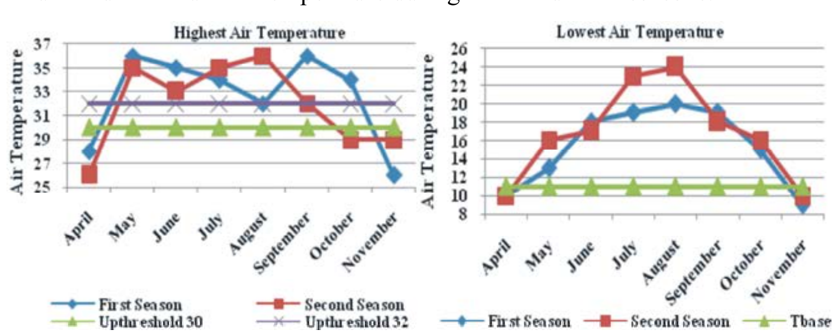

Fig. 2: Highest and lowest air temperature values in both growing season 2011 and 2012.

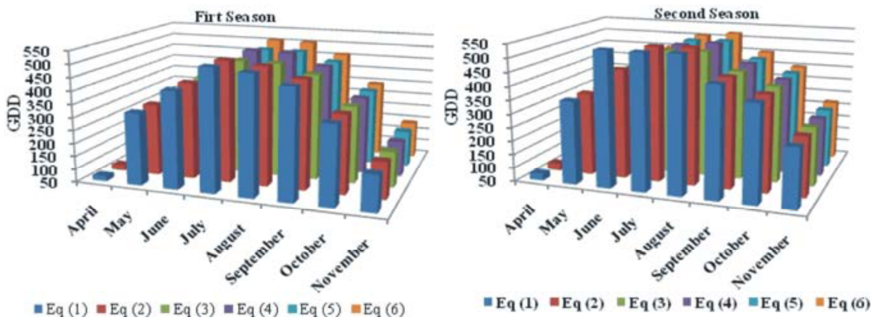

Fig. 3: Accumulative growing degree-days for each equation per months during the growing seasons 2011 and 2012.

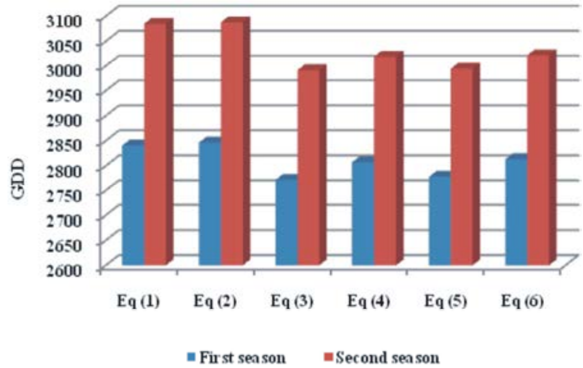

Fig. 4: Accumulative growing degree-days for tested equations in both crop growing seasons 2011 and 2012.

Table 1: Monthly accumulative growing degree-days during seasons of 2011 and 2012.

Months	2011	2012
April	68.5	74.5
May	327	354.5
June	421	541.5
July	516	541
August	504	544
September	466.5	451
October	350	401
November	186	266

(Fig. 5) presented the growing degree-days values for each equation at all period of months and different sowing dates in both growing seasons. It is indicated that Eq3 and Eq5 gave the lowest growing degree-days all over sowing dates except May and October in first season and only May in second season at three sowing dates.

From mentioned before, the same results were found at all over different sowing dates in both crop seasons (Fig. 6).

On another side, data in (Table 2) deduce that all tested equations had high correlation with stander degree-day method (Eq1). Although, the highest correlation values were recorded with Eq2, Eq3 and Eq5 in both crop growing seasons. Moreover, from step wise regression analyses found that Eq2, Eq3 and Eq5 more regression with basic equation (Eq1) more than Eq4 and Eq6 through 2011 and 2012 seasons.

According to Yang*et al*. [38] and Ruml*et al*. [39] studies, noticed that the stander deviation (SD) and coefficient of variation (CV) methods produced almost identical results when the mean development period temperature was used to calculate (GDD). In this respect, results in (Fig. 7 and 8) showed that both Eq3 and Eq5 equations recorded the lowest values for SD, CV and root mean square error (RMSE) through two crop seasons and at different sowing dates in over both seasons than other tested equations. Obtained results are harmony with Perry *et al*. [28], who mentioned that the most reliable method was defined as the one with the smallest coefficient (CV) and heat unite summation technique, recommended for reduced ceiling method multiplied by daylength. Furthermore, Perry *et al*. [31] and Perry and Wehner [29] found that among 14 heat unit summation methods, the reduced ceiling methods was the best to determine the harvest date of cucumber. The reduced ceiling method sum days from planting to harvest the difference between the daily maximum and a base temperature; but if the maximum temperature exceeds the ceiling temperature, it is replaced by the ceiling minus the difference between the maximum and the ceiling, before subtracting the base. Dufault [40] also, found this reduced ceiling method produced the lowest coefficient of variation (CV) when it was used to determine the heat unite requirements. Dufault [41] and [42] obtained that, it was necessary first to determine the method of least variability. The method with lowest (CV) for predicting first harvest was to sum, over days from planting to harvest. Also, a great emphasis on including maximum temperatures and ceiling temperatures in heat unite summation for broccoli may reduce the variation and error in predicting harvest dates.

Table 2: Partial correlation coefficients between five additional constraints and formula stander degree day method in both crop during 2011 and 2012 seasons.

	Eq1	Eq2	Eq3	Eq4	Eq5	Eq6
Eq1	1.000000	0.999808	0.987004	0.962451	0.987262	0.962244
		<.0001	<.0001	<.0001	<.0001	<.0001
Eq2	0.999808	1.000000	0.986186	0.961726	0.986872	0.961925
	<.0001		<.0001	<.0001	<.0001	<.0001
Eq3	0.987004	0.986186	1.000000	0.984223	0.999761	0.983609
	<.0001	<.0001		<.0001	<.0001	<.0001
Eq4	0.962451	0.961726	0.984223	1.000000	0.984148	0.999784
	<.0001	<.0001	<.0001		<.0001	<.0001
Eq5	0.987262	0.986872	0.999761	0.984148	1.000000	0.983987
	<.0001	<.0001	<.0001	<.0001		<.0001
Eq6	0.962244	0.961925	0.983609	0.999784	0.983987	1.000000
	<.0001	<.0001	<.0001	<.0001	<.0001	

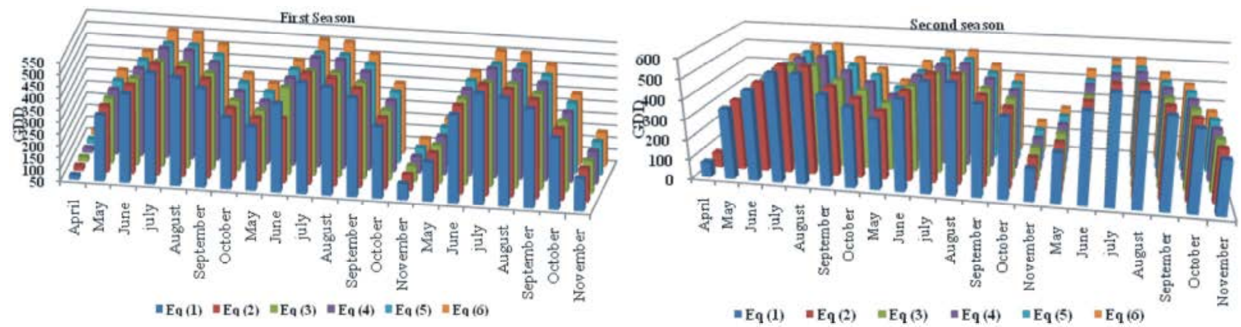

Fig. 5: Growing degree-days values per months through different sowing dates during 2011 and 2012 seasons.

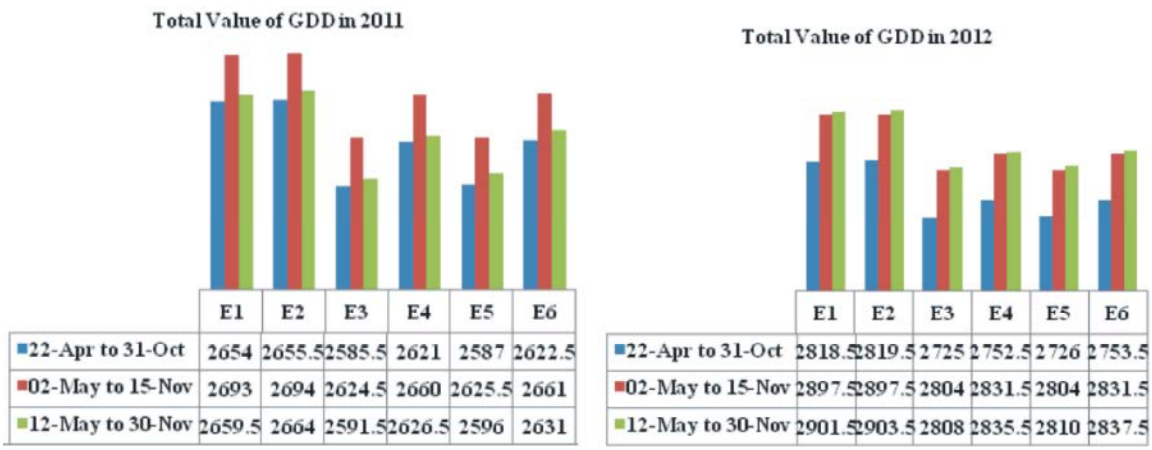

Fig. 6: Total growing degree-days values in 2011 and 2012 seasons.

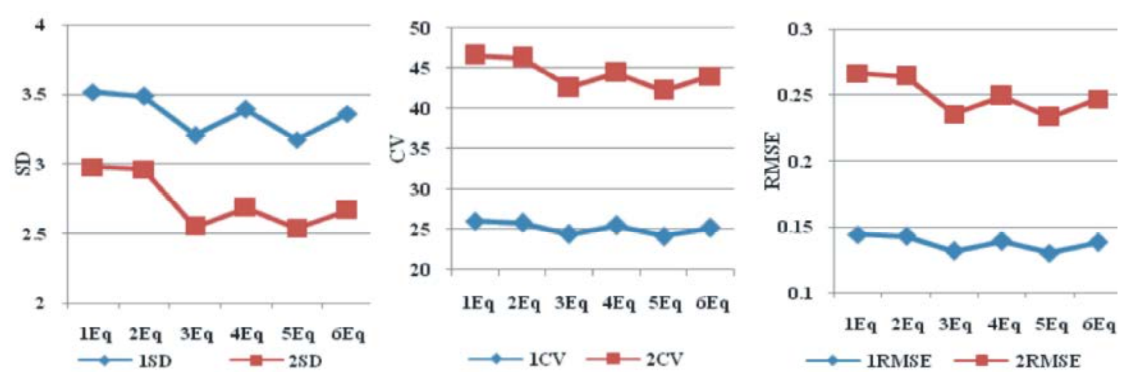

Fig. 7: Values of SD, CV and RMSE for tested equations in two seasons 2011 and 2012.

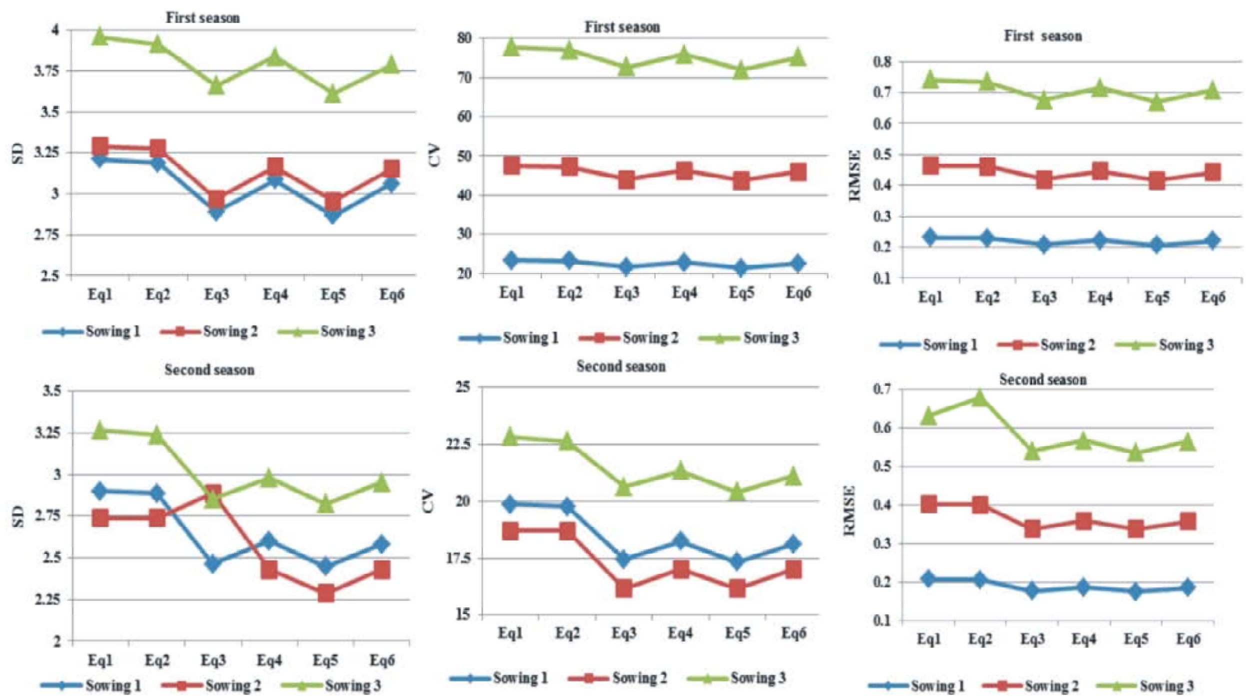

Fig. 8: SD, CV and RMSE values tested equations at different three seeds sowing dates in both growing seasons 2011 and 2012.

Ruml *et al*. [39] reported that, the best agreement with observation was obtained by the method that minimizes (RMSE) between the observation and predicted number of days.

CONCLUSION

The goal of this paper is to determine the most reliable equation for calculating growing degree-days (GDD) at multiple sowing dates of eggplant. The results suggested that both equations (Eq3 and Eq5) are suitable to use as function for calculating GDD, because Eq3 and Eq5 methods gave very low identical values of tested characteristics (accumulative GDD all over months, sowing dates and seasons) and high correlation and regression with stander equation (Eq1). Moreover, reduced ceiling methods were very good by Eq3 and Eq5. In addition, two equations had minimum values of SD, CV and RMSE.

So, considering from that, Eq3 is more suitable to calculate GDD for summer vegetables, when Eq5 is most reliable to calculate GDD for vegetables which grown in autumn or winter seasons and complete life cycle in spring or summer seasons.

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REFERENCES

1. Boyer, J.S., 1982. Plant productivity and environment. Science. 218: 443-448.
2. Bray, E.A., J. Bailey-Serres and E. Weretilnyk, 2000. Responses to a biotic stresses. In: Gruissem W, Buchannan B, Jones R (eds) Biochemistry and molecular biology of plants. ASPP, Rockville, MD, pp: 1158-1249.
3. Bell, G.D., M.S. Halpert, R.C. Schnell, R.W. Higgins, J. Lowrimore, V.E. Kousky, R. Tinker, W. Thiaw, M. Chelliah and A. Artusa, 2000. Climate Assessment for 1999. Bull. Amer. Meteor. Soc., 81: S1-S50.
4. Bray, E.A., 2002. Abscisic acid regulation of gene expression during water-deficit stress in the era of the *Arabidopsis* genome. Plant Cell Environ. 25: 153-161.

5. Erickson, A.N. and A.H. Markhart, 2002. Flower developmental stage and organ sensitivity of bell pepper (*Capsicum annuum* L.) to elevated temperature. Plant Cell Environ. 25: 123-130.
6. Sato, S., M.M. Peet and J.F. Thomas, 2002. Determining critical pre- and post-anthesis periods and physiological process in *Lycopersicon esculentum* Mill. Exposed to moderately elevated temperatures. J. Exp. Bot., 53: 1187-1195.
7. Capiati, D.A., S.M. País and M.T. Téllez-Iñón, 2006. Wounding increases salt tolerance in tomato plants: evidence on the participation of calmodulin-like activities in cross-tolerance signaling. J. Exp. Bot., 57: 2391-2400.
8. Hazra, P., H.A. Samsul, D. Sikder and K.V. Peter, 2007. Breeding tomato (*Lycopersicon esculentum* Mill) resistant to high temperature stress. Int. J. Plant Breed. 1(1).
9. Prasad, P.V.V. and S.A. Staggenborg, 2008. Impacts of drought and/or heat stress on physiological, developmental, growth and yield processes of crop plants. In: Ajuha LR, Reddy VR, Saseendran SA, Yu Q (eds) Response of crops to limited water: understanding and modeling water stress effects on plant growth processes. American Society of Agronomy/ Crop Science Society of America / Soil Science Society of America, Madison, WI. pp: 301-356.
10. Cesaraccio, C., D. Spano, P. Duce and R.L. Snyder, 2001. An improved model for determining degree-day values from daily temperature data. International Journal of Biometeorology. 45: 161-169.
11. Fealy, R. and R.M. Fealy, 2008. The spatial variation in degree days derived from locational attributes for the 1961 to 1990 period. Irish Journal of Agricultural and Food Research, 47: 1-11.
12. Cross, H.Z. and M.S. Zuber, 1972. Prediction of flowering dates in maize based on different methods of estimating thermal units. Agron. J., 64: 351-355.
13. Gilmore, E.C. Jr. and J.S. Rogers, 1958. Heat units as a method of measuring maturity in corn. Agron. J., 50: 61 1-615.
14. Klepper, B., R.K. Belford and R.W. Rickman, 1984. Root and shoot development in winter wheat. Agron. J., 76: 117-122.
15. McMaster, G.S., 1993. Another wheat (*Triticum* spp.) model? Progress and applications in crop modeling. Rivista di Agronomia. 27: 264-272.
16. McMaster, G.S. and D.E. Smika, 1988. Estimation and evaluation of winter wheat phenology in the central Great Plains. Agric. For. Meteorol., 43: 1-18.
17. Russelle, M.P., W.W. Wilhelm, R.A. Olson and J.F. Power, 1984. Growth analysis based on degree days. Crop Sci., 24: 28-32.
18. McMaster, G.S. and W.W. Wilhelm,1997. Growing degree-days: one equation, two interpretations. Agric. For. Meteorol., 87: 291-300.
19. Chen, C., 1973. Digital computer simulation of heat units and their use for predicting plant maturity. Int. J. Biometerol., 17: 329-335.
20. Gesch, W.R. and W.D. Archer, 2005. In?uence of sowing date on emergencecharacteristics of maize seed coated with a temperature activated polymer. Agron. J., 97: 1543-1550. http://dx.doi.org/10. 2134/agronj 2005.0054.
21. Nielsen, R., P. Thomison. G. Brown and A. Halter, 2002. Delayed planting effects on?owering and grain maturation of dent corn. Agron. J., 94: 549-558.
22. Haider, S., M. Alam, M. Alam and N. Paul, 2003. Influence of different sowing dates onthephenology and accumulatedheatunits in wheat. J. Biol. Sci., 3: 932-939.
23. Pal, R. and N. Murty, 2010. Thermal requirements of wheat under different growing environments of Tarairegion (Uttarakhand). In: ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on, Agriculture, pp: 78-79.
24. Qadir, G., F.U. Hassan and M.A. Malik, 2007. Growing degree days and yield relationship in sunflower (*Helianthus annus* L.). Int. J. Agric. Biol., 9: 564-568.
25. Kaleem, S., F.U. Hassan, M. Ahmad, I. Mahmood, A. Wasaya, M.A. Randhawa and P. Khaliq, 2011. Effect of growing degree days on autumn planted sunflower. Afr. J. Biotechnol., 10: 8840-8846.
26. Yuan, F. and W. Bland, 2005. Comparison of light and temperature based index models for potato (*Solanum tuberosum* L.) growth and development. Amer. J. of Potato Res., 82: 345-352.
27. Alsadon, A., 2002. The best planting dates for vegetable crops in Saudi Arabia: evaluation of compatibility between the dates planned based on heat units and dates suggested from the regional offices of the ministry of agriculture and water. J. King Saudi. Univ., 14: 75-97.

28. Perry, K.B., Y. Wu, D.C. Sanders, J.T. Garrett, D.R. Decoteau, R.T. Nagata, R.J. Dufault, K.D. Batal, D.M. Granberry and W.J. Mclaurin,1997. Heat units to predict tomato harvest in the southeast USA. Agricultural and Forest Meteorology. 84: 249-254.
29. Perry, K.B. and T.C. Wehner, 1990. Prediction of cucumber harvesting date using a heat unit model. Hort Science. 25: 405-406.
30. Perry, K.B. and T.C. Wehner, 1996. A heat unit accumulation method for predicting cucumber harvest date. Hort Technology. 6: 27-30.
31. Perry, K.B., T.C. Wehner and G.L. Johnson, 1986. Comparison of 14 methods to determine heat unit requirements for cucumber harvest. Hort Science. 21: 419-423.
32. Bossie, M., K. Tilahun and T. Hordofa, 2009. Crop coefficient and evapotranspiration of onion at Awash Melkassa, Central Rift Valley of Ethiopia. Irrig Drainage Syst., 23: 1-10.
33. Petkeviciene, B., 2009. The effects of climate factors on sugar beet early sowing timing. Agronomy Research. 7(Special issue I): 436-443.
34. Filho, J., N. Nova and H. Pinto, 1993. Base temperature and heat units for leaf flushing emission and growth of Heveabrasih'ensis. Muell. Arg. Int. J. Biometeorol., 37: 65-67.
35. Rouphael, Y., M. Cardarelli, N. Ajouz, A. Marucci and G. Colla, 2010. Estimation of eggplant leaf number using thermal time model. Journal of Food, Agriculture & Environment. 8: 847-850.
36. SAS, 1996. SAS/STAT User's Guide (Release 6.03). SAS Institute Inc. Cary, NC.
37. Duncan, N.B., 1955. Multiple range and multiple F-tests. Biometrics, 11: 1-42.
38. Yang, S., J. Logan and D.L. Coffey, 1995. Mathematical formulae forcalculating the base temperature for growing degree-days. Agric For Meteorol., 74: 61-74.
39. Ruml, M., A. Vuković and D. Milatović, 2010. Evaluation of different methods for determining growing degree-day thresholds in apricot cultivars. Int.J. Biometeorol., 54: 411-422
40. Dufault, R.J., D.R. Decoteau, J.T. Garrett, R.T. Nagata, K.D. Batal, W.J. McLaurin, D.M. Granberry, K.B. Perry and D.C. Sanders, 1989. Determination of heat unit requirements for collard harvest in the Southeast United States. J. Am. Soc. Hort. Sci., 114: 898-903.
41. Dufault, R.J., 1996. Dynamic relationships between field temperatures and broccoli head quality. J. Amer. Soc. Hort. Sci., 121: 705-710.
42. Dufault, R.J., 1997. Determining heat unit requirements for broccoli harvest in costal South Carolina. J. Amer. Soc. Hort. Sci., 122: 169-174.