

Determination of a Suitable Formula for the Calculation of Sum Growing Degree Days in Watermelon [*Citrullus lanatus* (Thunb.) Mansf.]

R. Onsinejad^{1*}, K. Abak² and B. Kaviani¹

¹Department of Horticultural Science, Rasht Branch, Islamic Azad University
Rasht, Iran

²Department of Horticulture, Faculty of Agriculture, University of Cukurova
01330 Adana, Turkey

*Corresponding author, Email: onsinejad@yahoo.com

Abstract

The purpose of this study was to explore the possibility of adaptation to watermelon of the temperature sum methods by the calculation of the sum growing degree days (SGDD), which was already used successfully in other crops. In the experiments, ten watermelon cultivars which express various degrees of earliness were used. These genotypes were sown at various dates and the experiments were carried out in 1990 and 1991. Variations in the daily temperatures were created under different growing conditions, i.e. greenhouse, high tunnel, low tunnel, and the open field. The duration of the period from sowing to harvesting dates, as well as temperatures encountered were recorded for all the experiments. All the total SGDDs were calculated by three different models using the temperatures of three daily maximums, i.e., 30, 32 and 35°C and four bases, i.e., 10, 13, 15 and 18°C, being 36 equations altogether. The F test was applied to the data obtained and CVs were calculated. The formula, i.e. $SGDD = \sum (T_{max} + T_{min})/2 - T_b$, $[(T_{max} + T_{min})/2] > T_b$, using 18°C as the base temperature (T_b) was determined to be the most suitable for the calculation of the SGDDs from sowing to harvesting dates in the watermelon compared to the rest.

Keywords: base temperature, maximum temperature, sum growing degree days, watermelon

Introduction

Watermelon is the most important vegetable crop in the world. The production of watermelon is around 98 million ton in the world and China, USA, Turkey and Iran are 1st to 4th countries, respectively which produce watermelon in the world (FAO, 2008). Watermelon is mainly cultivated in the open field, but a raising interest has appeared recently in growing the crop under plastic tunnels and greenhouses. In recent years, in Turkey, Spain, and Iran, watermelon cultivation in protected area is increasing. It would be desirable to know the sum growing degree days (SGDD) of the various cultivars used for the purpose of production planning in which the development or adaptation of

mathematical models are necessary. Various mathematical models have been studied for the calculation of SGDDs on several vegetable crops such as sweet corn (Caldwell et al., 1947), peas (Boswell, 1929; Reath and Wittwer, 1952; Mikkelsen, 1981; Ney and Turk, 1993), lettuce (Madariaga and Knott, 1951), tomato (Lipari et al., 1988), bean (Mauromicale et al., 1988; Dimeny, 1989; Dood, 1996) and cucumber (Katharine et al., 1986; Perry et al., 1986; Perry and Wehner, 1990). Madariaga and Knott (1951), stated that in calculation of effective temperature sums, addition of daily average temperatures occurring between 4.4 and 21.1°C is suitable. They also suggested that day length should be taken into consideration. Also, Kristiansen et al. (1985) reported that the use of

4°C as the base temperature in calculation of SGDDs of lettuce was suitable. In cucumber, a comprehensive study was carried out to compare the effectiveness of two formula using five bases and four maximum temperatures. The formula $GDD = \sum (\max - \text{base})$ was determined to be the suitable one when 15.5 and 32°C were used as base and maximum temperatures, respectively. Using these models, both production planning and management can be realized effectively, and economical analysis can be carried out for under cover cultivation with respect to energy cost and profits. Thus, the aim of the present study was to compare the effectiveness of nine different models for the calculation of SGDDs based on three formulas with regards to harvest date prediction of watermelon on the basis of temperature measurements recorded between sowing and harvest.

Materials and Methods

A total of ten watermelon cultivars including Red Cutie, Early Star, Summer Chaser, Rubin, Panonia, Fabiola, Halep Karasi, Crimson Sweet, Sugar Baby and Black Sweet, which express various degrees of earliness were used in the experiment (Figure 1).

These genotypes were sown at various dates (December, January, February and March) and grown under various growing conditions consisting greenhouse, high and low plastic tunnel and the open field. For each of the growing conditions, a completely randomized blocks experimental design with three replicates, each plot containing eight plants were used. The experiments were carried out in 1990 and 1991. The temperature data used in the formula were obtained from the thermographs, present in each of the growing conditions (Figure 2).

Daily average, minimum and maximum temperatures were extracted from the recorded data by the thermographs. For each of the growing conditions, SGDDs between seed sowing and harvest were calculated by nine different formulas, each using four different base temperatures.



Figure 1 The 10 watermelon varieties which we used in the trial.

1. $SGDD = \sum (T_d - T_b), T_d > T_b$ (A)
2. $SGDD = \sum (T_{\max} + T_{\min})/2 - T_b, (T_{\max} + T_{\min}/2) > T_b$ (B)
3. The formula B, provided that temperatures above 35°C was considered 35°C.
4. The formula B, provided that temperatures above 32°C was considered 32°C.
5. The formula B, provided that temperatures above 30°C was considered 30°C.

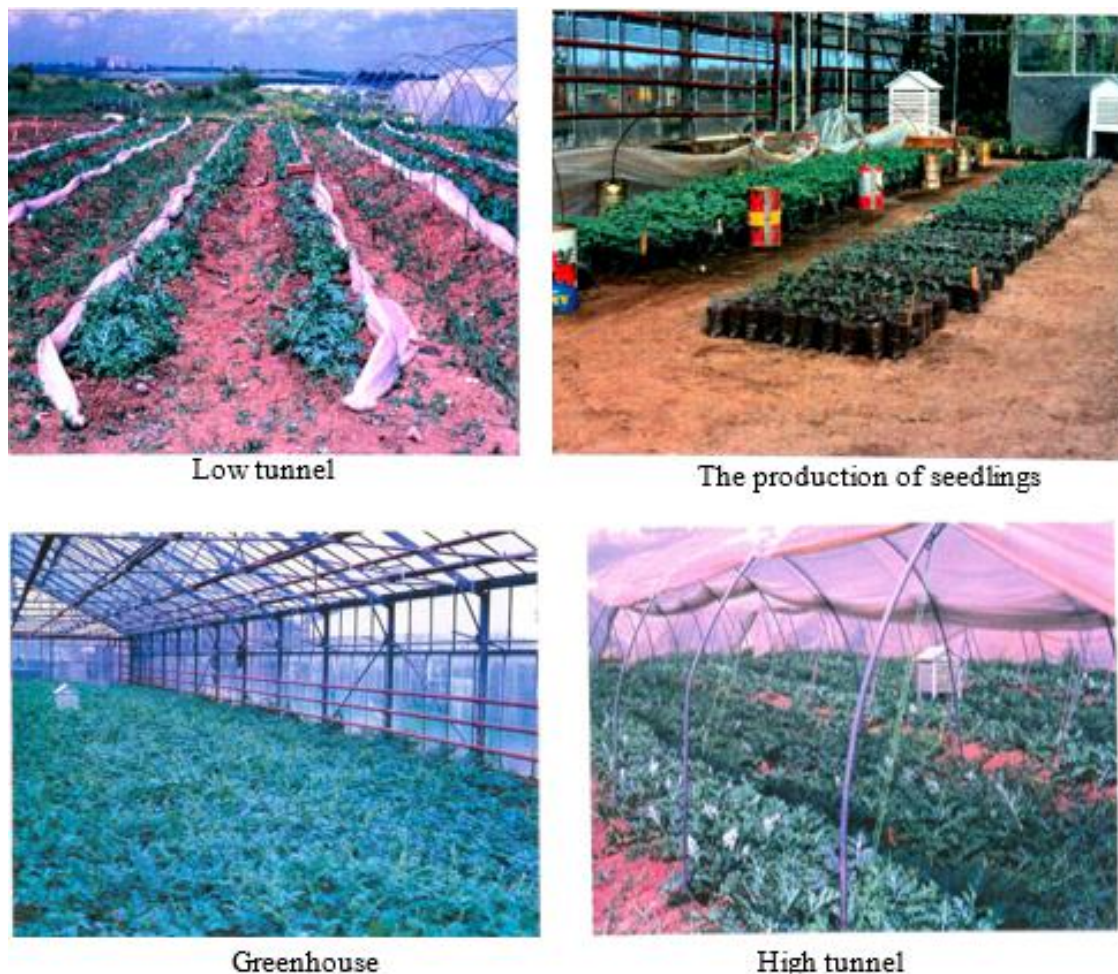


Figure 2 The growing of various watermelon genotypes under different cover systems and production of seedling in the greenhouse.

6. $SGDD = \sum (T_{max} - T_b), T_{max} > T_b$ (C)
7. The formula C, provided that temperatures above 35°C was considered 35°C.
8. The formula C, provided that temperatures above 32°C was considered 32°C.
9. The formula C, provided that temperatures above 30°C was considered 30°C.

A total of four base temperatures, i.e. 10, 13, 15 and 18°C were chosen according to previous experiences (Sachs, 1977; Onsinejad and Abak, 1992), to be tested in each of the formula. Thus, 36 SGDD values were obtained by the combination of nine formulas with the four base temperatures (9×4), for each of the growing type, cultivar and year. An analysis of variance was applied to the calculated SGDD values, to check the significance of differences occurring between the growing types and years. The coefficient of variation (CV) for

each of the equations was calculated, subsequently. The criteria for a suitable formula for the calculation of SGDDs were considered to be an insignificant F value for each of the formula, the base temperature and a CV value lower than 13 (Katherine et al., 1986) for a particular equation. When significant F values were encountered, then the formula was interpreted to be unsuitable.

Results and Discussion

The two years experiment for the calculation of 36 different SGDD values for various watermelon cultivars, from sowing to harvest, using base and ceiling temperatures were concluded by the application of analysis of variance to the values. The results of the ANOVA, and the F values, and the CV values are presented in Table 1. Irrespective of the used base constants, significant F values and

high CVs varying between 33 and 57% were obtained from the formulas 6, 7, 8 and 9. The results obtained from the formula 5, in spite of a decrease observed in the F values, being between 34.7 and 78.2, they still were significant at the 0.1% level and the CVs were determined to vary between 24 and 41 which are higher than the reference, i.e. 13. In the first year, the formula 2

using the base temperature of 18°C resulted in most satisfactory, and in the second year the formulas 1, 2 and 3 again using the 18°C base constant, in addition to the formula 1 using the base constant of 13 and 15°C resulted in low F and CV values. Also, in the second year, the formula 4 produced low levels of F and CV values. According to the above, when the two years results are assessed as a whole,

Table1 The SGDD values, their F test results and CV values obtained from the 36 equations.

Formula No.	Base temperature (°C)	F Value ^{1/}		CV (%)	
		First year	Second year	First year	second year
1	10	16.0***	12.6***	19	14
	13	7.4***	0.2 ^{ns}	16	2
	15	18.5***	1.1 ^{ns}	30	6
	18	31.1***	3.4 ^{ns}	56	20
2	10	170.2***	57.7***	45	24
	13	97.6***	30.0** *	38	19
	15	49.9***	9.8 ***	30	12
	18	1.8 ^{ns}	4.1 *	8	10
3	10	171.1***	62.0***	46	25
	13	104.9***	35.3***	38	21
	15	61.1***	15.0***	33	14
	18	7.2**	0.3 ns	15	2
4	10	151.1***	68.5***	45	27
	13	93.5***	42.1***	39	22
	15	58.9***	22.9***	34	18
	18	18.9***	4.9*	25	11
5	10	72.6***	78.2***	41	28
	13	56.1***	74.4***	35	26
	15	39.7***	43.1***	33	24
	18	34.7***	41.5***	41	30
6	10	416.3***	193.1***	57	42
	13	386.4***	196.5***	56	43
	15	365.4***	200.8***	55	44
	18	337.5***	210.0***	53	46
7	10	391.8***	196.5***	57	42
	13	362.5***	198.7***	56	43
	15	345.3***	203.6***	55	44
	18	317.8***	210.3***	54	46
8	10	327.0***	201.4***	56	43
	13	298.4***	204.4***	55	44
	15	278.7***	207.3***	54	45
	18	251.6***	212.3***	53	47
9	10	192.2***	207.2***	51	43
	13	114.8***	211.9***	48	44
	15	152.9***	217.3***	49	45
	18	134.5***	224.9***	49	47

^{1/} ***: Significant at $\alpha = 0.1\%$, **: Significant at $\alpha = 1\%$, *: Significant at $\alpha = 5\%$, ns = Not significant.

it can be pointed out that the most convenient base temperature is 18°C. Average of the two years results show that the lowest CV and F values are obtained from the formula 2, using the 18°C base temperature. The calculated SGDDs (°C d⁻¹) and the durations between sowing and first harvest using formula 2 and 18°C as a base temperature combination for the 10 cultivars grown in greenhouse, high and low tunnel conditions are presented in the Table 2. It can be pointed out in the Table 2 that, depending on the earliness of the cultivar used, variations occurred between the SGDD values. According to Table 2, it can clearly be seen that a variation occurred between the cultivars, with respect to the duration between sowing and first harvest, depending on the growing conditions and the temperature regime applied. The cultivars expressed a variation in their SGDD values, depending on their earliness, that is being in the earliest, 235-245; mid-earliest, 250-260 and the latest, 350-400. On the other hand, for the same cultivar, the SGDD durations were determined to be similar irrespective of their growing conditions. For example, the number of days between sowing and first harvest of Crimson Sweet cultivar were 177 and 166, in the greenhouse; 119 and 150 in the high tunnel and 124 and 129 in the low tunnel, first and second years, respectively (Table 3). Despite this, the SGDD durations, for the same cultivar were between 288 and 326°C d⁻¹ for all the

conditions and years tested. Similar results also were obtained in other cultivars. The results suggest that the time of harvest in watermelon can be calculated using mathematical models, employing base temperature constants. It was determined that the most suitable base temperature for watermelon is 18°C and the formula for the calculation of the SGDD is;

$$SGDD = \sum (T_{max} + T_{min})/2 - T_b$$

This formula provides that [(T max + T min)/2] is greater than T_b. The small differences encountered between the two years results suggest that alterations to the formula may be necessary, especially taking the light factor into account, to ensure a higher precision. This case is supported by other authors for lettuce (Kristensen et al., 1985) and cucumber (Akinci, 1995) with a suggestion that the day length factor should be taken into account as a constant in the formula for the calculation of temperature sums of cultivars. The differences observed between the results of the two years studies are actually not significant and in practice the differences translate into a 1-2 days difference in the field, which is assumed that they may have been caused by the practice of external evaluation of harvest maturity maintained throughout seems to be lacking precision.

Table 2 The SGDDs (°C d⁻¹), their F test results and CV values obtained by the formula 2 using the 18°C base temperature.

Varieties	SGDD Value ^{1/}						
	Greenhouse		High tunnel		Low tunnel		Average
	First year	Second year	First year	Second Year	First year	Second year	
Red Cutie	237	191	255	231	262	242	236
Early Star	232	229	243	231	265	239	240
Summer Chaser	252	221	248	237	262	237	243
Rubin	225	234	244	230	265	234	239
Panonia	250	243	251	251	265	242	250
Fabiola	265	240	251	259	273	253	257
Black Sweet	431	348	366	397	381	246	378
Halep Karasi	-	303	-	304	-	339	315
Crimson Sweet	326	288	289	288	294	294	297
Sugar Baby	264	219	250	233	262	241	245
Average	276	252	266	266	281	267	268

^{1/} F: 1.83^{NS} at first year and 4.1^{*} at second year, CV (%): 8.26 at first year and 10.33 at second year.

Table 3 The time of sowing to first harvest of various watermelon genotypes under different cover system (day)^{1/}.

Varieties	Greenhouse		High tunnel		Low tunnel	
	First year	Second year	First year	Second year	First year	Second year
Red Cutie	159	140	113	130	118	120
Early Star	159	151	110	130	118	117
Summer Chaser	162	149	111	132	118	117
Rubin	156	153	110	129	118	112
Panonia	162	155	112	140	118	117
Fabiola	165	154	112	142	120	122
Black Sweet	195	182	132	166	137	137
Halep Karasi	-	169	-	153	-	136
Crimson Sweet	177	166	119	150	124	129
Sugar Baby	165	149	111	130	118	119
Average	167a	157a	114c	140b	121b	122c

^{1/} D% 1 (Cover type): 2.8 at first year and 2.9 at second year.

References

- Akinci, S. 1995. Determination of minimum growth temperature and effective sum growing degree days in cucumber. Ph.D. Thesis, Univ Yuzuncu Yil, Van, Turkey.
- Boswell, V.R. 1929. Factors influencing yield and quality of peas. Maryland Agric. Exp. Ssta. Bul. 306.
- Caldwell, J.S., C.W. Culpepper and M.C. Hutchins. 1947. Dehydrating sweet corn food packer. 28: 25-28.
- Dimeny, J. 1989. Possibilities of qualitative improvement in green bean cultivation. Hort. Abst. 59: 1146.
- Dodd, M. 1991. Thermal time assessment of suitable areas for navy bean (*Phaseolus vulgaris*) production in the UK. Ann. App. Boil. 119: 521-531.
- Katharine, B.P., T.C. Wehner and G.L. Johnson. 1986. Comparison of 14 methods to determine heat unit requirements for cucumber harvest. Hort. Sci. 21: 419-423.
- Kristensen, S., E. Friis, K. Henriksen and S.A. Mikkelsen. 1985. Application of temperature sums in the timing of production of crisp lettuce. Acta Hort. 198: 217-225.
- Lipari, U., G. Mauromikale and S. Cosentino. 1988. Validity of thermal unit summations for purposes of prediction in *Phaseolus vulgaris* L. cropped in Mediterranean environment. Acta Hort. 229: 321-331.
- Madariaga, F.J. and J.E. Knott. 1951. Temperature summations in relation to lettuce growth. Proc. Amer. Soc. Hort. Sci. 147-152.
- Mikkelsen, A.A. 1981. Predicting the date of harvest of vining peas by means of growing-degree-days models. Acta Hort. 122: 211-221.
- Ney, B. and O. Ture. 1993. Heat-unit-based description of the reproductive development of pea. Crop Sci. 33: 510-514.
- Onsinejad, R. and K. Abak. 1992. Relationship between temperature and germination. Proc. First Turk. Hortic. Cong. 11: 217-222.
- Perry, K.B. and T.C. Wehner. 1990. Prediction of cucumber harvest date using a heat unit model. HortSci. 25: 405-406.
- Perry, K.B., T.C. Wehner and G.L. Johnson. 1986. Comparison of 14 methods to determine heat unit requirements for cucumber harvest date using a heat unit model. HortSci. 21: 419-423.
- Reate, A.N. and S.H. Wittwer. 1952. The effect of temperature and photoperiod on the development of pea varieties. Proc. Amer. Soc. Hort. Sci. 60: 301-310.
- Sach, M. 1977. Priming of watermelon seeds for low temperature germination. J. Amer. Soc. Hort. Sci. 102: 175-178.

Manuscript received 23 May 2014, accepted 29 November 2014